

Chapter-3

Renewable Energy Sources

3.1 Solar Energy.

3.1.1 Solar Radiation
Solar radiation is the total frequency spectrum of electromagnetic radiations produced by the sun. This spectrum covers visible light and near-visible radiation such as X-rays, ultraviolet radiation, infrared radiation and radio waves.

The visible light and heat of the sun

makes life possible.

The earth atmosphere deflects or filters the majority of the sun's harmful radiation, and our near-perfect positioning in the solar system allows us to receive the benefits proximity to the sun without being backed or broiled like Venus or Mercury.

Total Solar Irradiance (TSI)

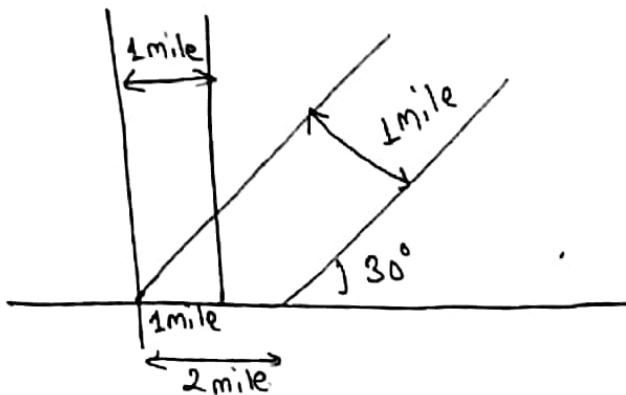
It is a measure of the solar power over all wavelength per unit area incident on the Earth's upper atmosphere.

Isolation

It is the power received on Earth per unit area on a horizontal surface. It depends on the height of the sun above the horizon.

Projection effect

Isolation onto the surface is largest when the surface directly faces (normal) to the sun. As the angle between the surface and the sun moves from normal, the isolation is reduced in proportion to the angle's cosine.

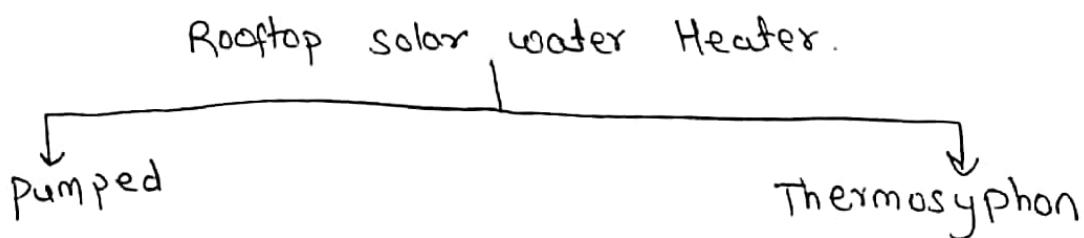


One sunbeam one mile wide shined on the ground at a 90° angle and another at a 30° angle. The oblique sunbeam distributes its light energy over twice as much area.

3.1.2 Solar Thermal Energy.

Solar thermal energy (STE) is a form of energy and a technology for harnessing solar energy to generate thermal energy or electrical energy for use in industry, and in the residential and commercial sectors.

The rooftop solar water Heater.



i) Pumped:

The main absorber might be a steel plate bonded to copper or steel tubing through which water circulates. The plate is sprayed with a special black paint or coated with a selective surface to maximize the solar absorption. It is normally covered with a single sheet of glass or plastic and the whole assembly is insulated on the back to cut heat losses.

Thermosyphon: It relies on the natural convection of hot water rising from the collector panel to carry heat up to the storage tank, which must be installed above the collector. There is no need for a heat exchanger as the required domestic hot water circulates directly through the panel.

Solar Collectors (Solar Thermal Collector)

* Low - Temperature collector

→ A Trombe wall

→ Solar space heating.

→ Solar wall.

* Medium - Temperature collector

→ Photovoltaic pumping.

→ Permanently wetted collector.

→ Stagnation

* Solar drying, cooking, Distillation.

* High - temperature collectors.

→ Heat engines

→ steam turbines.

→ Gas turbines

→ High - voltage transformers.

Varieties of solar heating system

→ Swimming pool heating

→ Conservatory (or 'sunspace')

→ Trombe wall

→ Direct gain

1.3 Solar cell (Photovoltaic Technology)

A solar cell or photovoltaic cell is an electrical device that converts the energy of light directly into the electricity by the photovoltaic effect.

which is a physical and chemical phenomenon.
The operation of a photovoltaic (PV) cell requires three basic attributes:

- The absorption of light, generating either electron-hole pairs or excitons.
- The separation of charge carriers.
- The separate extraction of those carriers to an external circuit.

Applications:

Assemblies of solar cells are used to make solar modules that generates electrical power from sunlight, as distinguished from a "solar thermal module" or "solar hot water panel". A solar array generates solar power using solar energy.

Working of Solar Cells:

- 1 → Photons in sunlight hit the solar panel and are absorbed by semiconducting materials, such as silicon.
- 2 → Electrons are excited from their current molecular/atomic orbital. Once excited an electron can either dissipate the energy as heat and returns to its orbital or travel through the cell ~~unit~~ until it reaches an electrode. Current flows through the material to cancel the potential and this electricity is captured. The chemical bonds of the material ~~are~~ are vital for the process to work, and usually silicon is used in two layers, one layer bonding bonded with boron ~~and~~ the other phosphorus. These layers have different chemical electric charges and subsequently both drive and direct the current of electrons.
- 3 → An array of solar cells converts solar energy into a usable amount of direct current (DC) electricity.
- 4 → An inverter can be ~~u-30-~~ to convert the power to alternating current (AC).

Solar Constant :

The solar constant is a measure of flux density and is the conventional name for the mean "Solar electromagnetic radiation" per unit area that would be incident on a plane perpendicular to the rays, at a distance of one astronomical unit (AU) from the sun.

Peak-Sun Hours

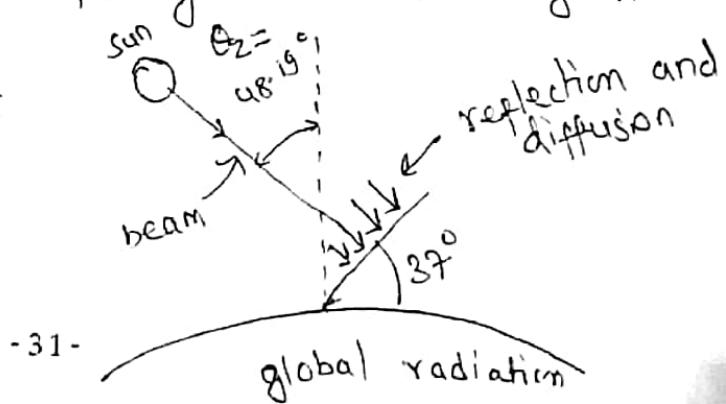
PV system designers are interested in the average solar isolation for a location, which when multiplied by the number of sun hours gives them the total solar energy received at the location (in $\text{kWh/m}^2/\text{day}$)

This value is exactly equivalent to assuming that the sun shines at its maximum intensity for a fixed number of hours, and by doing so delivers the same amount of energy as received during total number of sun hours. This hypothetical equivalent number of hours is called peak-~~base~~ sun hour.

Eg! A place that $7 \text{ kWh/m}^2/\text{day}$ as average isolation can be said to have 7 "peak-~~base~~ sun hours".

Global radiation

Global radiation is the total short-wave radiation from the sky falling onto a horizontal surface on the ground. It includes both the direct Solar radiation and the diffuse radiation resulting from reflected or scattered Sunlight.



B.2 Hydropower

Hydropower or water power is power derived from the energy of falling water or fast running water, which may be harnessed for useful purposes. Since ancient times, hydropower from many kinds of watermills has been used as a renewable energy source for irrigation and the operation of various mechanical devices, such as gristmills, sawmills, textile mills, dock cranes, trip hammers etc.

Hydropower types

1. Conventional Hydroelectric referring to hydroelectric dams.
2. Run-of-the river hydroelectricity, which captures the kinetic energy in rivers or streams without a large reservoir and sometimes without use of dams.
3. Small Hydro: projects are 10 MW or less and often have no artificial reservoir.
4. Micro Hydro: projects provide a few kW to few hundred kW to isolated homes, villages or small industries.
5. Conduit hydroelectricity: projects utilize water which has already been diverted for use elsewhere; in a municipal water system for example.
6. Pumped-storage hydroelectricity: stores water pumped uphill into reservoirs during periods of low demand to be released for generation when demand is high or system generation is low.
7. Pressure Buffering hydropower: use natural sources for water pumping to turbines while exceeding water is pumped uphill into reservoirs and released when incoming water flow isn't enough.

calculating the amount of available power.

$$P = \eta \rho Qgh$$

where,

P = power in watts.

η = efficiency of turbine.

ρ = density of water.

Q = flow in cubic metres.

g = Acceleration due to gravity.

h = height difference between ~~outlet~~ inlet and outlet.

- Q. A potential site has the net head of 100 m with 200 lit/sec flow, what will be the power delivered from such site if the efficiency is 50%?

Soln:

Net head (h) = 100 m.

Flow (Q) = 200 lit/sec

= 0.2 cubic meter/sec.

η = 0.5

ρ = 9.8

s = 1000 kg/m³.

$$\therefore P = \eta \rho Qgh$$

$$= 0.5 \times 1000 \times 0.2 \times 9.8 \times 100$$

$$= 39200 \text{ watt.}$$

$$= 39.2 \text{ kW.}$$

3.2.1 Water Sources and Power.

Hydropower plants capture the energy of falling water to generate electricity. A turbine converts the kinetic energy of falling water into mechanical energy. Then a generator converts the mechanical energy from the turbine into electricity. In this way power is generated.

3.2.2 Water turbines and hydroelectric plants

Turbines.

Converts energy in the form of falling water into rotating shaft power.

Types of turbines

1. Impulse turbines:

Pelton, crossflow, Turgo.

2. The reaction turbines considered are:

Francis turbine, propeller Turbine, Kaplan turbines

S.N	Turbine type	Speed	Head (m)	Best efficiency
1.	Kaplan	300-1000	4-40	0.91
2.	Francis	300-1000 50-450	40-450	0.92 to 0.94
3.	Pelton	10-70	100-2000	0.90
4	Cross - flow	20-70	5 to 200	0.80
5	Turgo	20-80	80-300	0.85

1 Kaplan Turbines:

Kaplan turbines is a propeller-type water turbine which has adjustable blades. It was developed in 1913 by Australian professor Viktor Kaplan, who combined automatically adjusted propeller blades with automatically adjusted wicket gates to achieve efficiency over a wide range of flow and water level.

Speed \rightarrow 300-1000

Head \rightarrow 40-4 m

Best efficiency \rightarrow 0.91

2. Francis Turbines

The Francis turbine is a type of water turbine that was developed by James B. Francis in Lowell, Massachusetts. It is an inward-flow reaction turbine that combined radial and axial flow concepts. These turbines are the most common water turbine today.

Speed → 50-450

Head → 30-450 m

Best efficiency → 0.92 to 0.94

Pelton Turbines

The Pelton wheel is an impulse type water turbines. It was invented by Lester Allan Pelton in 1870s. The Pelton wheel extracts energy from the impulse of moving water, as opposed to water's dead weight like the traditional overshot water wheel.

Speed → 10-70

Head → 100-2000 m

Best efficiency → 0.90.

Cross - Flow turbines

In a cross-flow turbine the water passes through the turbine transversely or across the turbine blades.

Speed → 20-70

Head → 5-200 m

Best efficiency → 0.80

Turgo - Turbines

The Turgo turbine is an impulse water turbines designed for medium head applications. It was developed by Gilkes in 1919 as a modification of pelton-wheel.

It is less-expensive

Speed → 20-80

Head → 30-300 m

Best - efficiency → 0.85

Hydro-electric plants

Less than 1000 kW : Mini-micro

1000 kW to 10 MW : Small-hydro

10 MW to 300 MW : Medium hydro

Plants above 300 MW : Big hydro

3.2.3 Hydro-Power plant classification

Pico hydro is a term used for hydroelectric power generation ~~of~~ under 5 kW. It is useful in small, remote communities that require only a small amount of electricity. For example to power one or two fluorescent light bulbs and a TV or radio in 50 or so homes.

Pico-hydro systems typically are run-of-stream, meaning that a reservoir of water is not created, only a small weir is common, pipes divert some of the flow, drop this down a gradient, and through the turbine before being exhausted back to the stream.

Micro-hydro

Micro-hydro is a type of hydroelectric power that typically produces from 5 kW to 100 kW of electricity using the natural flow of water. These installations can provide power to an isolated home or small community or are sometimes connected to electric power networks, particularly where net metering is offered. Micro-hydro systems complement solar PV power systems because in many areas, water flow, and thus available hydro power is highest in the winter when solar energy is at a minimum. Micro-hydro is frequently accomplished with a pelton wheel for high head, low flow water supply.

Small-hydro

Small hydro is the development of hydroelectric power on a scale suitable for local community and industry, or to contribute to distributed generation in a regional electricity grid. The definition of a small hydro project varies, but a generating capacity of 1 to 20 MW is common.

Small hydro projects may be built in isolated areas that would be uneconomic to serve from a national electricity grid, or in areas where a national grid does not exist.

Medium Hydro

Few kW to few-hundred kW.

Large Hydro

Generation of power is in Megawatts.

* Turbine Selection

Turbine Type	Head classification.		
	High (>50m)	Medium (10-50m)	Low (<10m)
Impulse	Pelton Turgo Multi-Jet Pelton	Cross-flow Turgo Multi-Jet Pelton	Crossflow
Reaction		Francis	Propeller Kaplan.

3.3 Wind Energy

Wind power is the use of air-flow through wind turbines to mechanically power generators for electric power. Wind power, as an alternative to burning fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation, consumes no water and uses little land.

It is also defined as the conversion of wind energy into useful form, such as electricity, using wind turbines.

Wind Machines (Turbines) /wind parks and power control

Wind machines use blades to collect the wind's kinetic energy.

Windmills work because they slow down the speed of the wind. The blades³⁷ are connected to a drive shaft that turns an electric generator to produce

electricity.

Wind turbines are also called wind energy conversion systems (WECS) and sometimes described as wind generators or aerogenerators.

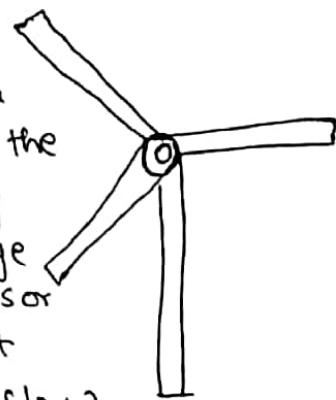
* There are two types of wind machines based on the direction of rotating shaft.

1) Horizontal-axis wind machines.

2) Vertical-axis wind machine.

1) Horizontal-axis wind machines

Horizontal-axis wind turbines (HAWT) have the main rotor shaft and electrical generator at the top of a tower, and must be pointed into the wind. Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor coupled with a servo motor. Most have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive an electrical generator.



Since a tower produces turbulence behind it, the turbine is usually positioned upwind of its supporting tower. Turbine blades are made stiff to prevent the blades from being pushed into the tower by high winds. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted forward into the wind a small amount.

Turbines used in wind farms for commercial production of electric power are usually three-bladed and pointed into the wind by computer-controlled motors. These have high tip-speeds of over 320 km/h (200 mph), high efficiency and low torque ripple, which contribute -38- good reliability. The blades are usually colored white for daytime

Visibility by aircraft and range in length from 20 to 46 m (66 to 131 ft), or more. The tubular steel towers range from 60 to 90 meters (200 to 300 ft) tall.

The blades rotate at 10 to 22 revolutions per minute. At 22 rotations / minute the tip exceeds 90 m/sec. (300ft/s). A gear box is commonly used for stepping up the speed of generator. Higher tip speeds means more noise and blade erosion.

2) Vertical axis Wind machines

Vertically-axis wind turbines (VAWT) have the main rotor shaft arranged vertically. One advantage of this arrangement is that the turbine does not need to be pointed into the wind to be effective, which is an advantage on a site where the wind direction is highly variable. It is also an advantage when the turbine is integrated into a building because it is inherently less steerable. Also, the generator and placed near the ground, using a direct gearbox assembly to the ground-based gearbox, improving accessibility for maintenance.



gearbox can be drive from the gearbox, improving

However these designs produce much less energy averaged over ever time, which is a major drawbacks.

Disadvantages:

- The relatively low rotational speed with the consequential higher torque and hence higher cost of the drive train
- low power coefficient
- 360° rotation of the aerofoil within the wind flow during each cycle and hence the highly dynamic loading on blades.
- The pulsating torque generated by some rotor designs on the drive train.

- Difficulty in modelling the wind flow.
 → challenges of analysing and designing the rotor prior of fabricating a prototype

Darrieus Wind turbines.

"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.

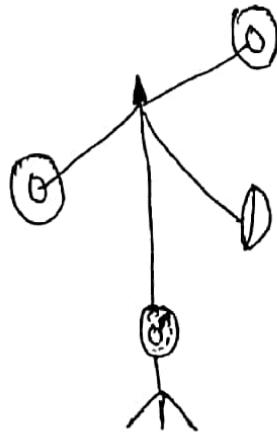
Anemometers

Anemometer is a device used for measuring the speed of wind and is also a common weather station instrument.

Types

Velocity anemometers.

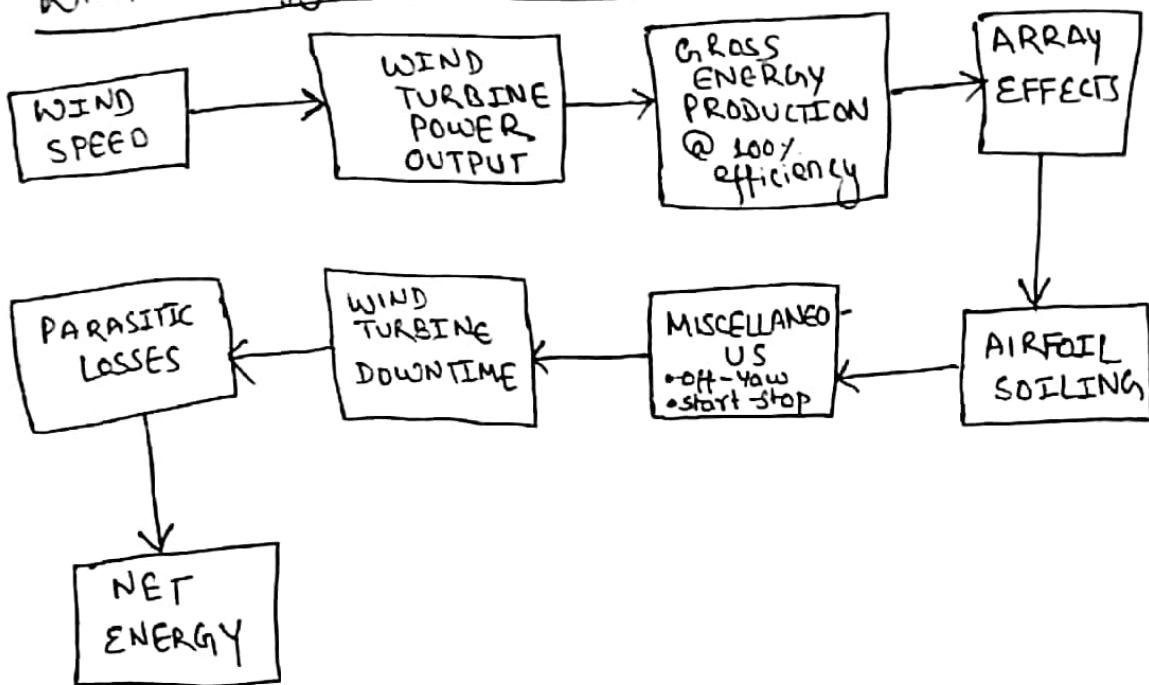
- Cup anemometers
- Vane anemometers
- Hot-wire anemometers
- Laser Doppler anemometers
- Ultrasonic anemometers
- Acoustic resonance anemometers
- Ping-pong ball anemometers



Pressure anemometers.

- Plate anemometers
- Tube anemometers
- Pitot tube static anemometers

Wind - Energy Conversion & losses



Wind parks

Wind-parks is a group of wind-turbines in the same location used to produce electricity. A large wind parks may consist of several hundred individual wind turbines and cover an extended area of hundreds of square miles, but the land between the turbines may be used for agricultural or other purposes. A wind park can also be located offshore.

Power Output of Wind Machines.

$$P = 0.59 \frac{1}{2} \rho V^3 A$$

where

A = Effective area of disk

V = Velocity of wind

ρ = air density.

Power Control of Wind Turbines.

↪ Pitch control

↪ Stall control

↪ Active-stall control.

3.1 Wind Energy Availability

Factors determining wind - energy availability.

- 1) Velocity of wind.
- 2) Cross-section area of wind passing through blade.
- 3) Density of air.

~~4)~~ Given by,

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

Important Terms

Drag coefficient

$$C_D = \frac{D}{0.5 \rho V^2 A_b}$$

D = Drag force

A_b = Area of Blade.

L = lift force

ρ = air density

V = velocity of air approaching the aerofoil.

Lift Coefficient

$$C_L = \frac{L}{0.5 \rho V^2 A_b}$$

Question: Describe the scope of wind energy in Nepal.

Hint: → Pressure of wind flow in Mountains, hills and in terai region.

→ Geographical conditions.

→ Drag force

→ Lift force.

Advantage of Wind Energy

- 1) It is pollution free, sustainable form of energy
- 2) It doesn't require fuel
- 3) It doesn't create greenhouse gases
- 4) It doesn't produce toxic & radioactive waste.
- 5) Available everywhere

8.4

Geothermal Energy.

The word geothermal is derived from greek word geo and therme where geo means earth and therme means heat.

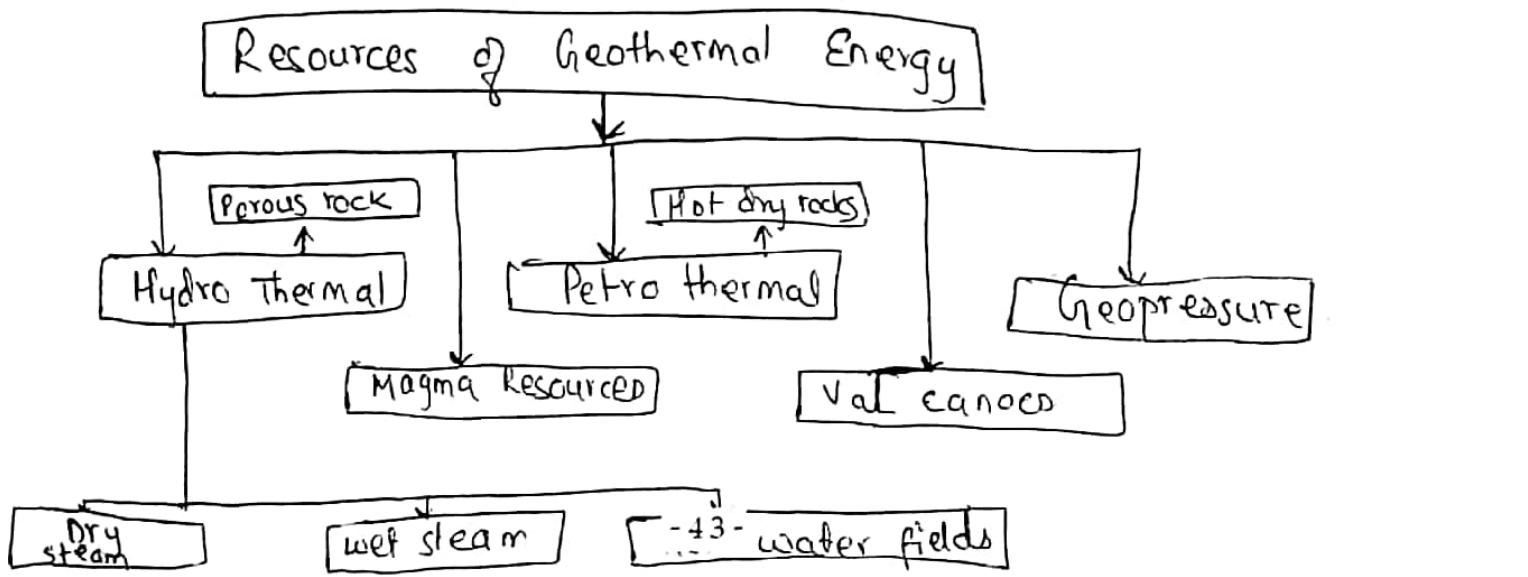
Geothermal energy is heat energy generated and stored in earth. The geothermal energy of the Earth's crust originates from the original formation of the planet and from radioactive decay of materials.

Geothermal energy is clean and sustainable.

Resources of geothermal energy ranges from the shallow ground to hot water and hot rock found a few miles beneath the Earth's surface and down even deeper to the extremely high temperatures of molten rock called magma.

Sources of Geothermal Energy.

- Generating electricity from the earth's heat
→ Geothermal energy production.
- Geothermal Direct Use.
→ Producing heat directly from hot water within the earth.
- Using Shallow ground to heat and cool buildings.
→ Geothermal heat pumps.



Power-plant System.

There are three designs for geothermal power plant, all of which pull hot water and steam from the ground, use it and then return it as warm water to prolong the life of the heat source.

- Dry steam Power plant
- Flash steam Power plant
- Binary Cycle power plant.

Hot-Dry Rock Technology.

- Wells drilled 3-6 km into crust.
 - Hot crystalline rock formations.
- Water pumped into formations.
- Water flows through natural fissures picking up heat.
- Hot water / steam returns to surface.
- Steam used to generate power.

Environmental Impacts.

1) Land

- * Vegetation loss
- * Soil erosion
- * Landslides.

2) Water

- * Watershed impact
- * Damping streams
- * Hydrothermal eruptions
- * Lower water table.

3) Air

- * Slight air heating
- * Local fogging.

4) Ground

- * Reservoir cooling
- * Seismicity.

4.2 Applications

* Generation of electric power

* Industrial process heat

* Food processing.

A. * Space heating for building.

1) * Bathing facilities.

2) It

3) It

4) Availa

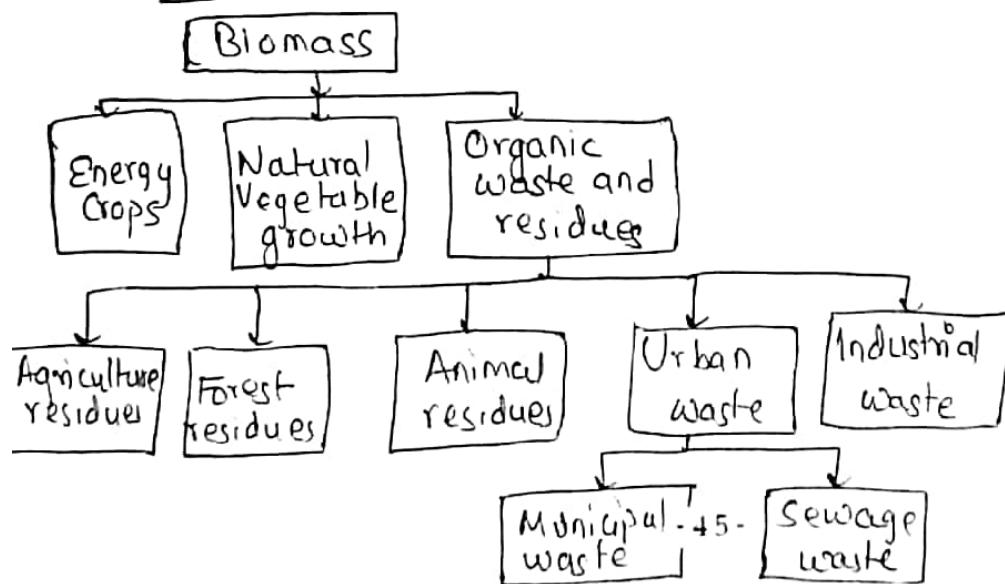
8.5 Bio-mass and Bio-energy

The material of plants and animal is called biomass. It is organic carbon based material that reacts with oxygen in combustion and natural metabolic processes to release heat. The initial material may be transformed by chemical and biological processes to produce intermediate biofuels, such as methane gas, ethanol liquid or charcoal solid. The initial energy of bio-mass-oxygen system is captured from solar radiations in photosynthesis process.

Types of Biomass.

1. Forestwaste - saw dust, leaves, twigs, shrubs, residues of herbs & herbal products.
2. Agricultural residues - rice husk, rice straw, rice bran, wheat husk, wheat straw, wheat bran, maize cobs, maize stalks, sugarcane leaves.
3. Industrial waste/residues - sugarcane bagasse, coffee husk, tobacco waste, tea waste, Herbal residue.

Biomass classification



V
V
V
S
S
F
E:

3.5.1 Synthetic fuels from Biomass

Synthetic fuel or synfuel is a liquid fuel or sometimes called gaseous fuel, obtained from syngas, a mixture of carbon monoxide and hydrogen, in which the syngas was derived from gasification of solid feedstocks such as coal or biomass by reforming of natural gas.

Biogas

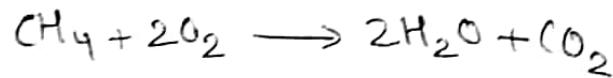
Biogas typically refers to a mixture of different gases produced by the breakdown of organic matter in the absence of oxygen. Biogas can be produced from raw materials such as agricultural waste, manure, municipal waste, plant material, sewage, green waste or food waste.

Biogas is a renewable energy source.

Biogas can be produced by anaerobic digestion with anaerobic organisms, which digest material inside a closed system, or fermentation of biodegradable materials.

Biogas is primarily methane (CH_4) and carbon dioxide (CO_2) and may have small amounts of hydrogen sulfide (H_2S), moisture and siloxanes. The gases methane, hydrogen and carbon monoxide (CO) can be combusted or oxidized with oxygen.

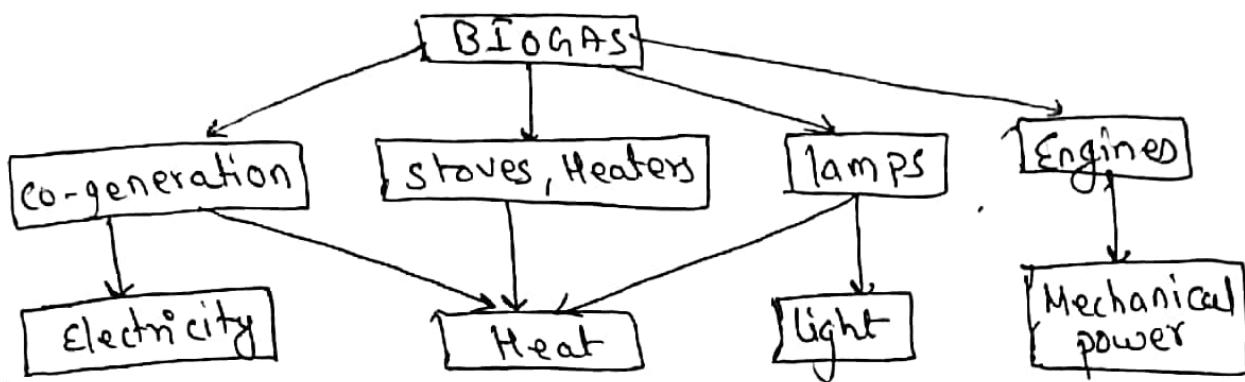
Chemical equation



Properties of Biogas

- It is non compressible
- Storage is not feasible
- Energy content : 20 MJ/m^3
- Stove efficiency = 44%

Possible Uses of Biogas as Energy



Factors Affecting production of Bio-energy

- 1) C/N Ratio
- 2) PH
- 3) Digestion temperature
- 4) Consistency
- 5) Toxicity
- 6) Subsidy

Benefits of Biogas

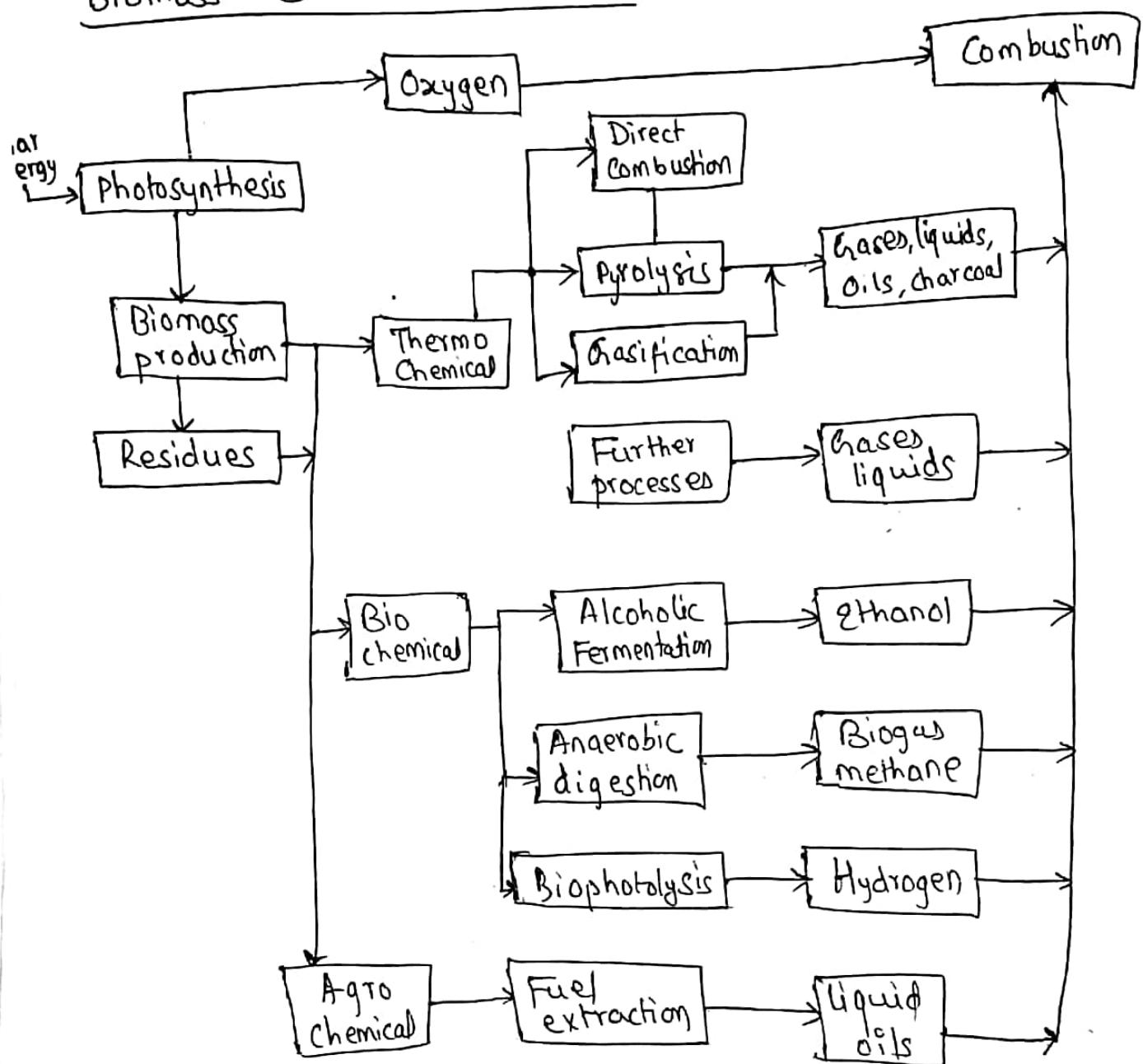
- a) Saving of Fuelwood and Kerosene.
- b) Health Improvement
- c) Saving of Time
- d) Availability of High Quality Manure
- e) Reduction of Workload.
- f) Environmental Benefits
 - ↳ Local perspective
 - ↳ National "
 - ↳ Global "

3.5.2 Thermo-chemical, physio-chemical and Bio-chemical conversion

Conversion of biomass to energy and other useful products takes place in four routes. They are:

- 1) Thermo-chemical conversion process
- 2) Bio-chemical conversion process
- 3) Physical conversion processes
- 4) Agro-chemical conversion process.

Biomass Conversion Process



Thermochemical Bioconversion

Thermochemical Bioconversion is done by following processes:

1 Direct Combustion

- * Direct Combustion input is -48- for immediate heat.
- * Dry homogeneous " " " preferred.

cooking, comfort heat, crop drying, factory processes and raising steam for electricity production and transport.

2. Pyrolysis

This is general term for all processes whereby organic material is heated or partially combusted to produce secondary fuels and chemical products. The input may be wood, biomass residues, municipal waste.

It is a physical and chemical decomposition of organic matter brought about by heating in the absence of air. The products of pyrolysis are char, liquid distillates and gas.

The products are gases, condensed vapours as liquids, tars and oils, and solid residues as charcoal and ash.

* Gasification is pyrolysis adapted to produce a maximum amount of secondary fuel gases.

3. Gasification

It is a process in which solid fuels are broken down by the use of heat with a restricted supply of air to produce combustible gases which can be used as a fuel for internal combustion engines.

The gas known as producer gas is a mixture of

$\text{CO} \rightarrow 15-29\%$

$\text{H}_2 \rightarrow 5-15\%$

$\text{CO}_2 \rightarrow 5-15\%$

$\text{N}_2 \rightarrow 50-65\%$

$\text{CH}_4 \rightarrow \text{few \%}$

4. Liquefaction

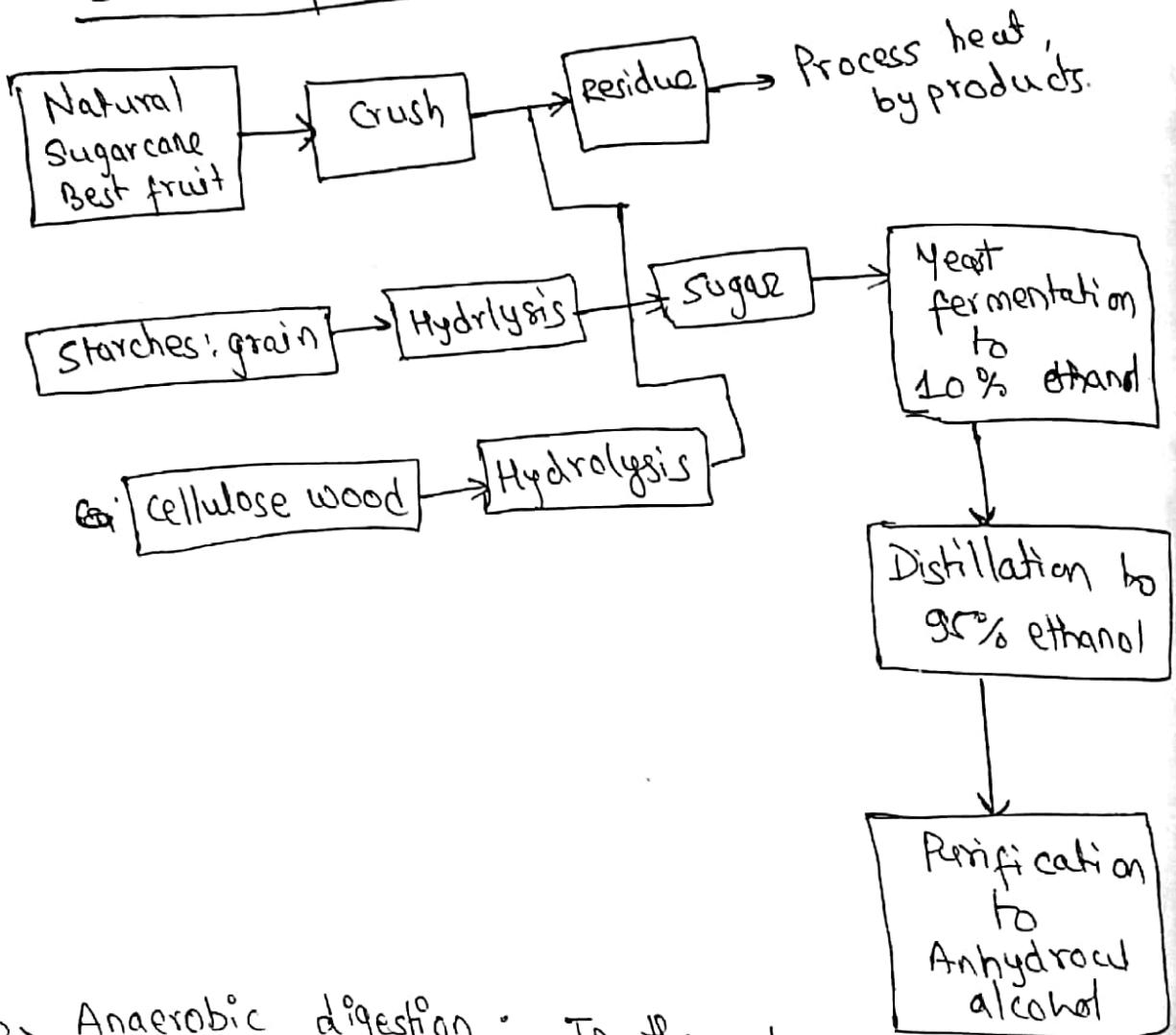
It is a high temperature and high-pressure catalytic process, which converts biomass to fuel-energy.

2) Biochemical Methods of Bioconversion
Biochemical Methods consist of following processes.

→ Alcoholic Fermentation: Ethanol is a volatile liquid fuel that may be used in place of refined petroleum. It is manufactured by the action of micro-organisms and is therefore a fermentation process.

Conventional fermentation has sugars as feedstock. Ethanol $\text{C}_2\text{H}_5\text{OH}$ is produced naturally by certain micro-organisms from sugars under acidic condition, pH 4 to 5.

Ethanol production

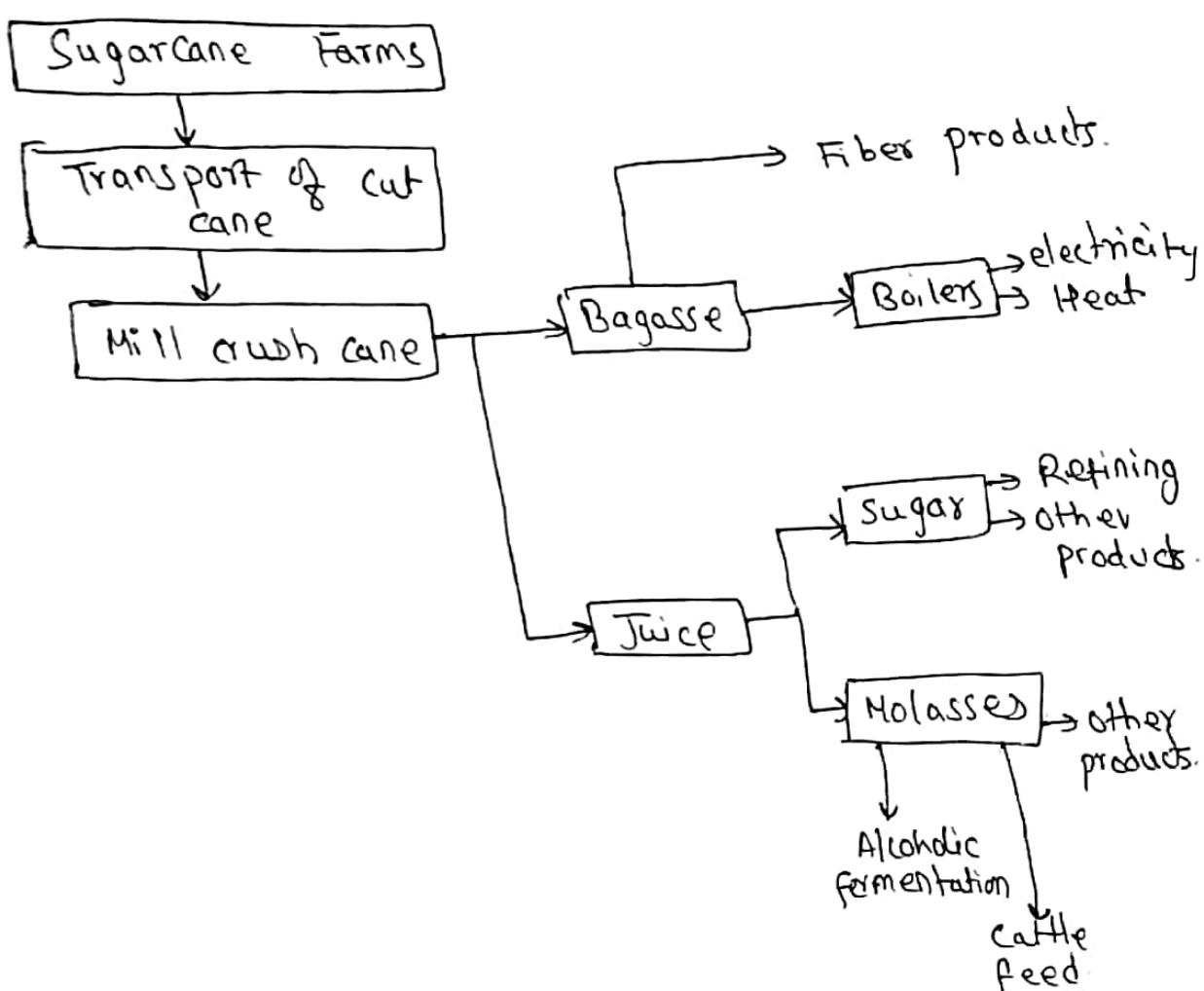


→ Anaerobic digestion: In the absence of free oxygen, certain micro-organisms can obtain their own energy supply by reducing compounds in medium reduction level to produce methane CH_4 .

Decaying biomass and animal wastes are broken down to elementary nutrients and soil humus by decomposer organisms, fungi and bacteria. The process are favored by wet, warm and dark conditions. The final stages are accompanied by many different species of bacteria classified as either aerobic or anaerobic.

Biomass Example:

sugarcane Agro Industry.



3) Agrochemical Methods of Bioconversion.

Occasionally liquids or solid fuels may be obtained directly from living or freshly cut plants. The materials are called exudates and are obtained by cutting into the stems or trunks of the living plants or by crushing recently harvested material. A well known process is the production of natural rubber.

4) Physical Conversion

Physical conversion techniques are aimed at physically altering the form of biomass. For example physically altering the form of biomass by chipping,

(i) The size reduction of biomass

pulverizing.

(ii) Drying to reduce water.

(iii) Screening.

(iv) densification or briquetting

The main purpose is to prepare biomass suitable for combustion.

Briquette

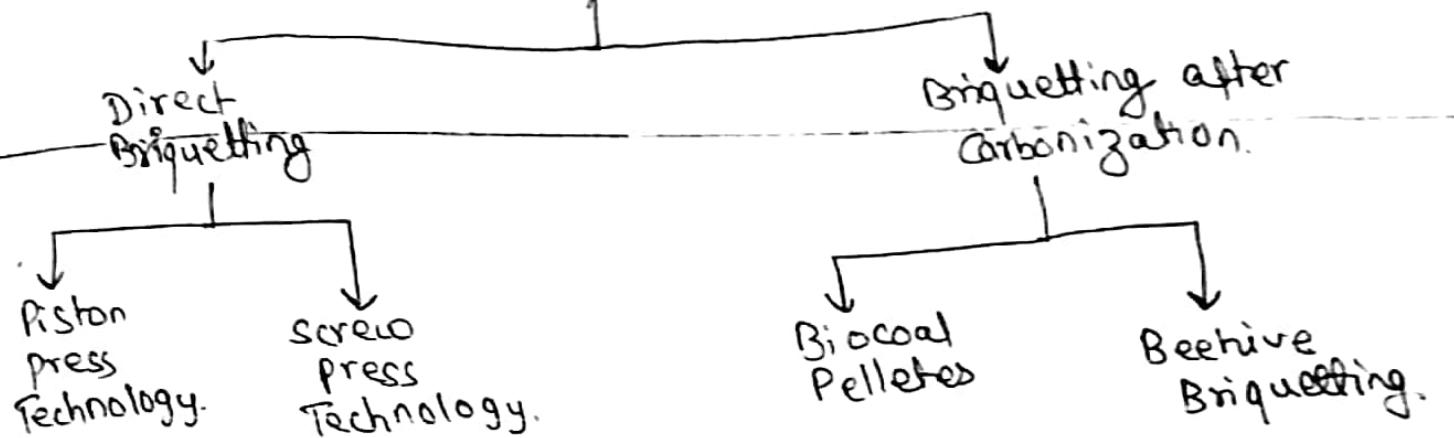
Biomass briquetting is the densification of loose biomass materials (agricultural residue, forestry wastes, animal wastes etc) to produce compact solid composites of different sizes called briquettes.

* Desification is the general process of compressing the raw materials to a certain shape or form using a mould and pressure.

Briquetting is applied to

- (a) Improve fuel characteristics.
- (b) Combustion efficiency
- (c) Waste utilization
- (d) Easy handling
- (e) Minimize wastage
- (f) Transportation
- (g) Storage

Biomass Briquetting



Uses

Present Uses

- Space heating of residence, lodges and restaurants.
- Open fire space.
- Wool Dyeing.

Potential Uses

- Tea processing
- Water heating using waste chimney heat.
- Cardamom drying.
- Vegetables and mushroom drying.
- Tobacco curing.
- Drying of silk & cocoons.

3.5.3 Bio-fuel Cells

Bio fuel cell uses living organisms to produce electricity. It may refer to:

- Microbial fuel cell.
- Enzymatic biofuel cell.

Microbial fuel cell

A microbial fuel cell (MFC) or biological fuel cell, is a bio-electrochemical system that drives an electric current by using bacteria and mimicking bacterial interactions found in nature.

Enzymatic biofuel cell

An enzymatic biofuel cell is a specific type of fuel cell that uses enzymes as a catalyst to oxidize its fuel, rather than precious metals.

B.6 Hydrogen Energy and Fuel Cells.

H₂ Introduction :

Hydrogen is the smallest element known to man and also the most potential gas in the universe. Hydrogen gas is lighter than air and as a result it is not found in atmosphere.

Hydrogen is;

- a) Not detonative at open air
- b) not decomposing
- c) not auto-igniting
- d) not oxidizing
- e) not toxic
- f) not corrosive
- g) not radioactive
- h) not badly smelling
- i) not contagious
- j) not endangering water
- k) not damaging the fetus
- l) not causing cancer.

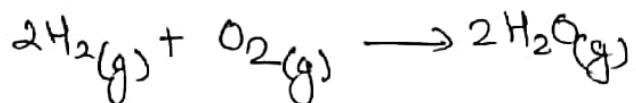
Safety Aspects of Hydrogen

- a) Hydrogen is lighter than air and vanishes rapidly upwards
- b) Hydrogen has a high diffusion coefficient (4-times that of methane) and dilutes rapidly in air.
- c) Hydrogen has significantly narrower detonation limits in air than explosion limits + when ignited early, it burns before detonation limits are reached.
- d) Hydrogen burns with an invisible flame with very little heat radiated from the flame.
- e) Hydrogen is colorless and odorless.

Hydrogen fuel

Hydrogen fuel is a zero-emission fuel when burned with oxygen and used in a contained cell - and also capable of 'reversing' the reaction if needed. It often uses electrochemical cells or combustion in internal engines to power vehicles and electric devices. It is also used in the propulsion of spacecraft and might potentially be mass-produced and commercialized for passenger vehicles and aircrafts.

In a flame of hydrogen gas, burning in air, the hydrogen (H_2) reacts with oxygen (O_2) to form water (H_2O) and releases energy.



The energy released enables hydrogen to react as a fuel.

Advantages of hydrogen fuel

- When hydrogen is burned, the only emission it makes is water vapor, so a key advantage of hydrogen is that when burned, carbon dioxide (CO_2) is not produced.
- clearly hydrogen is less of a pollutant in the air because it emits little tail pipe pollution.
- Hydrogen has the potential to run a fuel-cell engine with greater efficiency over an internal combustion engine.
- The same amount of hydrogen will take a fuel-cell car at least twice as far as a car running on gasoline.

Disadvantages

- Currently, it still costs a considerable amount of money to run a hydrogen vehicle because it takes a large amount of energy to liquefy the fuel.
- Research shows that cars could store hydrogen in high pressure tanks like those used for compressed natural gas. It would need to be packed tightly into a car's tank in order to avoid countless trips to the filling station every few miles.
- The department of Energy's goal is to produce hydrogen at \$2 to \$3 per gallon by 2015. Right now, the cost per gallon is between \$6 and \$8.

Advantages of Hydrogen economy

- Elimination of pollution caused by fossil fuels.
- The elimination of greenhouse gases.
- The elimination of economic dependence.

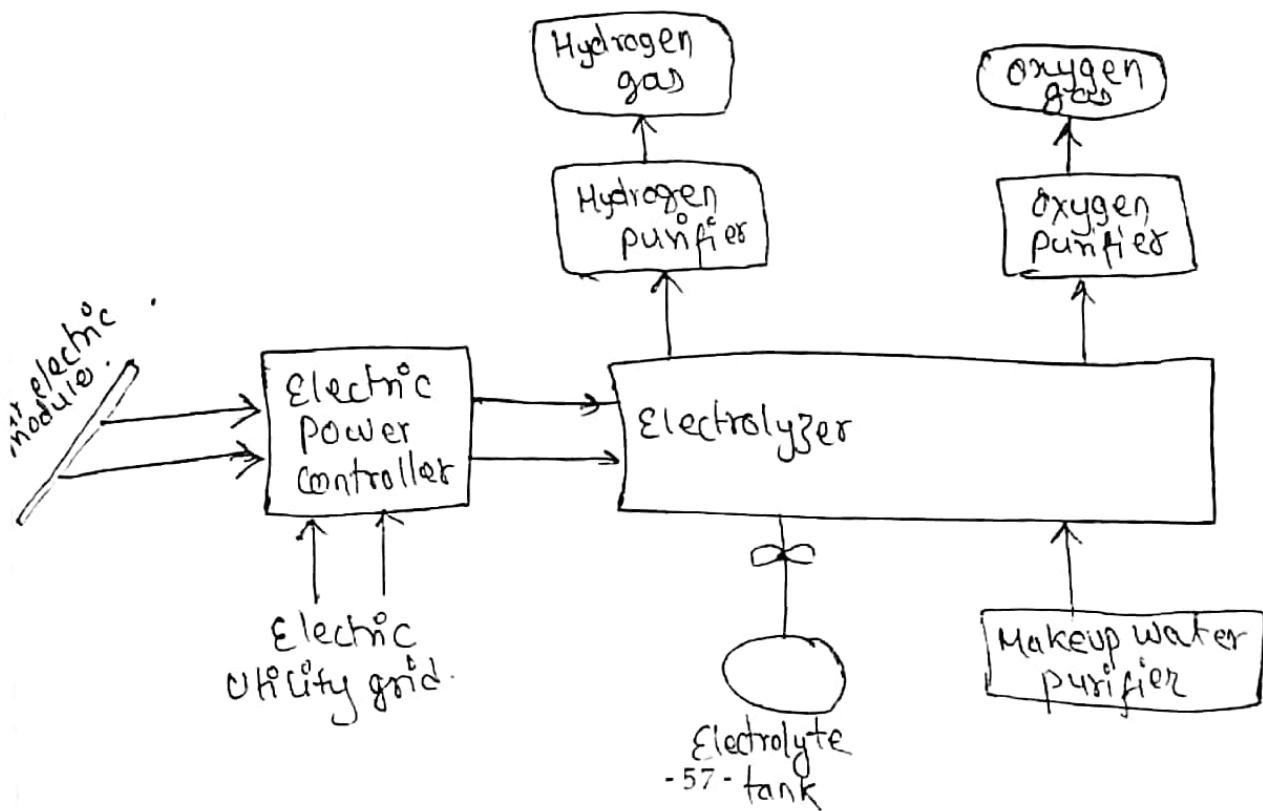
3.6.4 Hydrogen production

1. Steam reforming of natural gas
2. Coal gasification
3. Biomass gasification
4. Electrolysis of water
5. Thermolysis and thermo-chemical cycles.

Hydrogen storage

1. Compressed hydrogen storage
 - Hydrogen embrittlement.
2. Liquid hydrogen storage.
 - Hydrogen boil-off and insulation.
 - Hydrogen liquefaction and embrittlement.
3. Hydride storage
 - Metal hydrides
 - Chemical hydrides
 - Doping of hydrides
4. Carbon nanotubes.

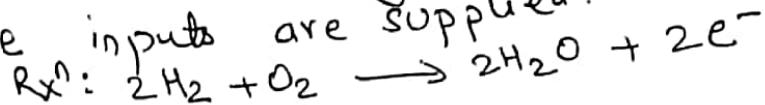
Solar Hydrogen Production by Electrolysis.



Fuel Cells

A fuel cell is a device that converts the chemical energy from a fuel into electricity through a chemical reaction of positively charged hydrogen ions with oxygen or another oxidizing agent.

Fuel cells are different from batteries in requiring a continuous source of fuel and oxygen or air to sustain the chemical reaction whereas in battery the chemicals present in the battery react with each other to generate an electromotive force (emf). Fuel cells can produce electricity continuously for as long as these inputs are supplied.



Types

3.6.2 Polymer membrane electrolyte (PEM) fuel cells.

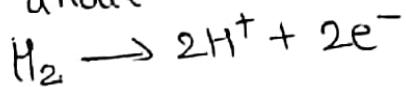
Polymer electrolyte Membrane (PEM) are also known as proton exchange membrane fuel cells. They are a type of fuel cells being developed for transport applications as well as for stationary fuel cell applications and portable fuel cell applications. Their distinguishing features include lower temperature/pressure ranges (50 to 100°C) and a special polymer electrolyte membranes.

Principle of Operation

They operates on the principle of PEM electrolysis.

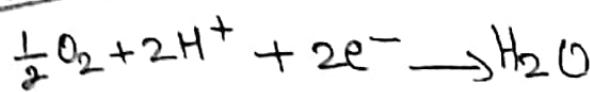
Reactions

At anode:



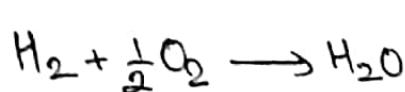
$$-58. E^\circ = 0V \quad \frac{dE^\circ}{dT} = 0mV K^{-1}$$

At cathode:



$$E^\circ = 1.2291V \quad \frac{dE^\circ}{dT} = -0.8456 \text{ mVK}^{-1}$$

Overall reaction



$$E^\circ = 1.2291V \quad \frac{dE^\circ}{dT} = -0.8456 \text{ mVK}^{-1}$$

Applications:

- ① Transportation (primary)
- ② Distributed / stationary and portable power generation. (secondary).

3.6.3 Solid Oxide Fuel cells (SOFCs)

A solid Oxide fuel cell (or SOFC) is an electro-chemical conversion device that produces electricity directly from oxidizing a fuel. Fuel cells are characterized by their electrolyte material; SOFC has a solid oxide or ceramic electrolyte. Advantages of this class of fuel cells include high efficiency, long-term stability, fuel flexibility, low emission and relatively low cost. The largest disadvantages is the high operating temperature which results in longer start-up times and mechanical and chemical compatibility issues.

Operation

A solid Oxide fuel cell is made up of 4-layers 3 of which are ceramics. A single cell consisting of these 4-layer stacked together is typically only a few mm thick. Hundreds of these cells are then connected in series to form what most people refer to as "SOFC stack". The ceramics used in SOFCs

do not become electrically and ionically active until they reach very high temperature and as a consequence, the stacks have to run at temperatures ranging from 500 to 1,000 °C.

Reduction of oxygen into oxygen ions occurs at the cathode. These ions can then diffuse through the solid oxide electrolyte to the anode where they can electrochemically oxidize the fuel. In this reaction, a water biproduct is given off as well as two electrons. These electrons then flow through an external circuit where they can do work. The cycle then repeats as those electrons enter the cathode material again.

3.6.5 Coal-fired plants and integrated Gasifier fuel cell (IGFC) System

Fossil fuel power station: It burns fossil fuel such as coal, natural gas, or petroleum to produce electricity. Central Station fossil fuel power plants are designed on large scale for continuous operation. It have machinery to convert heat energy of combustion into mechanical energy which then operates as electrical energy.

IGFC System

IGFC power plant is analogous to Integrated Gasification Combined Cycle power plant but with the gas turbine power generation unit replaced with a fuel cell power generation unit.