Geothermal Energy

By: Mudit M. Saxena, Dept. of Mech. Engineering

Liquid Dominated Geothermal Plants

- Liquid Dominated Geothermal Plants

  In liquid dominated plants, geothermal plants are built upon liquid reservoirs within the earth's surface. This liquid is sent through one or more separators in order to lower the pressure of the water, creating steam. This steam then propels a turbine generator causing it to produce electricity. This steam is then condensed back into a liquid and placed back into the liquid reservoir it originated from. This type of geothermal plant is very common and provides a sustainable, reusable form of energy.

  Liquid dominated power plants are also referred to as flash steam power plants; as they conduct flash steam by pressurizing hot water from the surface of the earth. Such power plants operate using water reservoirs with temperatures greater than 360 degrees Fahrenheit. Liquid dominated reservoirs are more common than others, causing them to produce more electricity and power more stations. These reservoirs are found in specific locations including rift zones, mantle hot spots, and near new volcanoes in the Pacific Ocean. The largest liquid-dominated system in the world is found at Cerro Prieto.

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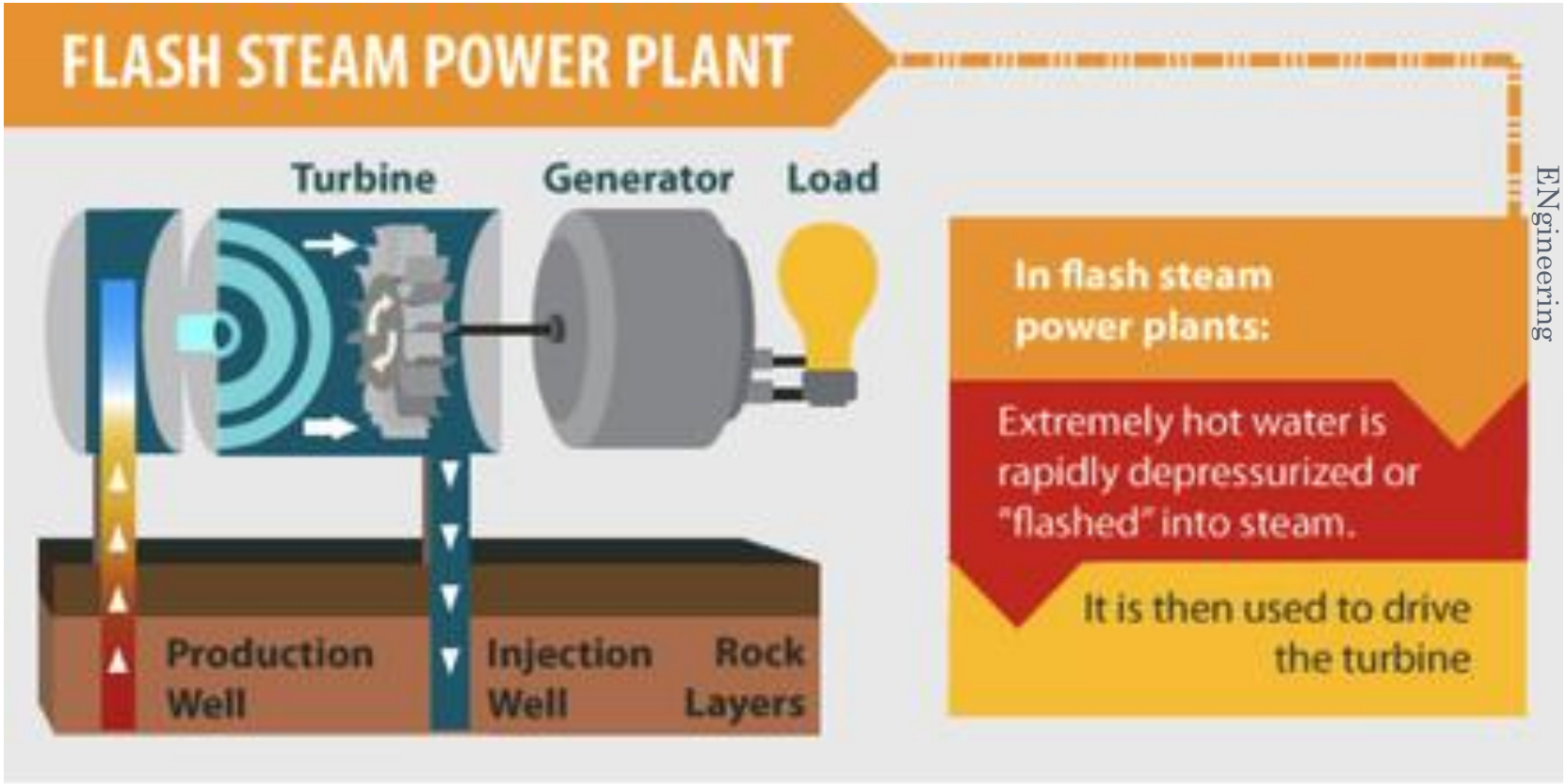
Liquid Dominated Geothermal Plants



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Vapor Dominated Geothermal Plants

- Vapor Dominated Geothermal Plants

  Steam reservoirs are very rare but are an incredibly efficient sustainable electricity source. The Geysers in California is the most prominent dry steam reservoir. A dry steam plant works in a similar fashion to a Liquid Dominated Geothermal Plant. Steam is obtained by drilling between seven to ten thousand feet deep into the earth's crust. The steam obtained is piped directly into a turbine generator, producing electricity. The steam is then condensed and placed back into the steam reservoir, providing a reusable energy source.

  Vapor Dominated Plants, also referred to as dry-steam power plants, are so rare that only two locations exist in the United States. These include The Geysers in California, previously mentioned above, and the famous dry steam reservoir held at Yellowstone National Park. Yellowstone is legally protected from geothermal development, so only one plant exists in the United States. The most prominent international dry steam power plant exists in Larderello, Italy. In Larderello, hot granite on the earth's surface creates boiling water and hot steam under the earth's surface. The geothermal plant in Larderello is able to convert this dry steam into 594 megawatts of electricity, enough to power 594,000 homes. Comparatively, the geothermal plant produces over 40 times this amount of energy, producing 27,500 megawatts of energy.

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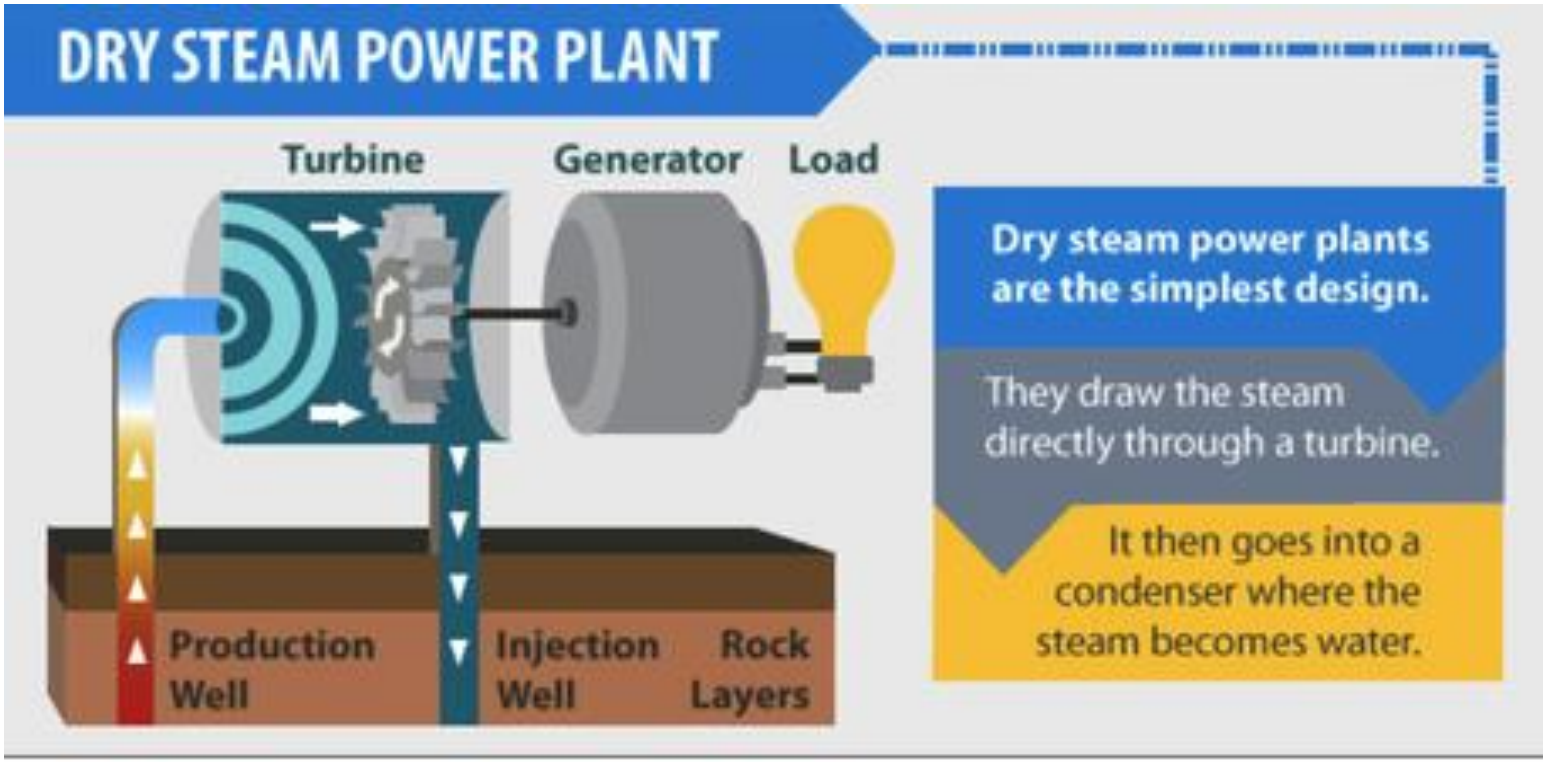
Vapor Dominated Geothermal Plants



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Binary Cycle Plants

- Binary Cycle Plants

  A binary cycle power plant is used when the water in a reservoir is not hot enough to transform into steam. This lower temperature water is instead used to heat a liquid that expands when heated. This fluid increases the pressure around a generator causing a turbine to turn, producing electricity. The fluid is recycled and used again to form a reusable energy source. This is the most readily available geothermal resource throughout the country, as it does not require specific liquid or steam reservoirs

  Binary plants work upon liquid dominated reservoirs found under the earth's surface. However, unlike the flash steam plants, Binary plants work with water at lower temperatures, between 225 and 360 degrees Fahrenheit. Due to the lower temperatures of this water, the water must be pumped up to the earth's surface and boiled into a working fluid. Due to the abundance of cold water reservoirs in the Earth's surface, binary cycle power plants make up the majority of geothermal plants in the United States. Binary cycle power plants also create minimal air emissions due to the constant separation between the water form the earth's surface and the working fluids used during the operation.

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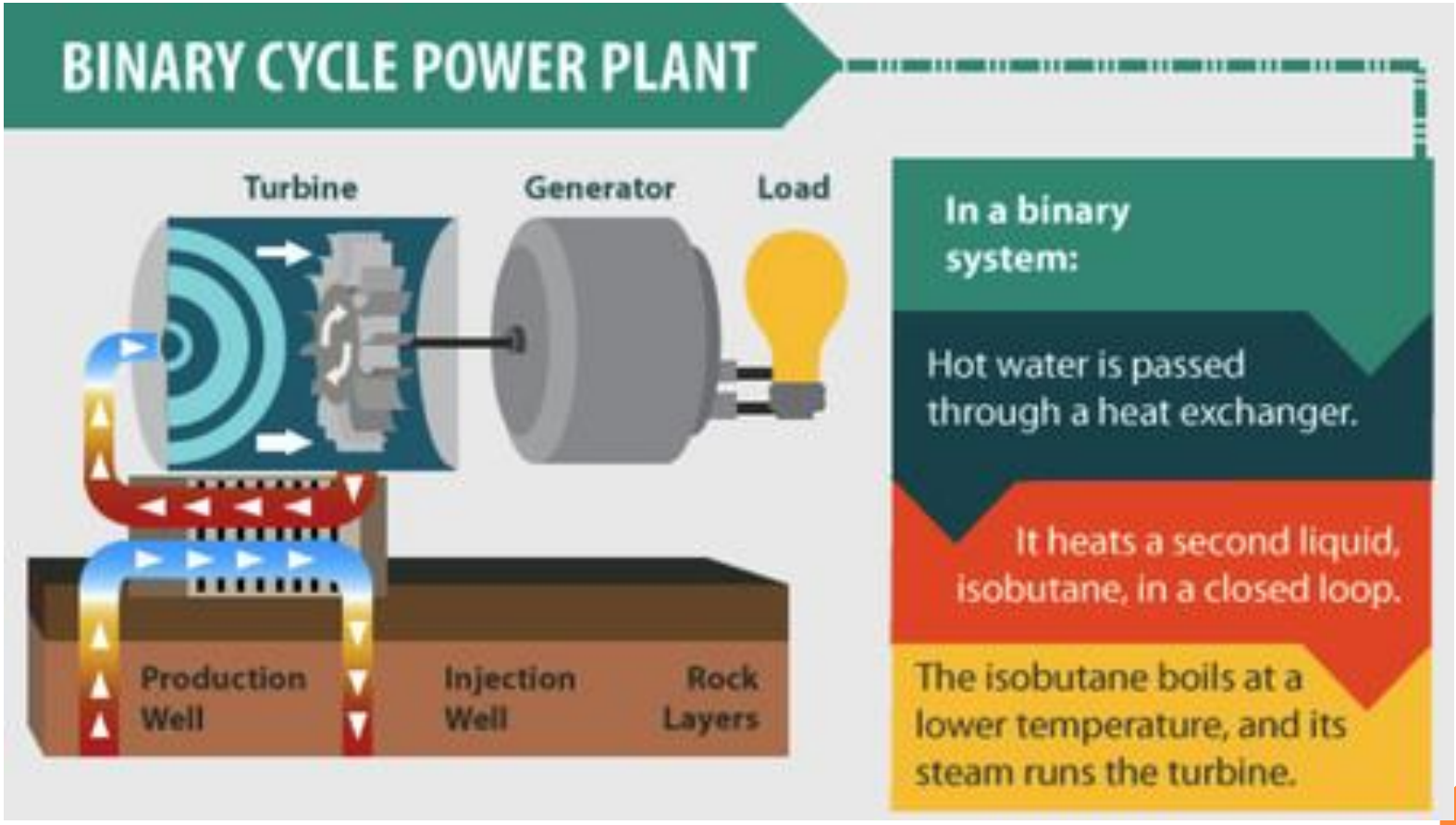
Binary Cycle Plants



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Hot Dry Rock Geothermal Power Plants

- Hot dry rock geothermal power is a specific type of geothermal power[1]. Geothermal power generation depends on capturing the heat produced naturally by the earth and transforming it into a more useful form of energy[2]. In the case of hot rock geothermal power generation, that more useful form of energy is steam. To approach generating the steam that is needed, boreholes are drilled into the earth to gain access to hot rocks below. Water is then fed into these boreholes and comes into direct contact with the hot rocks. Contact between water and the hot rocks produces high pressure steam. This steam is returned to the surface to be utilized in a steam turbine as one of the cleanest forms of power production known to date[3].
- This form of power generation has the potential to be very beneficial for several different reasons. The miniscule quantity of adverse impacts it has on the environment is one benefit that cannot be over emphasized. When a hot dry rock geothermal power plant is operating at a steady state there are virtually no emissions. No adverse elements are returned to the environment aside from a small amount of waste heat.[4] The emissions of dry rock geothermal power are negligible when compared to, for example, the thousands of tons of sulfur dioxide and millions of tons of carbon dioxide released into the environment by coal power plants.[5] Another advantage of this form of power production is that it is a very sustainable process. Hot water used in the process of power generation can be re-introduced into the boreholes to produce more steam.[6] These qualities allow hot dry rock geothermal power generation to easily adhere to the demands of a world yearning for a greener future. Lastly, there is the matter of location convenience. A hot dry rock geothermal power plant can be located anywhere that it is possible to access hot rock within the earth by drilling. This allows for large freedom of choice with regards to location and may even allow for more power production in areas where it is inconvenient for other methods to be implemented.[7] An example schematic of a HDR plant is shown to the right.

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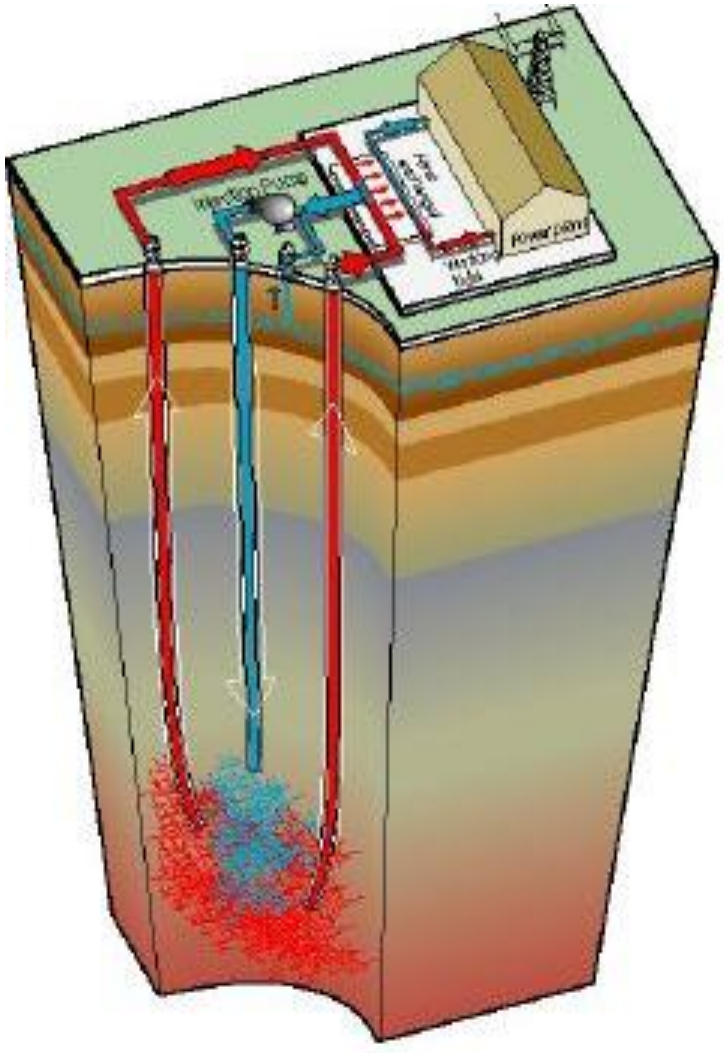
Hot Dry Rock Geothermal Power Plants



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Hot Dry Rock Geothermal Power Plants

- **Hot dry rock geothermal process**
- In order to harvest the heat found deep within the Earth's crust, high pressure cold water is pumped down several kilometers (usually between 3 and 7 kilometers) into hot, porous rock. Once enough water has been pumped down to create a significantly large thermal reservoir, steam or hot water returns to the surface and is harnessed either directly or indirectly. Once the steam has entered the power plant, the rest of the power generation cycle is very similar to one that can be found in coal or nuclear power plant: the steam passes through a series of turbines, is condensed back to liquid water, and is pumped back into the cycle (in this case, that means that it is pumped back underground). The turbines spin shafts that are attached to the generators that make the actual electricity that is sent to homes or businesses.
- **Construction**
- In order to push the water down far enough into the Earth, extremely high pressures are used. These pressures are tyipcally on the order of tens of megapascals, with some sources reporting operating pressures at up to 40 MPa for a drilling depths of about 5 km[8]. During the drilling of the holes that carry the water, enough holes must be drilled to accomodate the the water flow down and the steam flow up. Typically between 10 and 30 holes are drilled for flow each way.

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Magma Resources

- Geothermal energy uses the heat trapped beneath the Earth's surface to generate electricity. Conventional geothermal energy utilizes steam from natural sources such as geysers, or by drawing water from the hot, high-pressure depths of the Earth. The hot vapors are then used to drive electric turbines.
- In the case of volcanic geothermal energy, the heat comes from "supercritical water." The researchers explained that energy from so-called supercritical water is much higher than conventional geothermal steam. When molten rock and water meet, the extreme heat and pressure bring water to a "supercritical" state, where it is neither liquid nor gas. In this form, the water can carry more energy than normal steam, which could create up to 10 times the power output of other geothermal sources. Iceland is about to tap into water as hot as lava. Several kilometres below ground, a drilling rig named Thor will soon penetrate the area around a magma chamber, where molten rock from the inner Earth heats up water that has seeped through the seafloor. This water – up to 1,000°C and saturated with corrosive chemicals – will eventually be piped up to the surface and its heat turned into usable energy.
- It is a huge engineering challenge, and one which may usher in a new age of geothermal power production. Existing geothermal projects around the world need waters heated to less than 300°C, so why go to this extra effort and expense?
- The answer is simple: water at the most extreme temperatures exists in a state described as “supercritical”, where it behaves as neither a true liquid, nor a true gas, and is capable of retaining a phenomenal amount of energy. Supercritical water can generate up to ten times more power than conventional geothermal sources.

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Assignment

Q 1. Explain liquid dominated geothermal plants.

Q 2. Explain vapour dominated geothermal plant.

Q 3. Explain Hot Dry Rock Geothermal Power Plants.

Q 4. Explain magma resources of geothermal energy.

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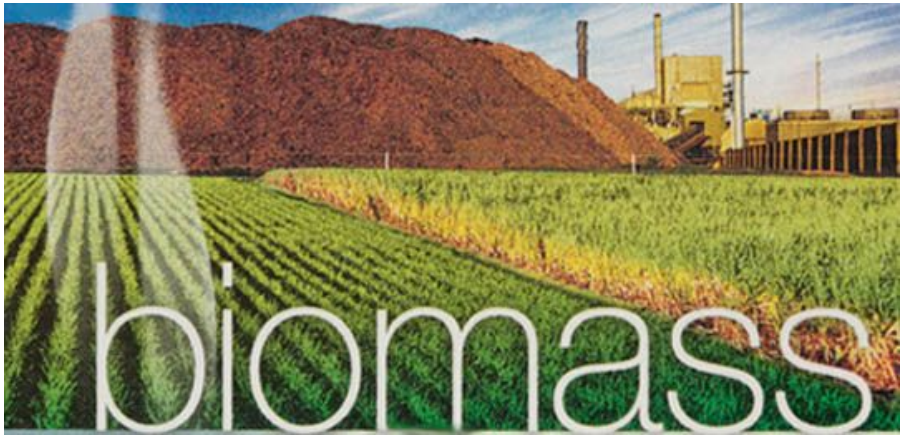


Biomass/Biofuel/Biogas

What is biomass?

- Biomass is a renewable energy source that is derived from living or recently living organisms.
- Biomass includes biological material, not organic material like coal.
- Energy derived from biomass is mostly used to generate electricity or to produce heat.
- Thermal energy is extracted by means of combustion,
- Biomass can be chemically and biochemically treated to convert it to a energy-rich fuel.

Types of Biomass

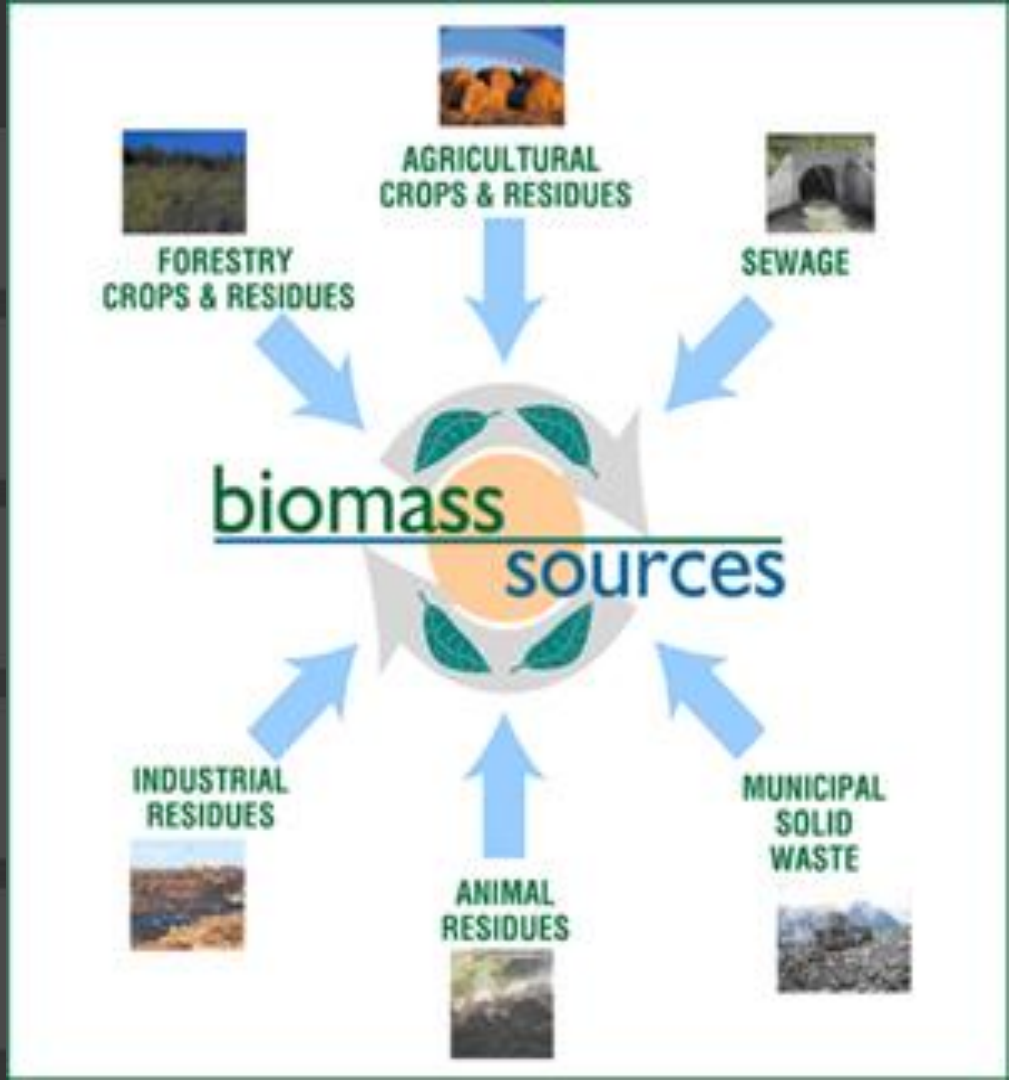
Wood fuel

Rubbish

Alcohol fuels

Crops

Landfill gas



Using biomass as a primary fuel source

Biomass is used as a primary fuel source in developing countries specifically in rural areas.

Something to know…

- Biomass has a smaller energy content for its bulk than fossil fuels
- Costs of labor, transportation, and storage would then be higher

Biofuels and biodiesels

Biofuels are created from vegetable or animal based oils (Ex: canola or soybean oil, palm oil, grease, sewage or leftover trash) It is used and fuels for vehicles.

Biodiesel is also a type of fuel created by vegetable or animal oils but it is often blended with regular diesel. Biodiesel is a cleaner alternative to diesel. But not all vehicles can use diesel.

Advantages for Biomass, Biogas, and Biofuel

1. It's renewable - You will always have a source for biomass (Crops and garbage)
2. Abundant - Biomass is available all over the world
3. Cheaper than other fuels - It cost ⅓ less than fossil fuel which can save you a lot of money
4. Carbon neutral - Biomass is a part of the carbon cycle. It is a clean source and do not contribute to global warming

ENVIRONMENTAL ADVANTAGES

- Renewable resource
- Reduces landfills
- Protects clean water supplies
- Reduces acid rain and smog
- Reduces greenhouse gases
- Carbon dioxide
- Methane

BIOMASS AND CARBON EMMISIONS

- Biomass emits carbon dioxide when it naturally decays and when it is used as an energy source
- Living biomass in plants and trees absorbs carbon dioxide from the atmosphere through photosynthesis
- Biomass causes a closed cycle with no net emissions of greenhouse gases

Disadvantages for Biomass, Biogas, and Biofuel

1. Expensive - Biomass is expensive to set up and store

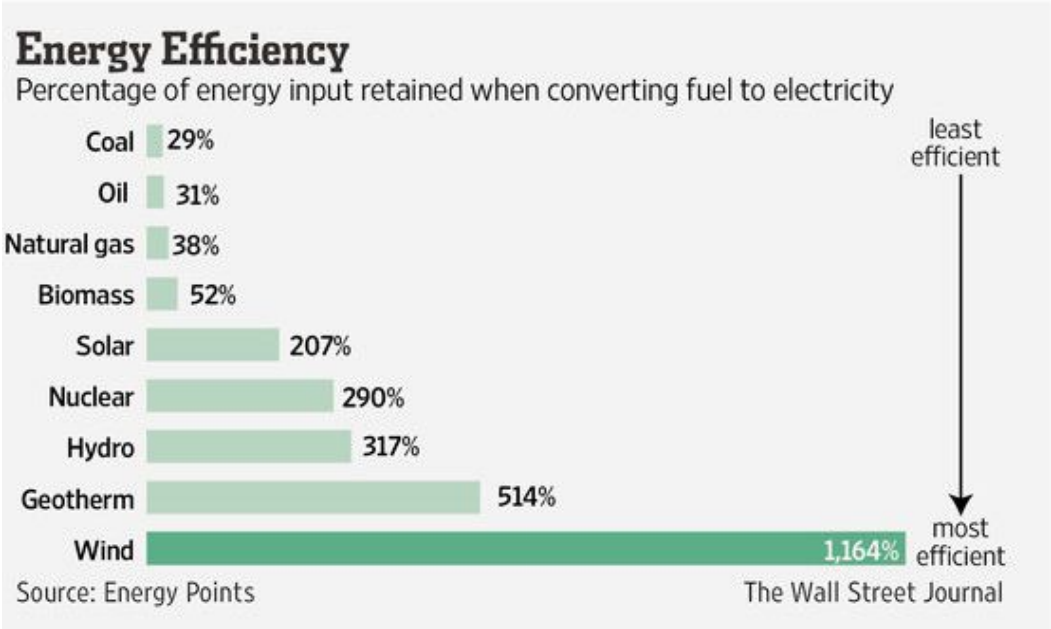
2. Requires a lot of space - We need a lot of space to store all the energy

ENVIRONMENTAL DISADVANTAGES

- Crop and forest residues often contain high concentrations of important nutrients
- If the residue is harvested as energy, the nutrients can be lost to the surrounding environment.
- Other synthetic chemical nutrients or fertilizers can later be added
- More plants and trees must be planted, because they will be used in a higher quantity

Energy Efficiency

Biomass is 52% efficient, so using it is less efficient because it only gives off half of its energy.



Sources of Biofuels

Algae

Ethanol

Vegetable oil

Biogas

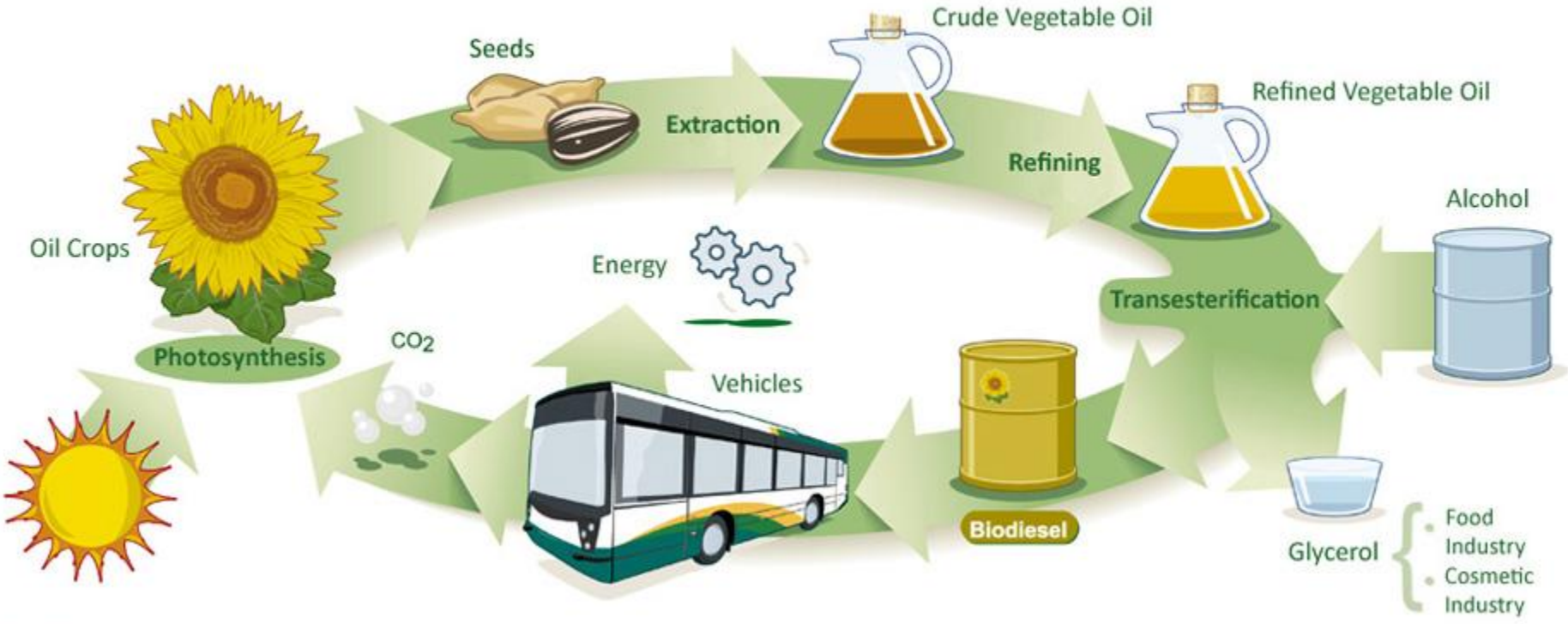
Syngas

Blended Biodiesel

Ethanol-how is it currently used and made?

- Ethanol: alcohol by fermenting the sugars found in plants, it is often blended with gasoline.
- The way ethanol is produced in the U.S. by using corn to be produced into ethanol.

The Biodiesel Cycle



Biodiesel

Biodiesel is a fuel made from vegetable or animal oils that is often blended with regular diesel fuel.

Pros

- Uses waste for fuel
- Resources are cheaper
- Reduced Methane (greenhouse gas)

Cons

- Needs lots of maintenance
- Less potential energy
- Thought to lead to higher pollution and more health problems.

Algae as a Biofuel?

- Algae grows 30 times as fast as plants and it stores up to half of its total body mass as oil; meaning that it has a greater oil supply to use as fuel.

- **Commercial use?**
  - It is very expensive to run plants to properly culture algae, making it a less likely source for commercial use.

Algae as a Biofuel

Pros:

- It grows a lot faster.
- Can be grown in a controlled area and at a controlled amount.
- Holds more oil than typical plants (that are used for biofuel)

Cons:

- More expensive.
- Grows rapidly.
- Harder to get oils out.

Biogas

- Biogas is defined as a mixture of different gases produced by the breakdown of once living organisms 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

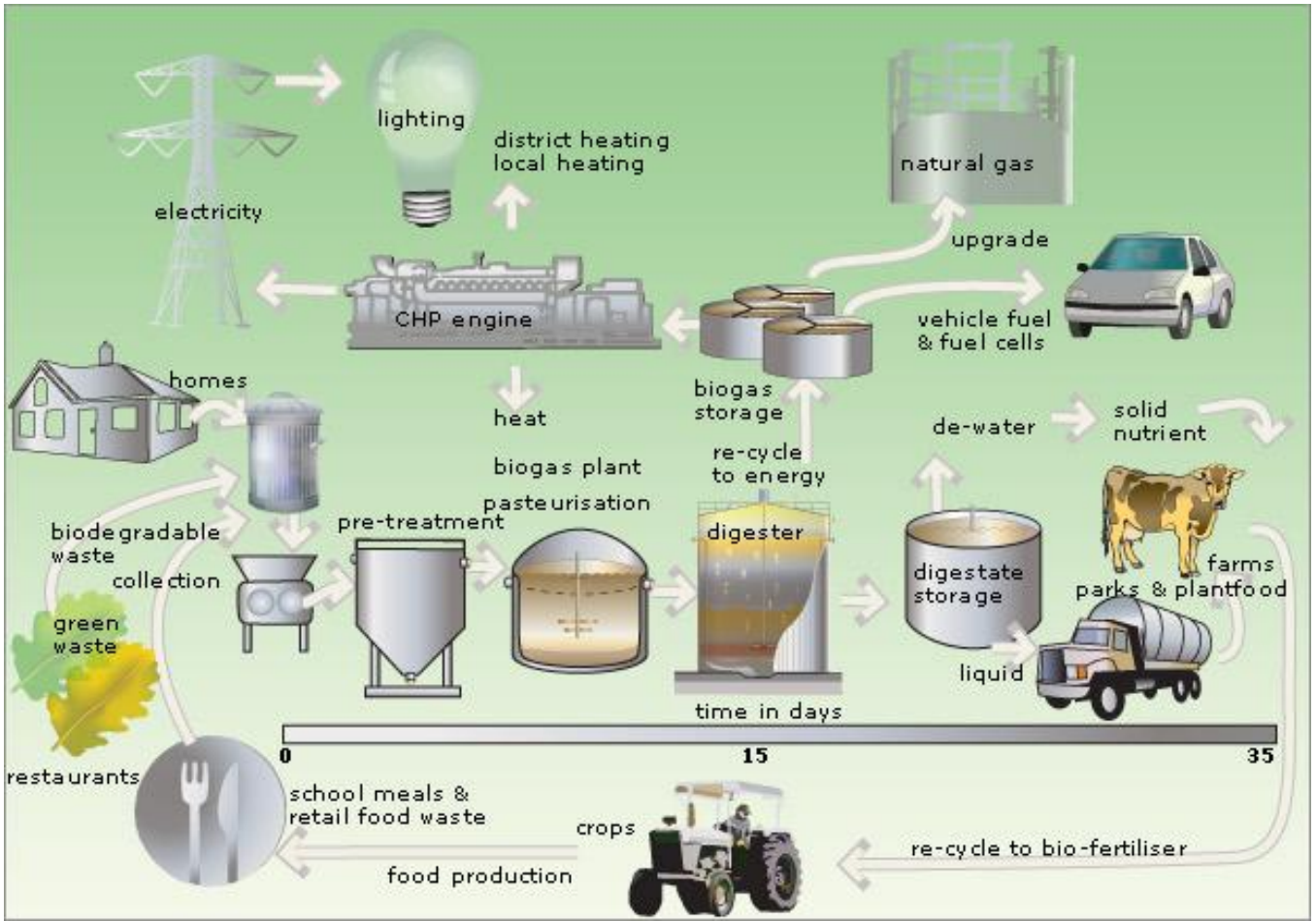
Pros of Biogas

- Provides non-polluting and renewable source
- efficient way of energy conversion(saves fuelwood)
- saves women and children from carrying firewood and exposure to kitchen smoke

Cons of Biogas

- Difficult to enhance efficiency of biogas systems
- contains some impurities and gas that are harmful
- it is somewhat unstable make it prone to combustion if methane comes in contact with oxygen

Biogas Digester



Biogas Digester Construction

BIO – GAS & BIO GAS PLANTS

BIOGAS

Mixture of gases.

Produced by anaerobic digestion of organic matter.

Consist of CH_4,CO_2,traces of H_2& other gases.

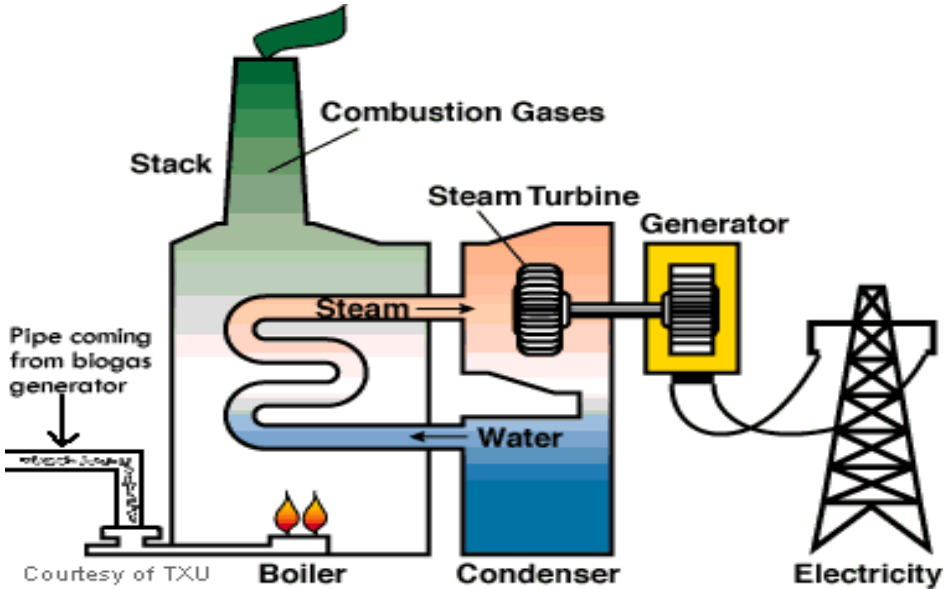
Composition of Biogas

Type of gas	% in the mixture by volume
Methane	50–80
Carbon dioxide	15–45
Water	5
Other gases including hydrogen	0–1
Hydrogen sulphide	0–3

BENEFITS FROM BIOGAS PLANTS

Used mainly for cooking & lighting purposes.

Used in internal combustion engines to power water pumps & electric generators.



Used as fuel in fuel type refridgerators.

Sludge - fertilizer.

↓ envt. pollution

SUBSTRATE

Plant & animal biomass.

Plant biomass –

Animal biomass – cattle dung,manure from poultry,goats & sheep slaughter house & fishery wastes.

Agricultural wastes also used

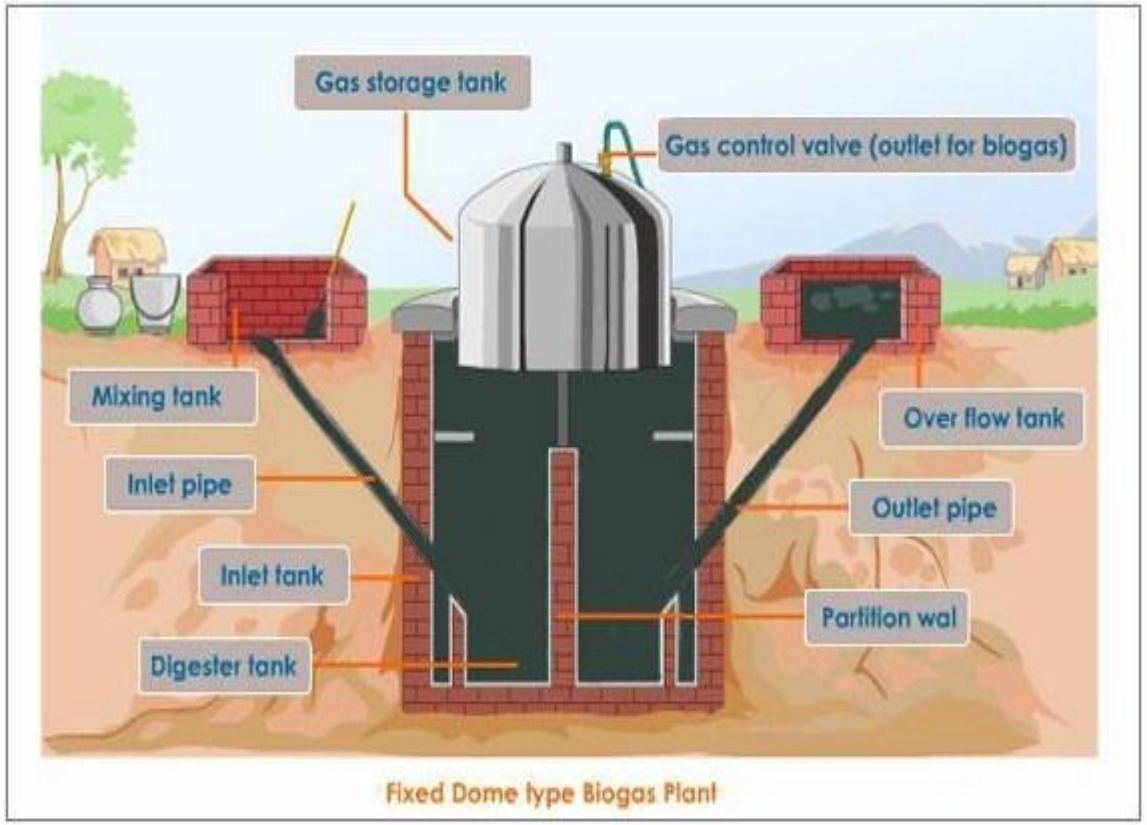
Parts of biogas plant

Digester

Gas holder

Inlet

Outlet



Inlet chamber

To supply cow dung to the digester

It is made at the ground level so that the cow dung can be poured easily.

made up of bricks, cement and sand.

The outlet wall of the inlet chamber is made inclined so that the cow dung easily flows to the digester.

Digester

Most important part of biogas plant

Fermentation takes place - fermentation tank.

Built underground – insulated,airtight

Made up of bricks, sand and cement.

Almost at the middle of the height of digester, two openings are provided on the opposite sides for inflow of fresh cow dung and outflow of used cow dung.

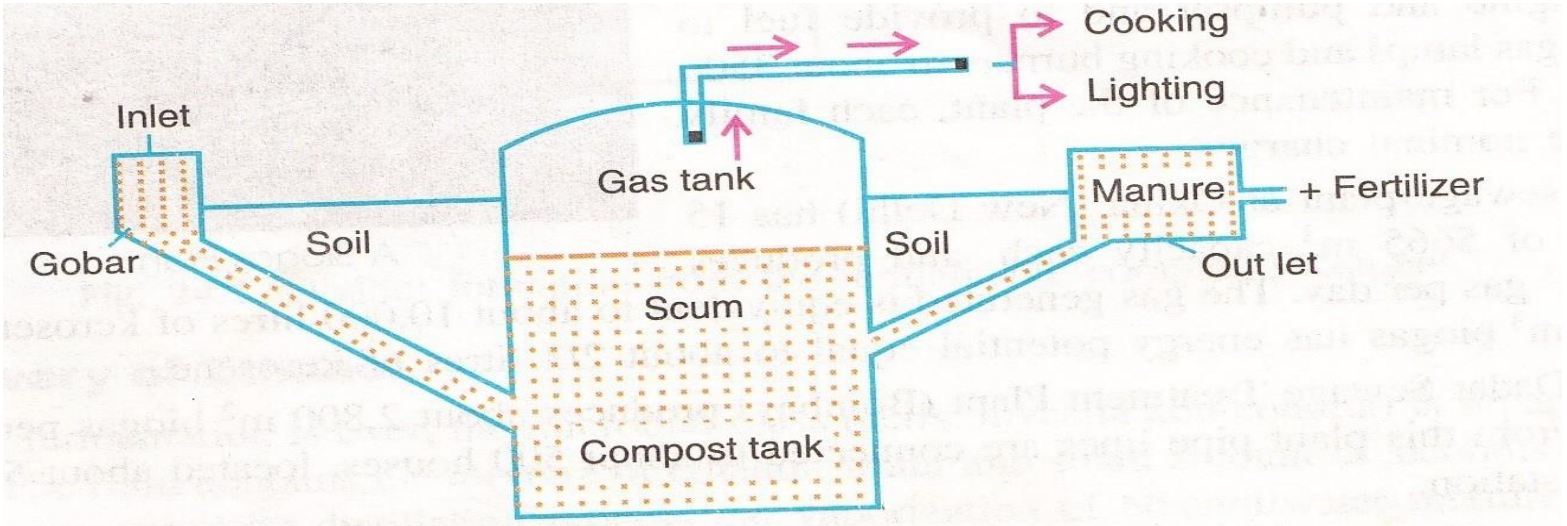


Fig. 24.2. Diagram of a Janata Vayu Gas (gobar gas) Plant.

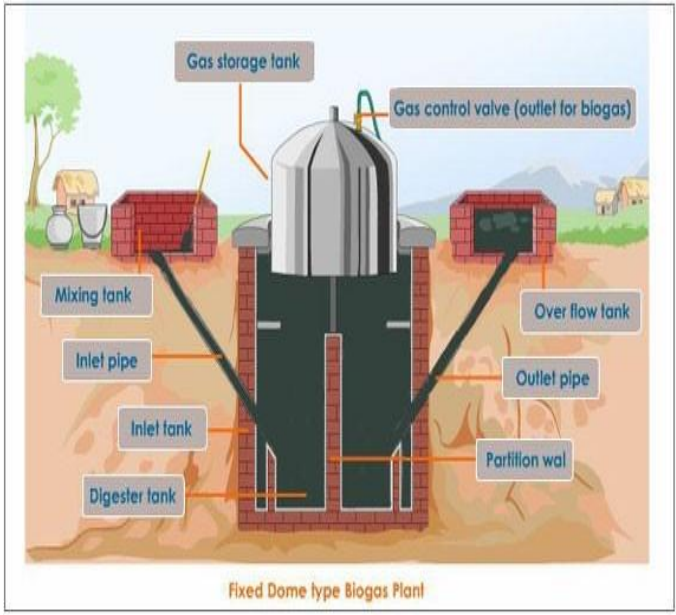
Gas holder

Cylindrical container

Above digester

Collect gas

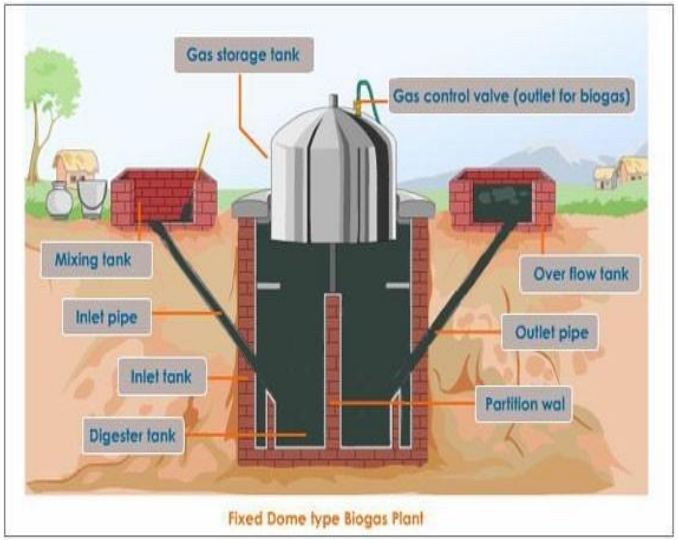
The gas pipe carries the biogas to the place where it is consumed.



Outlet Chamber

Digested slurry from which the biogas has been generated is removed from the biogas plant.

The outlet chamber is also at the ground level.



Fixed dome type

A fixed-dome plant consists of a digester with a fixed, non-movable gas holder, which sits on top of the digester.

Floating-drum type

Consist of an underground digester and a moving gas-holder.

Gas-holder floats either directly on the fermentation slurry or in a separate water jacket.

The gas is collected in the gas drum, which rises or moves down, according to the amount of gas stored

Floating-drum type

Batch type

Filled once,sealed.

Emptied when raw materials stop producing gas.

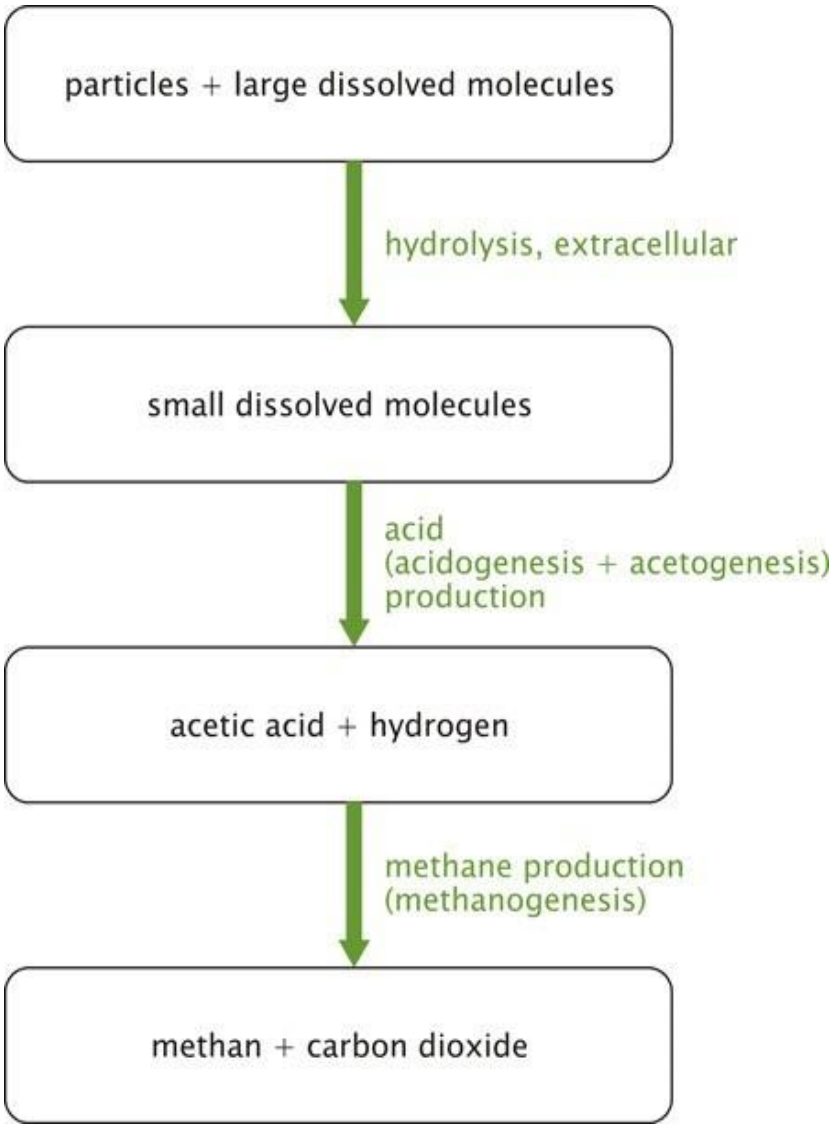
Continuous type

Fed with a definite quantity of wastes at regular intervals

Gas production continuous & regular

MICROBIOLOGY OF BIOGAS

- 4 steps
- Hydrolysis
- Acidogenesis
- Acetogenesis
- Methanogenesis



Hydrolysis

Biomass is made up of large organic polymers

Complex polymers hydrolysed to monomers

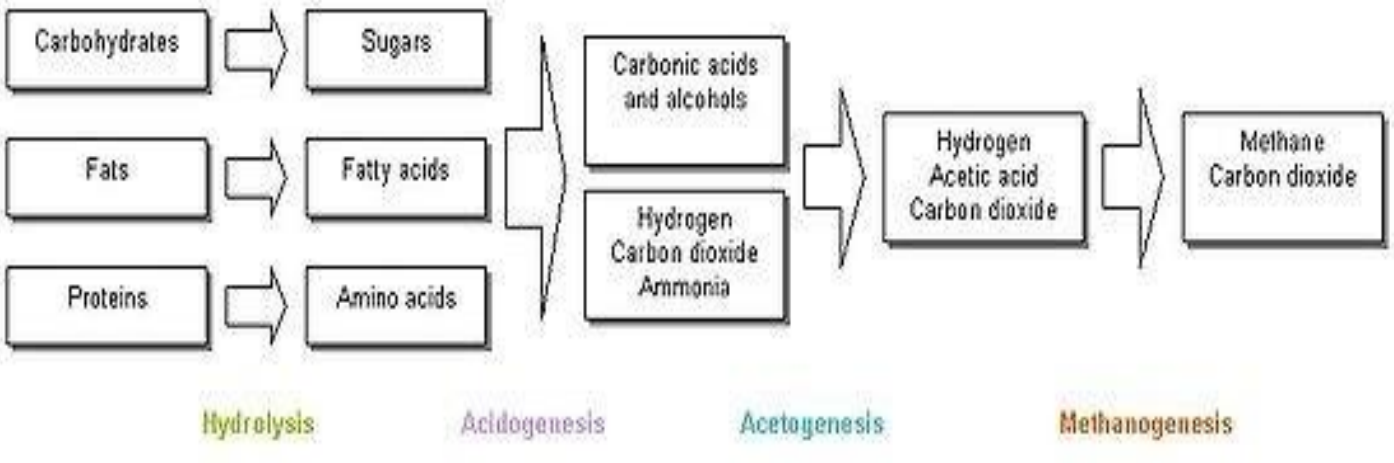
complex organic molecules → simple sugars, amino acids, and fatty acids.

Done by hydrolytic fermentative bacteria

Acidogenesis

Results in further breakdown of the remaining components by acidogenic bacteria.

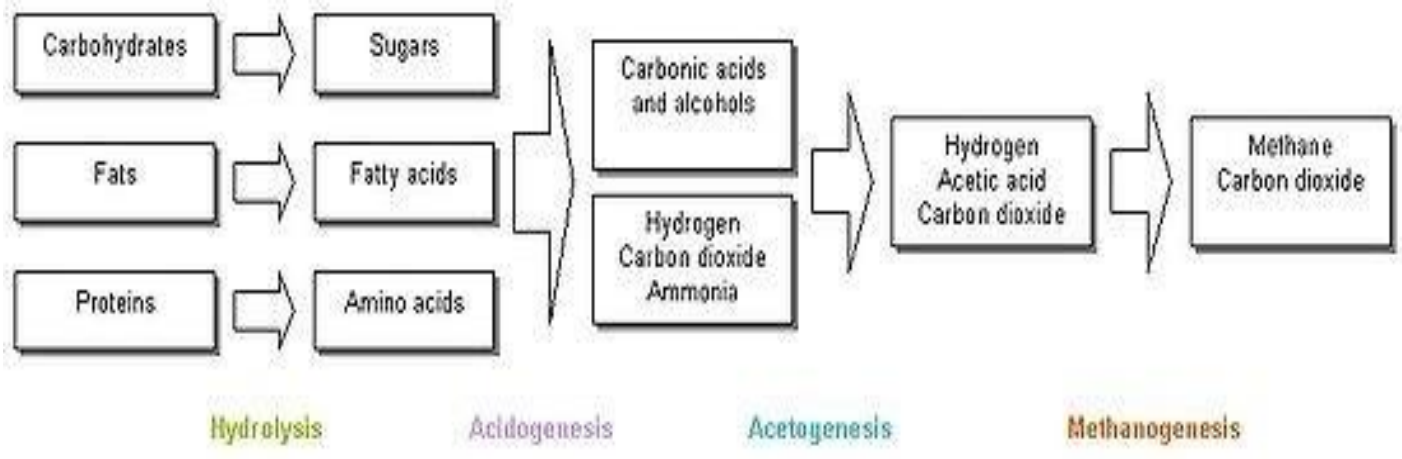
Ammonia, H_2, CO_2, H_2S, shorter volatile fatty acids, carbonic acids, alcohols, as well as trace amounts of other byproducts produced



Acetogenesis

Simple molecules created through the acidogenesis phase further digested to acetic acid, carbon dioxide and hydrogen.

Acetogenic bacteria



Methanogenesis

The terminal stage

Intermediate products of the preceding stages converted to methane, carbon dioxide, and water.

These components make up the majority of the biogas emitted from the system.

Methanogenic bacteria

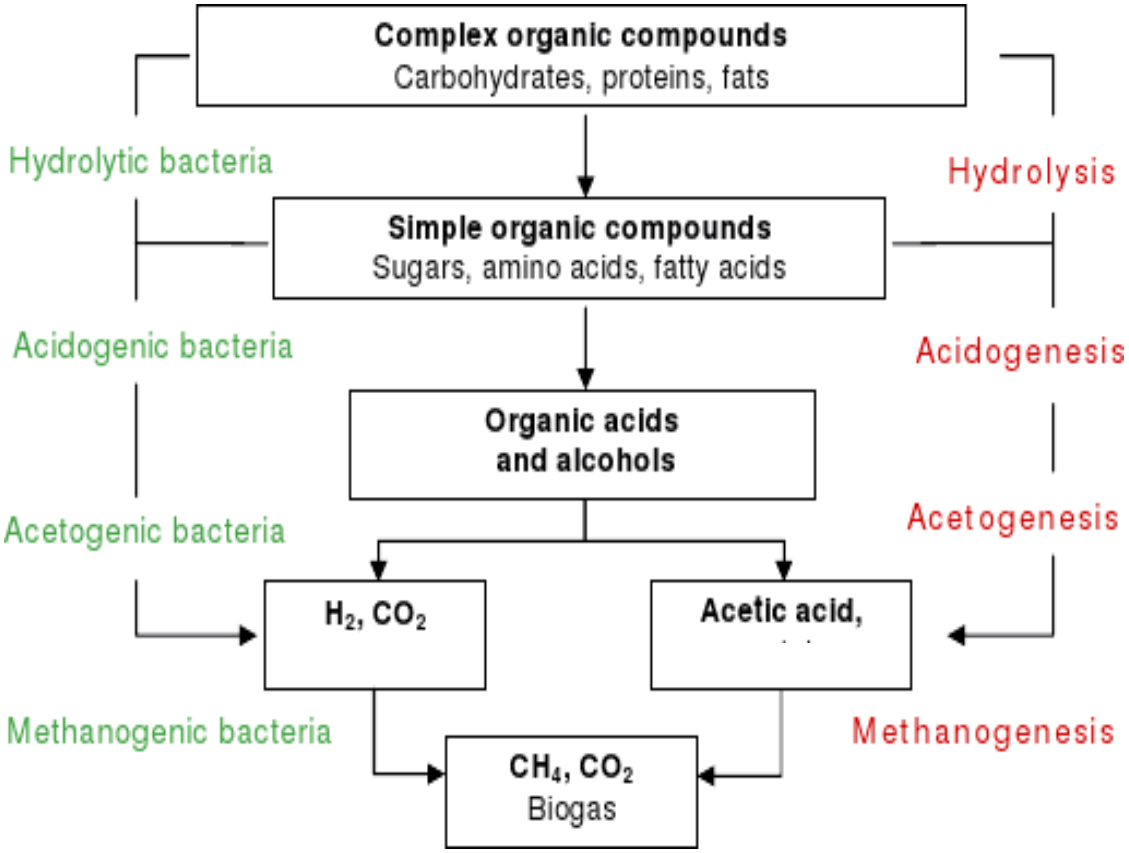
MICRO ORGANISMS

Hydrolytic & fermentative bacteria.

Acidogenic bacteria.

Acetogenic bacteria.

Methanogenic bacteria.


Complex organic compounds
Carbohydrates, proteins, fats
Hydrolytic bacteria
Hydrolysis
Simple organic compounds
Sugars, amino acids, fatty acids
Acidogenic bacteria
Acidogenesis
Organic acids
and alcohols
Acetogenic bacteria
Acetogenesis
H2, CO2
Acetic acid,
Methanogenic bacteria
Methanogenesis
CH4, CO2
Biogas

Methanogenic bacteria.

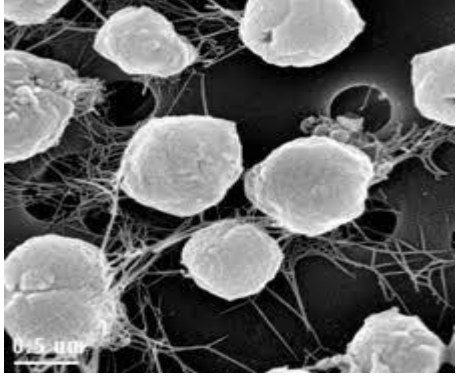
Create methane from the final products of acetogenesis as well as from some of the intermediate products from hydrolysis and acidogenesis .

Archaebacteria

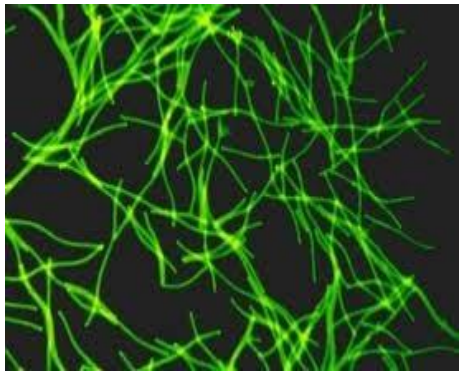
MAJOR GENERA OF METHANOGENIC BACTERIA

Genus	*Morphology*
Methanobacterium	Long rods or filaments
Methanomicrobium	Short rods
Methanogenium	Irregular, small cocci
Methanococcus	Irregular, small cocci
Methanobrevibacter	Lancet shaped cocci or short rods
Methanospirillum	Short to long spiral
Methanosarcina	

Cocci



Spirilli



Bacilli

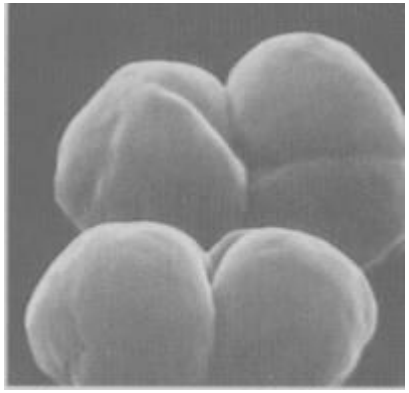
sarcina

Cocci forming colonies in cubical packets of eight or more are called sarcina

Methanogens are a diverse group of organisms that can live in a wide range of environments.

They have been found in a range of salinity from freshwater to hypersaline.

Biogas plant – *Methanosarcina barkeri*, *Methanobacterium omelianskii*



Factors affecting methane formation.

pH Temperature

Nitrogen concentration C:N ratio

Creation of anaerobic conditions

pH

6-8

Acidic medium lowers methane formation.

Temperature

Fluctuation ↓ methane formation – inhibit growth of methanogens.

30-40^{o}C

Nitrogen concentration

↑ N_2- ↓ growth of bacteria - ↓ CH_4

C:N ratio

Micro organisms in a biogas plant needs both N nitrogen and C carbon.

Research has shown that the methanogenic bacteria work best with a C/N ratio 30:1.

Creation of anaerobic conditions

CH_4 production takeplace in strictly anaerobic condition.

Digesters – airtight, burried under soil.

GASIFICATION

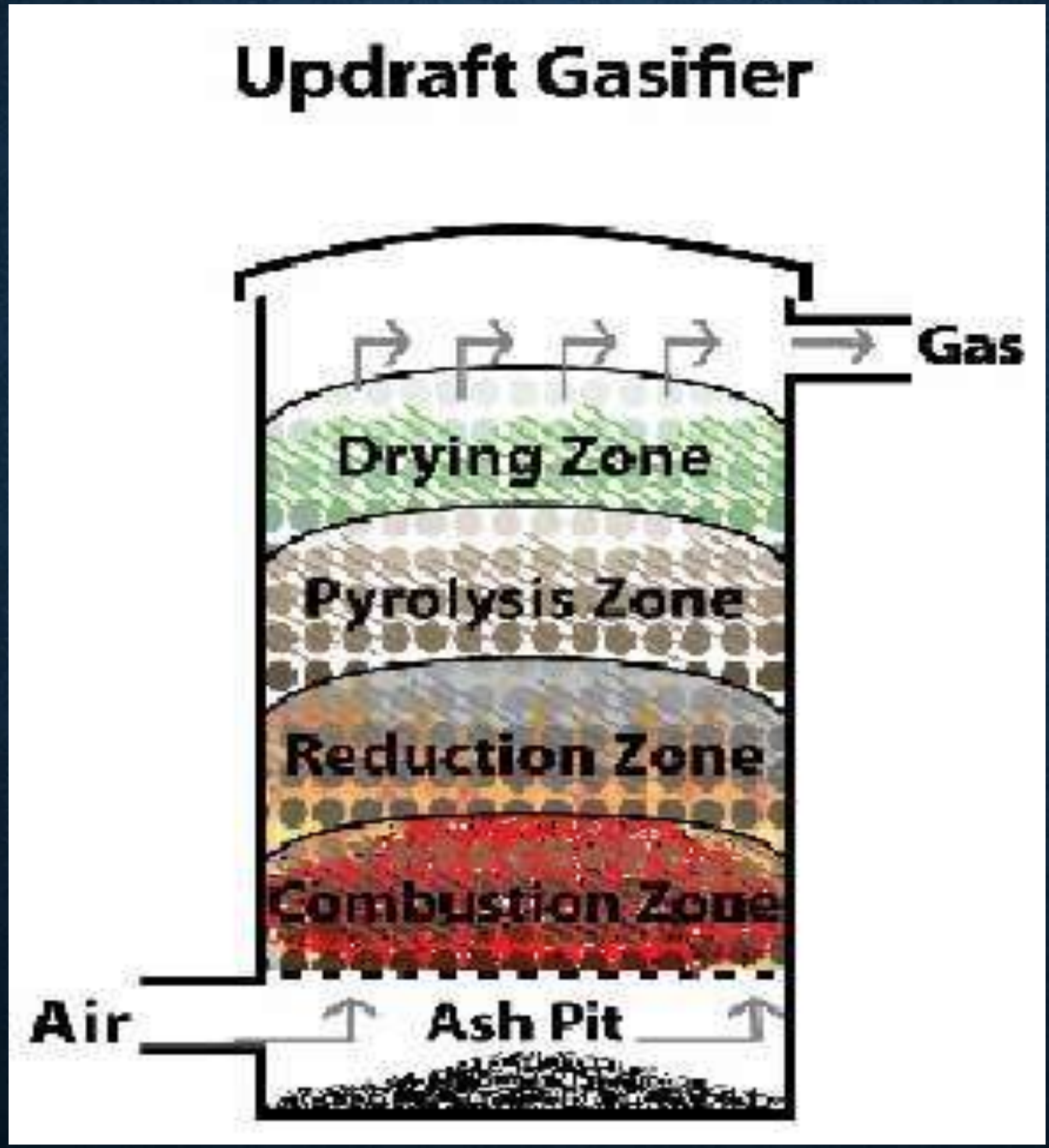
- **Gasification** is a process that converts organic or fossil fuel based carbonaceous materials into carbon monoxide, hydrogen and carbon dioxide. This is achieved by reacting the material at high temperatures (>700 °C), without combustion, with a controlled amount of oxygen and/or steam. The resulting gas mixture is called syngas (from synthesis gas or synthetic gas) or producer gas and is itself a fuel.
- The advantage of gasification is that using the syngas is potentially more efficient than direct combustion of the original fuel because it can be combusted at higher temperatures or even in fuel cells, so that the thermodynamic upper limit to the efficiency defined by Carnot's rule is higher or (in case of fuel cells) not applicable. Syngas may be burned directly in gas engines, used to produce methanol and hydrogen, or converted via the Fischer–Tropsch process into synthetic fuel. Gasification of fossil fuels is currently widely used on industrial scales to generate electricity.

TYPES OF GASIFIERS

- Gasifier equipments are generally classified as upward draft, downward draft and cross draft gasifiers, based on the direction of air/oxygen flow in the equipment. It should be noted that there are types of gasifier equipment which are different from types of gasification processes. Gasification processes can be categorized into three groups: entrained flow, fluidized bed and moving bed (sometimes called, somewhat erroneously, fixed bed).
- In gasifier Fuel Interacts with air or Oxygen and steam. So the gasifier are classified according to the way air or oxygen is introduced in it. On a bigger scale there are following four type of gasifiers.
- The choice of the one type of gasifier over there is mostly determined by the fuel, its final available form, its size , moisture content and ash content. First three type of gasifiers are mostly used in entrained bed gasification process and moving bed gasification process. While the last one is fluidized bed gasification process.

UPWARD DRAFT OR COUNTER-CURRENT GASIFIER

- This one is oldest and simplest type of gasifier. The air comes in at the bottom and produced syn gas leaves from the top of the gasifier. Near the grate at the bottom combustion reaction occurs, above that reduction reaction occurs. In the upper part of the gasifier heating and pyrolysis of the feedstock occurs as a result of heat transfer by forced convention and radiation from the lower zones. Tars and volatile produce produced during the reaction will leave along with the syn gas at the top of the gasifier. Which will be later separated by use of cyclone and candle filter.
- The major advantages of this type of gasifier are its simplicity, high charcoal burn out and internal heat exchange leading to low temperature of exit gas and high equipment efficiency. This gasifier can work with several kind of feedstock ranging from Coal to Biomass.
- Major drawbacks result from the possibility of "channeling" in the equipment, which can lead to oxygen break-through and dangerous, explosive situations and the necessity to install automatic moving grate.

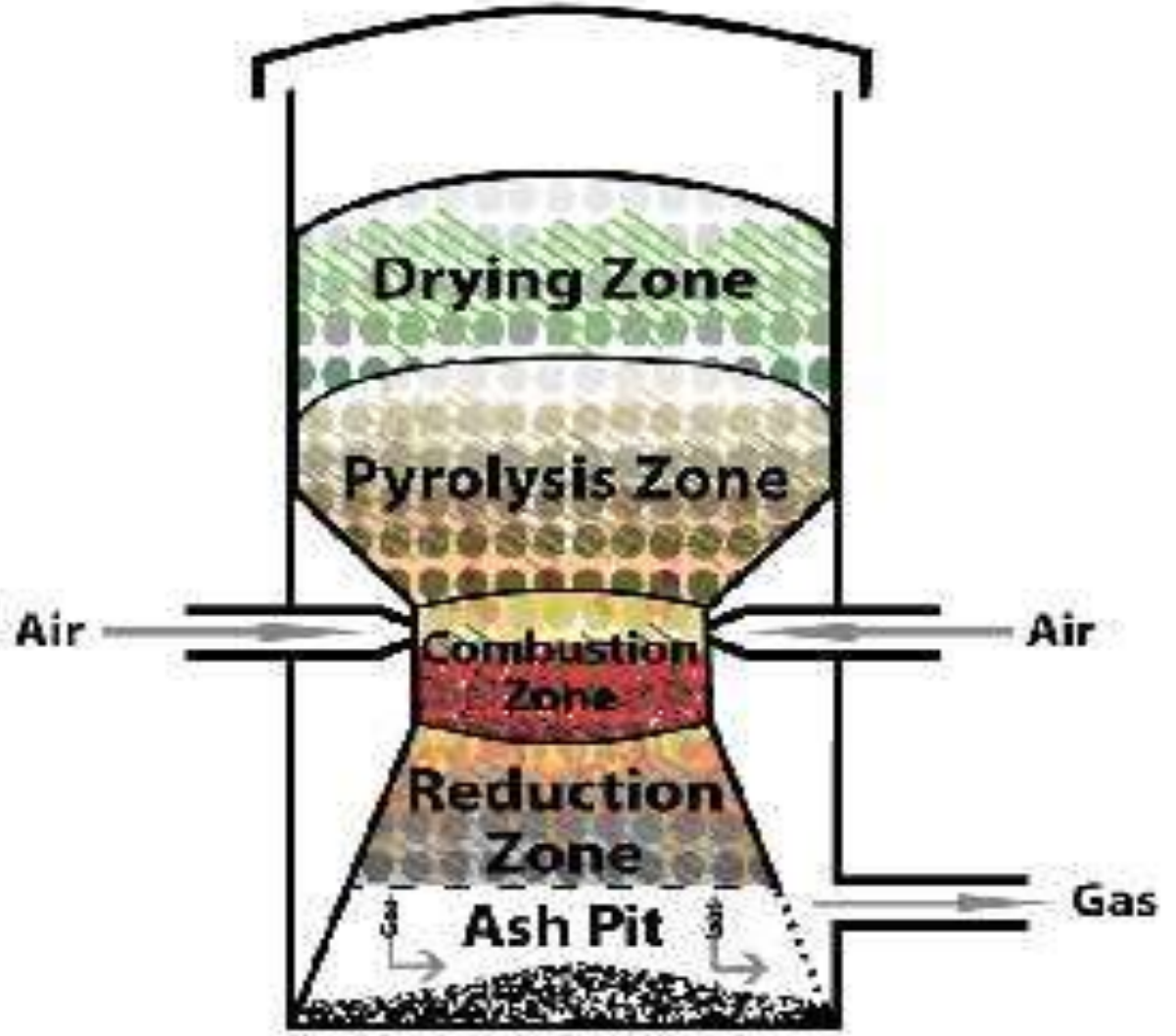

Updraft Gasifier
Gas
Drying Zone
Pyrolysis Zone
Reduction Zone
Combustion Zone
Air
Ash Pit

DOWNDRAFT OR CO-CURRENT GASIFIER

- In updraft gasifier there is a problem of tar entrainment in the product gas leaving stream. A solution is to have primary gasification air introduced at or above the oxidation zone in the gasifier. The produced gas is taken out from the bottom.
- On their way down, the acid and tarry distillation products from the fuel must pass through a glowing bed of charcoal and therefore are converted into permanent gases hydrogen, carbon dioxide, carbon monoxide and methane.
- Main advantage of downdraft gasifier lies in the possibility of producing tar free gas for engine operation. However in practice very rarely tar free gas is produced but the % of tar leaving in product stream is considerably lower than leaving through the updraft gasifier.
- Main disadvantage is that downdraft gasifier cannot be operated with range of different feedstocks. Low density feedstock gives rise to flow problems and excessive pressure drop. High ash content coal also gives more problem with this kind of gasifier than updraft gasifier.
- Other disadvantage is it gives lower efficiency, since there is no provision internal heat exchange compare to updraft gasifier. The product stream also has low calorific value.

Downdraft Gasifier

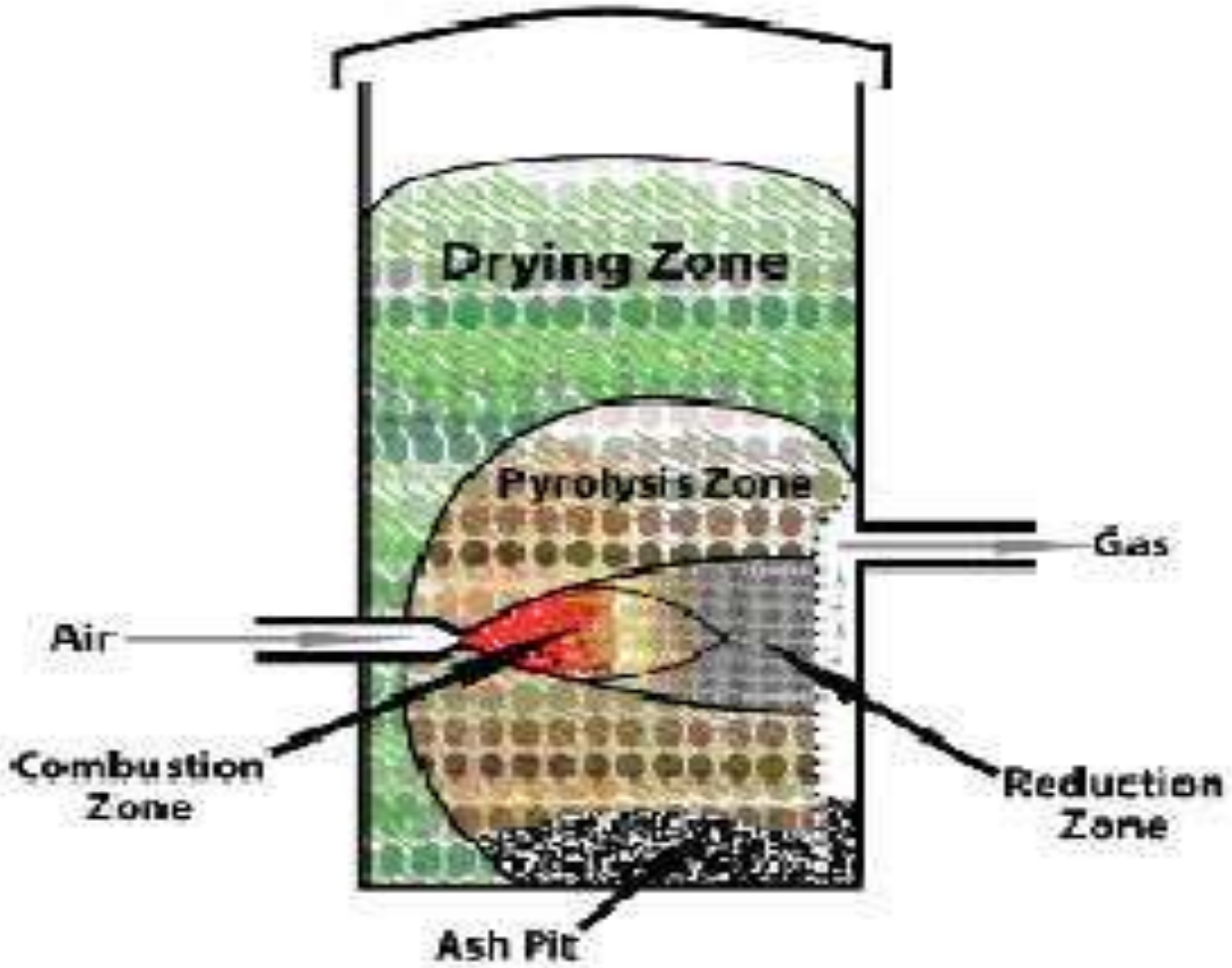
Nozzle and constriction (Imbert)



CROSS DRAFT GASIFIER

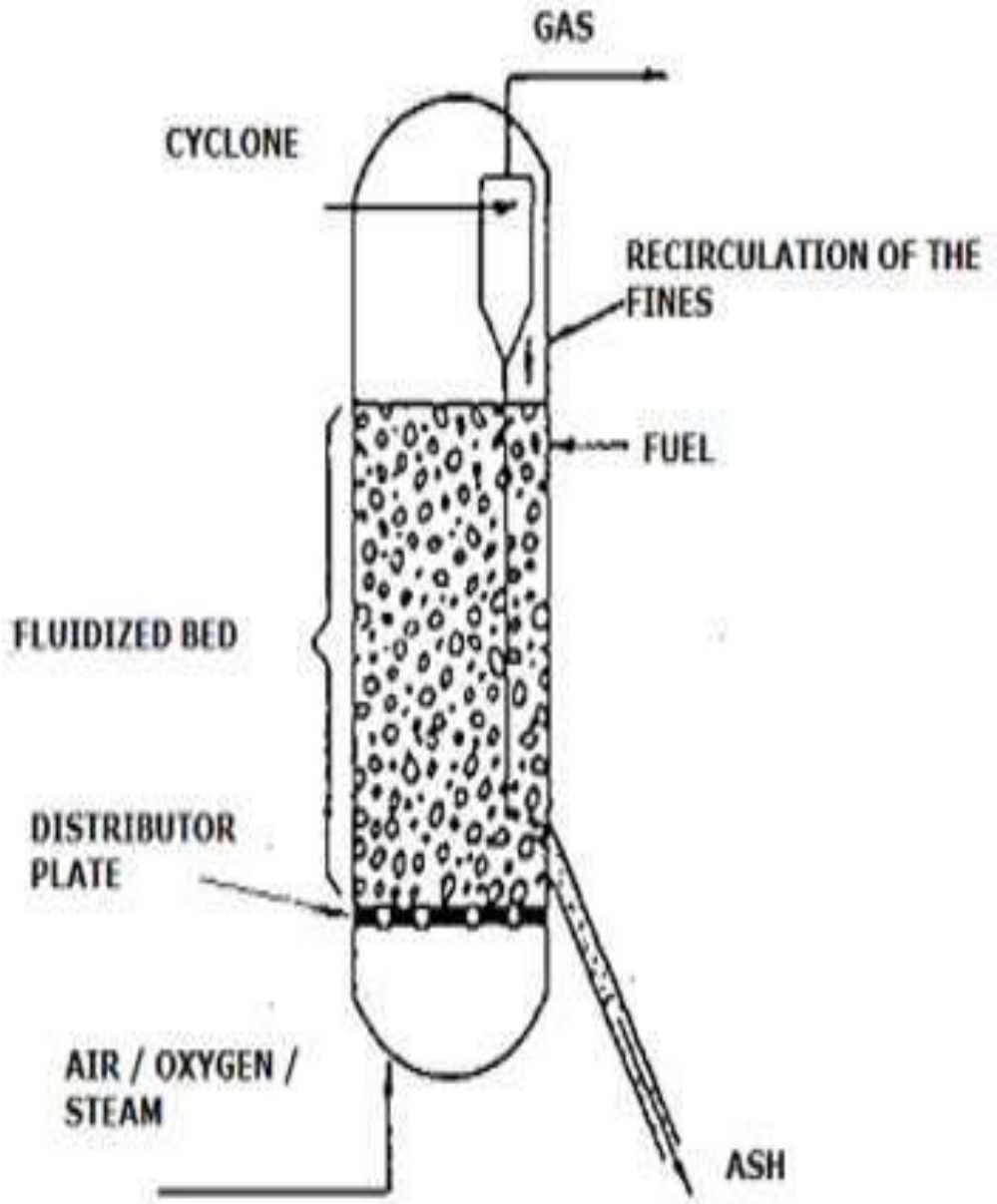
- Although cross draft gasifiers have certain advantages over updraft and downdraft gasifiers, they are not ideal. The disadvantages such as high exit gas temperature, poor CO_2 reduction and high gas velocity are the consequences of the design. Unlike downdraft and updraft gasifiers, the ash bin, fire and reduction zones in cross draft gasifiers are separate. These design characteristics limit the type of fuel usage restricted to only low ash fuels such as wood, charcoal and coke. The load following ability of cross draft gasifier is quite good due to concentrated zones which operate at temperatures up to 1200^0C. Start up time (5-10 minutes) is much faster than that of downdraft and updraft units. The relatively higher temperature in cross draft gas producer has an obvious effect on exit gas composition such as high carbon monoxide and low hydrogen and methane content when dry fuel such as charcoal is used. Cross draft gasifier operates well on dry air blast and dry fuel.

Crossdraft Gasifier



FLUIDIZED BED GASIFIER

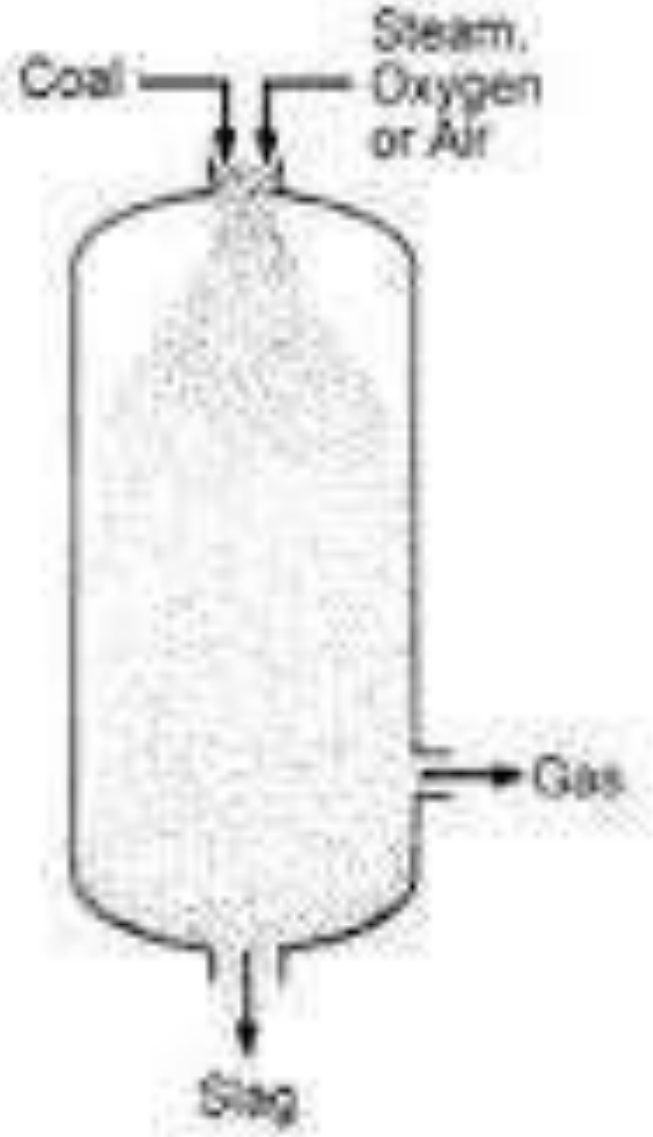
- The operation of both up and downward draft gasifiers is influenced by the morphological, physical and chemical properties of the fuel. Problems commonly encountered are: lack of bunker flow, slagging and extreme pressure drop over the gasifier.
- A new design to address all this difficulties is fluidized bed gasifier.
- Air is blown through a bed of solid particles at a sufficient velocity to keep these in a state of suspension. The bed is originally externally heated and the feedstock is introduced as soon as a sufficiently high temperature is reached. The fuel particles are introduced at the bottom of the reactor and almost instantaneously heated up to the bed temperature. As a result of this treatment the fuel is pyrolysed very fast, resulting in a component mix with a relatively large amount of gaseous material. Ash particles are also carried over the top of the reactor and have to be removed from the gas stream if the gas is used in engine applications. To remove ash particles cyclone and candle filter are used.
- The major advantage of fluidized bed is processing of feedstock. This type of gasifier are mostly used for high ash coal and biomass. Since temperature is below the ash softening temperature so handling of ash is relatively simple.
- Drawback of fluidized bed gasifiers is - high tar content in the produced syn gas.

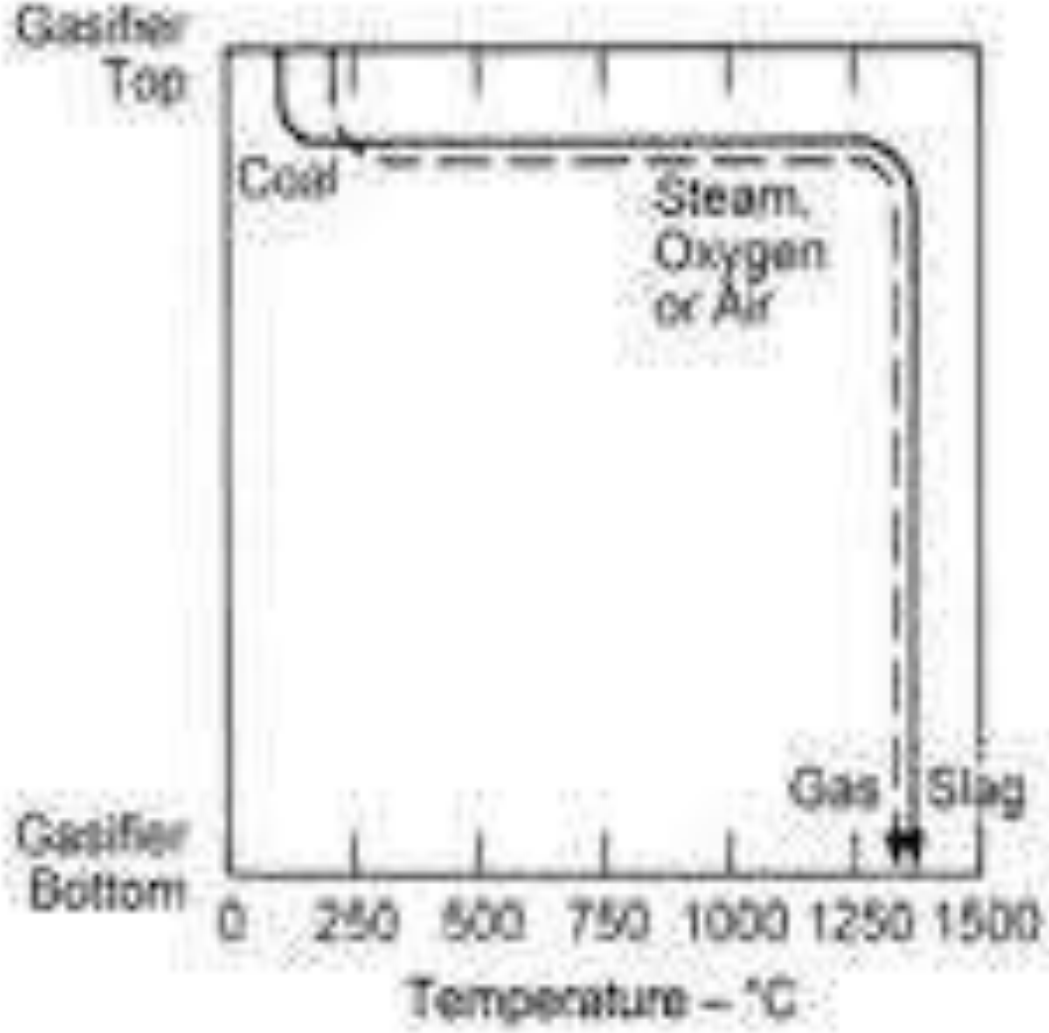

GAS
CYCLONE
RECIRCULATION OF THE FINES
FUEL
FLUIDIZED BED
DISTRIBUTOR PLATE
AIR / OXYGEN / STEAM
ASH

ENTRAINED FLOW GASIFIER

- A dry pulverized solid, an atomized liquid fuel or a fuel slurry is gasified with oxygen in co-current flow. The gasification reactions take place in a dense cloud of very fine particles.
- The high temperatures and pressures also mean that a higher throughput can be achieved, however thermal efficiency is somewhat lower as the gas must be cooled before it can be cleaned with existing technology.
- A smaller fraction of the ash is produced either as a very fine dry fly ash or as a black colored fly ash slurry. Some fuels, in particular certain types of biomasses, can form slag that is corrosive for ceramic inner walls that serve to protect the gasifier outer wall.

Entrained-Flow Gasifier





PLASMA GASIFIER

In a plasma gasifier a high-voltage current is fed to a torch, creating a high-temperature arc. The inorganic residue is retrieved as a glass-like substance