

UNIT - III
GASEOUS FUELS
BIOMAS AND GASIFICATION

Manoj Kumar
Assistant Professor
School of Mechanical Engineering
Galgotias University , Greater Noida

CONTENTS

- **DEFINATION**
- **FERMENTATION**
- **PYROLYSIS**
- **GASIFICATION**
- **FLUIDIZED BED GASIFICATION**
- **ADVANTAGES OF FLUIDIZED BED GASIFICATION**
- **CALORIFIC VALUE**
- **BIOMASS FUEL PROPERTIES FOR BIOMASS GASIFIER SELECTION**
- **GASIFIER DESIGN CALCULATIONS**
- **ADVANTAGES OF BIOMASS ENERGY**
- **DISADVANTAGES OF BIOMASS ENERGY**

Defination

- The biomass is biological material derived from living or recently living organism. It's an organic matter derived from biological organism - plants, algae, animals etc. The biomass for energy mean plant based material but biomass can equally apply to both animal and vegetable derived material..
- The sources of biomass are the forest and agricultural waste, animal waste, energy crops, co-products in the crop field or industrial process wastes or by-products.
- As a renewable energy source, biomass can either be used directly via combustion to produce heat, or indirectly after converting it to various forms of biofuel. Conversion of biomass to biofuel can be achieved by different methods which are broadly classified into: *thermal*, *chemical*, and *biochemical* methods.



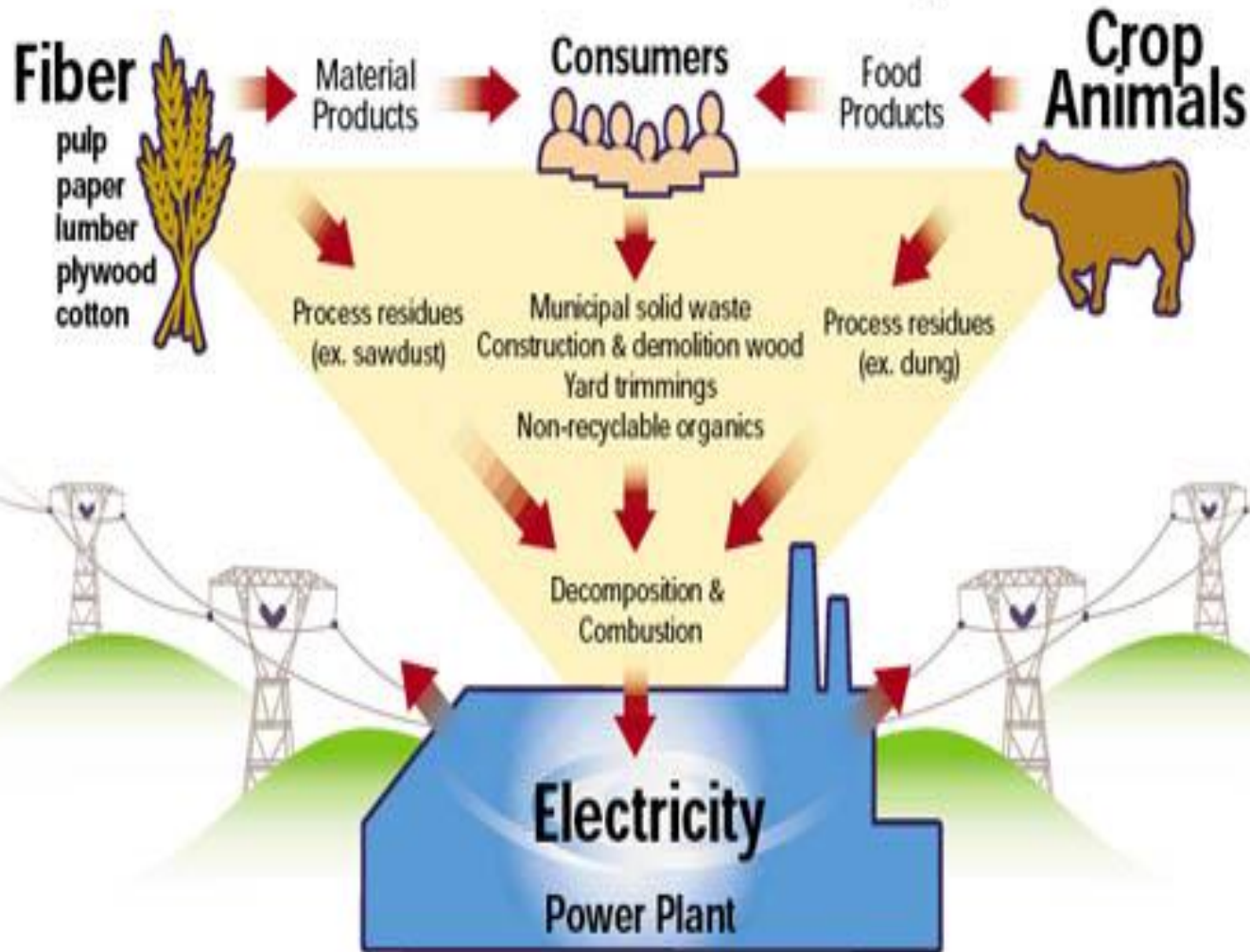
There are five basic categories of biomass source materials:

1. Wood: From forestry, agricultural activities or from wood processing.
2. Energy crops: High yield crops grown specifically for energy applications.
3. Agricultural residues: Residues from agriculture harvesting or processing.
4. Food waste: Waste from food manufacture, preparation and processing as well as postconsumer wastes.
5. Industrial waste and co-products : From manufacturing and industrial processes

- After hydropower biomass is the second leading resource of renewable energy. As much as 15% of coal can be replaced by biomass.
- Biomass has less sulfur than coal. Thus it can minimize the risks of formation of acid rain.
- Biomass can be converted into gas by gasification which is useful for production of electricity.
- The energy conversion from biomass can be either bio-chemical (Fermentation or digestion) or thermo-chemical methods to convert the biomass (solid fuel) into liquid or gaseous fuels.
- For electricity generation, two most competitive technologies are direct combustion and gasification.

- Typical plant sizes at present range from 0.1 to 50 MW. Co-generation applications are very efficient and economical.
- Fluidized bed combustion (FBC) is efficient and flexible in accepting varied types of fuels.
- Gasifiers first convert solid biomass into gaseous fuels which is then used through a steam cycle or directly through gas turbine/I.C.engine.
- Biomass materials used for power generation include bagasse, rice husk , straw, cotton stalk, coconut shells, soya husk, de-oiled cakes, coffee waste, jute wastes, ground nut shells and saw dust etc.

Biomass to Electricity

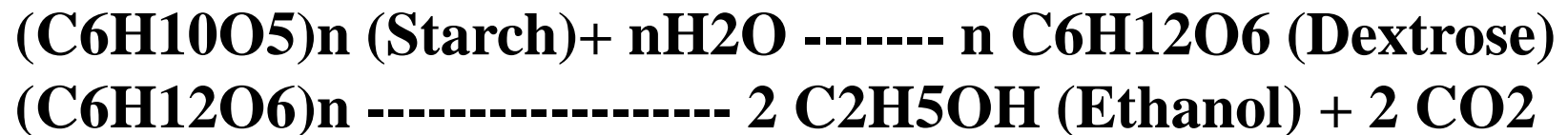


FERMENTATION

The process of bio-chemical degradation or decomposition of organic matter with the help of micro-organisms (bacteria/yeast) is called fermentation.

e.g. Chemical equations fermentation

Starch into Dextrose in the presence of enzyme at 20-30 °C and then dextrose into ethanol in the presence of yeast at 20-30 °C in 50 hours.



PYROLYSIS

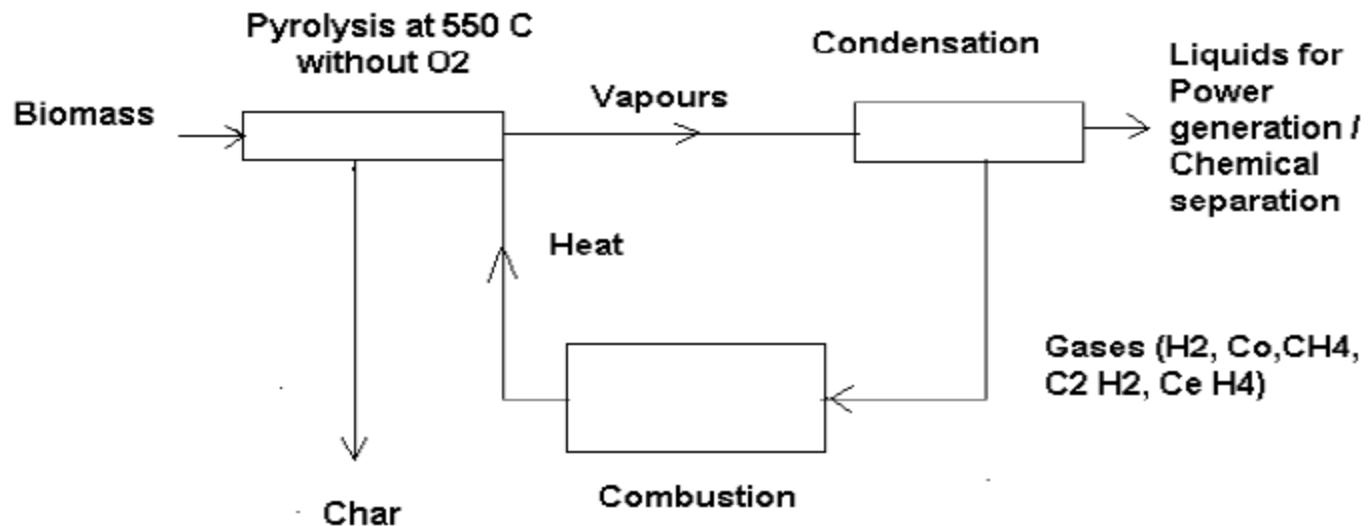
- Pyrolysis is the thermal decomposition of biomass occurring in the absence of oxygen.
- It is the fundamental chemical reaction that is the precursor of both the combustion and gasification processes and occurs naturally in the first two seconds.
- A wide range of biomass feed stocks can be used in pyrolysis processes.
- The pyrolysis process is very dependent on the moisture content of the feedstock, which should be around 10%. The efficiency and nature of the pyrolysis process is dependent on the particle size of feed stocks.
- Most of the pyrolysis technologies can only process small particles to a maximum of 2 mm keeping in view the need for rapid heat transfer through the particle.

TYPES OF PYROLYSIS

- Pyrolysis processes can be categorized as **slow pyrolysis** or **fast pyrolysis**. Fast pyrolysis is currently the most widely used pyrolysis system.
- Slow pyrolysis takes several hours to complete and results in bio-char as the main product. On the other hand, fast pyrolysis yields 60% bio-oil and takes seconds for complete pyrolysis. In addition, it gives 20% bio-char and 20% syngas.
- Fast pyrolysis processes include open-core fixed bed pyrolysis, ablative fast pyrolysis, cyclonic fast pyrolysis, and rotating core fast pyrolysis systems.

The essential features of a fast pyrolysis process :

1. Very high heating and heat transfer rates, which require a finely ground feed
2. Carefully controlled reaction temperature of around 500 °C in the vapour phase
3. Residence time of pyrolysis vapours in the reactor less than 1 sec
4. Quenching (rapid cooling) of the pyrolysis vapours to give the bio-oil product.

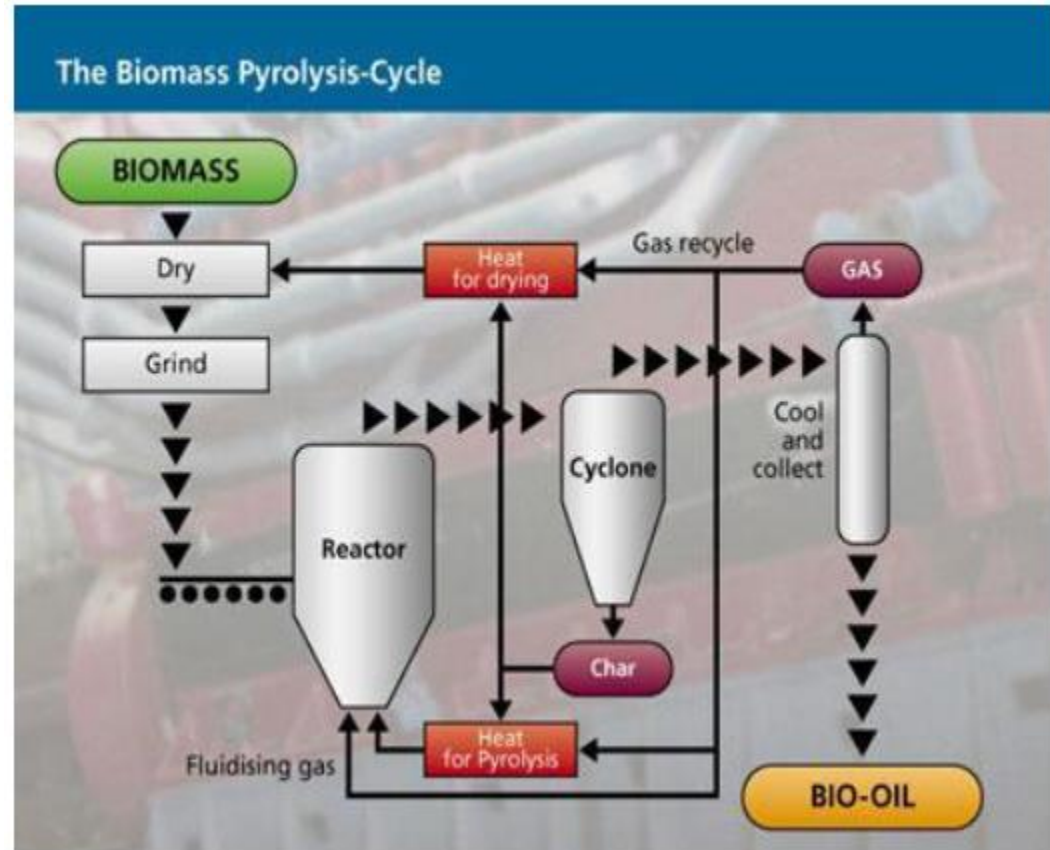


Pyrolysis of Biomass (Liquefaction - Converting solid to liquid fuel)

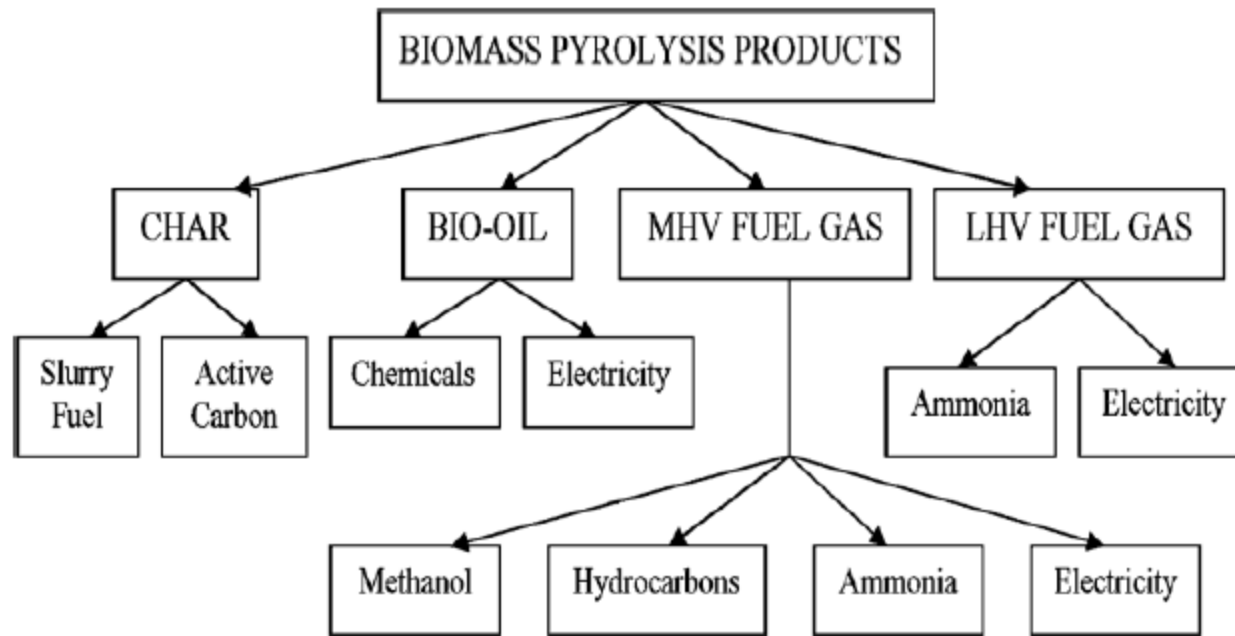
Biomass Pyrolysis flow chart

Biomass pyrolysis plant cycle

- The products of biomass pyrolysis include bio-char, bio-oil and gases including methane, hydrogen, carbon monoxide, and carbon dioxide.



- Depending on the thermal environment and the final temperature, pyrolysis will yield mainly bio-char at low temperatures, less than 450 °C, when the heating rate is quite slow, and mainly gases at high temperatures, greater than 800 °C, with rapid heating rates.



Biomass Pyrolysis Products

Pyrolysis offers a flexible and attractive way of converting solid biomass into an easily stored and transported liquid, which can be successfully used for the production of heat, power and chemicals.

GASIFICATION:

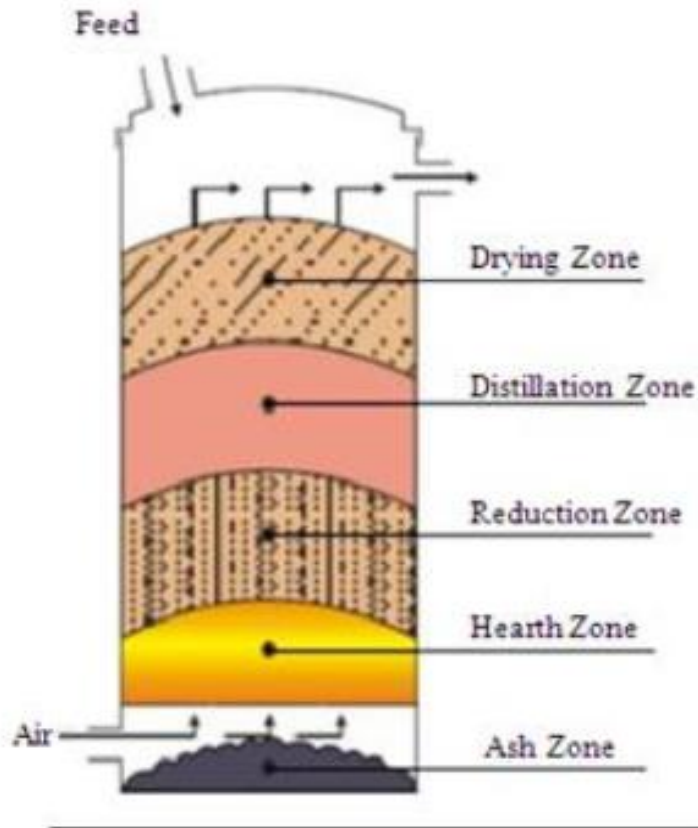
- Gasification is thermo-chemical conversion process that converts organic or fossil based carbonaceous material into carbon monoxide, hydrogen and carbon dioxide (gaseous fuels).
- This is achieved by reacting the material at high temperatures ($>700\text{ }^{\circ}\text{C}$), without combustion, with 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.

TYPES OF GASIFIERS

The gasifiers are classified based on the gas flow direction in the bed.

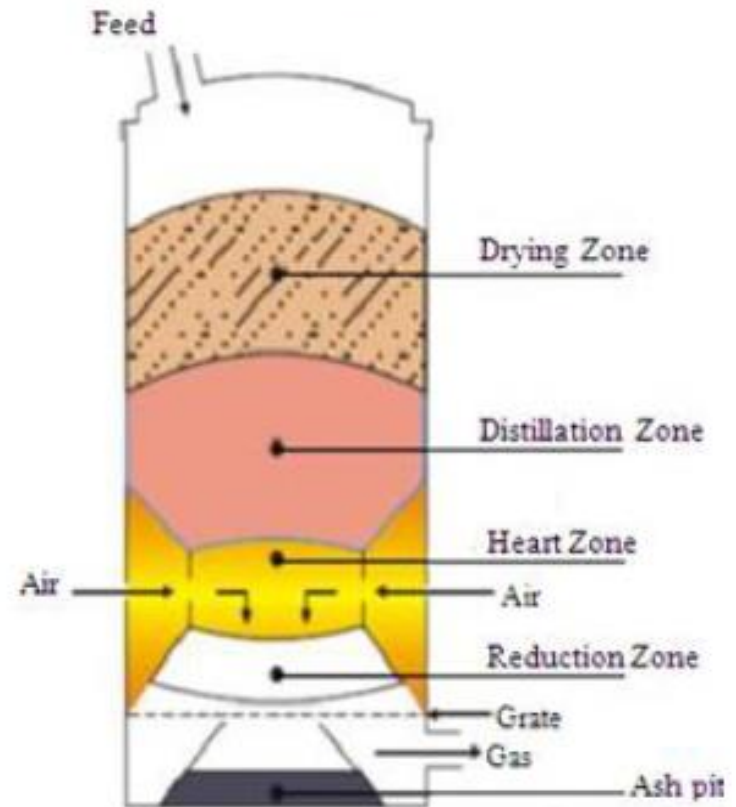
- 1) Upward in the up-draft
- 2) Downward in down-draft
- 3) Perpendicular in the cross flow type

Updraft or counter-current gasifier



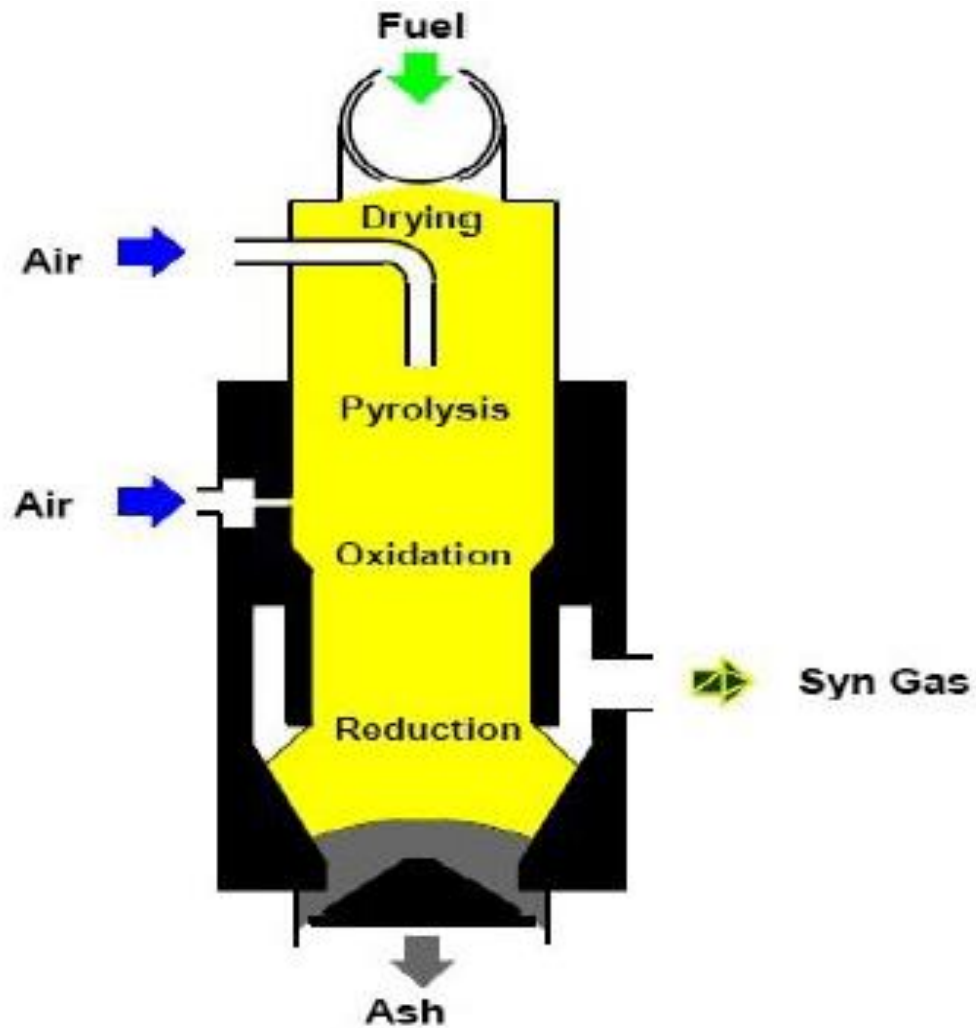
Updraft gasifiers are less sensitive to fuel size and moisture content as compared to a downdraft gasifier.

Downdraft or co-current gasifier



Downdraft gasifiers give relatively cleaner gas (low tar content) and are preferred for engine applications, niche applications demanding clean gas.

Updraft and Down Draft Gasifiers



Cross Flow Gasifier

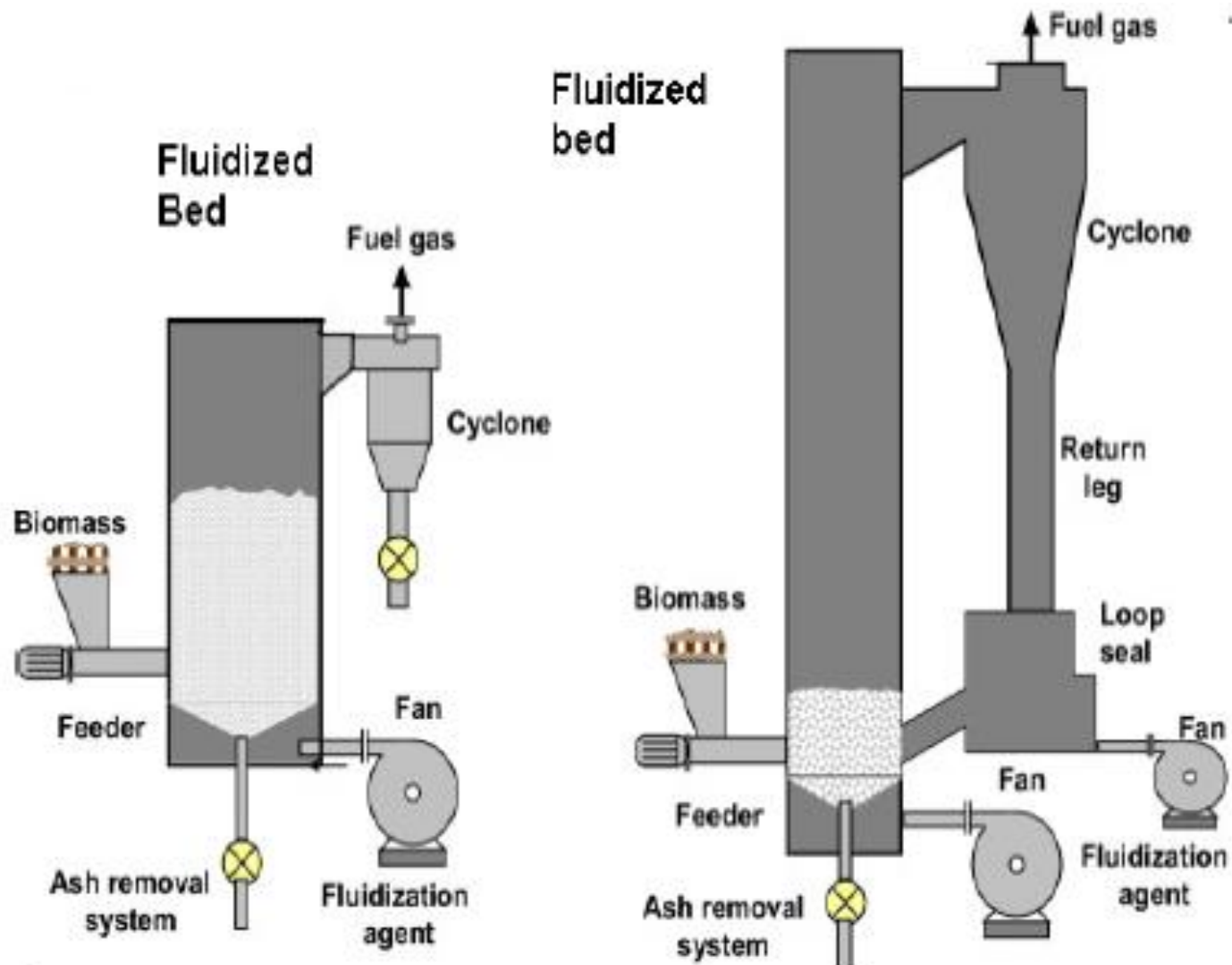
Comparison of advantages/disadvantages of updraft, downdraft and crossdraft gasifiers

Comparison of conventional gasifiers

Type of Gasifiers	Advantages	Disadvantages
Updraft	Small pressure drop, good thermal efficiency, small tendency to slag	Great sensitivity to tar/moisture , long time, poor reaction capability
Downdraft	Flexible adaptation of gas production to load, low sensitivity to charcoal dust and tar content	Taller design, no feasibility for small particle size of fuel
Crossdraft	Shorter design height, quick response to loads, flexible gas production	Very high sensitivity to slag formation, high pressure drop

FLUIDIZED BED GASIFICATION/COMBUSTION:

- The fluidized bed can be classified as bubbling fluidized bed and circulation fluidized bed.
- The unburnt fuel particles and bed particles are recovered in circulating bed and this gives better conversion (gasification) efficiency than the bubbling bed gasifier. The prepared biomass fuel has been sent to the gasifier and the fluidization velocity is given to the bed through fan.
- The fluidized biomass particles are gasified through the partial combustion of biomass and the producer gas is cleaned through cyclone separator and scrubber/filters before admitting the gas to applications.
- In the fluidized bed concept, the biomass particles are gasified and burnt in the floating condition by supplying air with the fluidization velocity. The fluidized bed can be operated as atmospheric or pressurized bed conditions.



Bubbling and Circulating Fluidised Bed Gasification/Combustion

ADVANTAGES OF FLUIDIZED BED GASIFICATION /COMBUSTION

- Greater fuel flexibility and types of fuels of CV from 3,300 kJ/kg to 33,000 kJ/kg.
- Good heat storage capacity ensures complete combustion.
- Quick start up.
- Higher combustion efficiency (99%) and high output rate.
- Consistency in combustion rate and usage of high moisture fuels.
- Low temperature combustion leads to less corrosion due to alkali compounds.
- Less boiler floor area than other grate systems
- Uniform temperature throughout the furnace volume.
- Reduced emission due to NO_x.
- Reduced SO_x with less expense with limestone addition in bed.
- Operation is as simple as oil fired boiler.

CALORIFIC VALUE

- The quantity of heat liberated during complete burning of 1 kg of fuel. The products of combustion is cooled to the original room temperature (initial condition) and the total heat value obtained is called as Gross calorific value (GCV) or Higher heating value whereas the products of combustion is not cooled and the heat obtained in this combustion process is called as Net calorific value (NCV) or lower heating value.
- The GCV is an indicative value and it can be calculated using Dulong's formula based on its components fraction. The NCV is useful while designing the furnace or combustor.

$$\text{GCV} = 33800 \text{ C} + 144000 (\text{H} - \text{O}/8) + 9270 \text{ S} \dots\dots\dots \text{kJ/kg}$$

$$\text{NCV} = \text{GCV} - 2466 \times (9 \text{ H} + \text{Moisture}) \dots\dots\dots \text{kJ/kg}$$

Where, C, H, O and S are in mass fraction.

$$\text{NCV for wood having 25\% Moisture} = 14000 \text{ kJ/kg}$$

$$\text{NVC for charcoal having 8\% moisture} = 28000 \text{ kJ/kg}$$

BIOMASS FUEL PROPERTIES FOR BIOMASS GASIFIER SELECTION

Need for selection of right gasifier for each fuel. Biomass fuels available for gasification include charcoal, wood and wood waste (branches, twigs, roots, bark, wood shavings and sawdust) as well as a multitude of agricultural residues (maize cobs, coconut shells, coconut husks, cereal straws, rice husks, etc.) and peat.

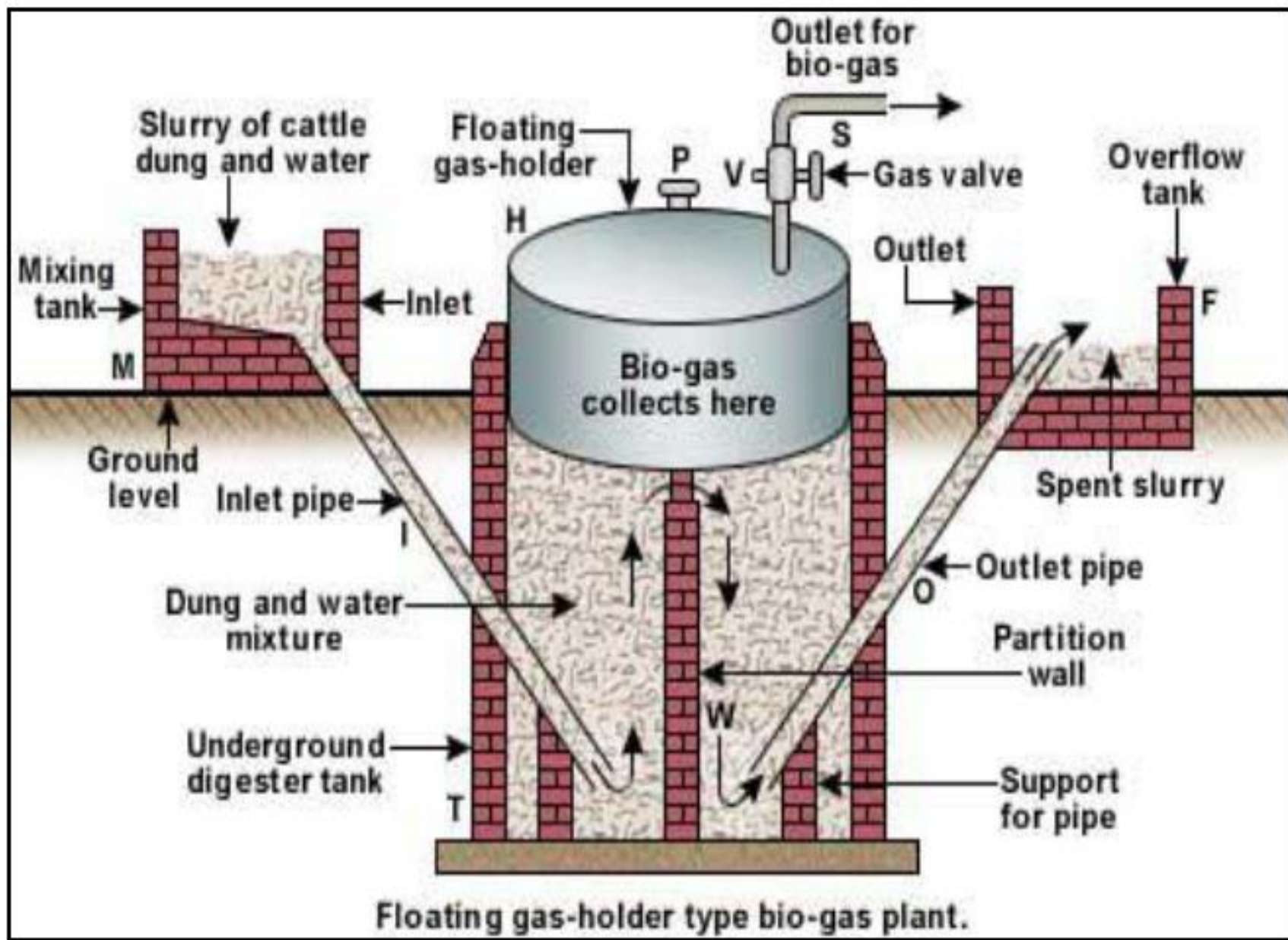
The following are the data required while choosing a fuel and gasifier and the producer gas produced is dependent on these:

1. Energy Content (Higher and lower heating values)
2. Moisture content
3. Volatile matter
4. Ash content and ash chemical composition
5. Reactivity
6. Particle size and distribution
7. Bulk density (e.g for Wood = 400 kg/m³)

TYPES OF BIOGAS DIGESTER PLANTS:

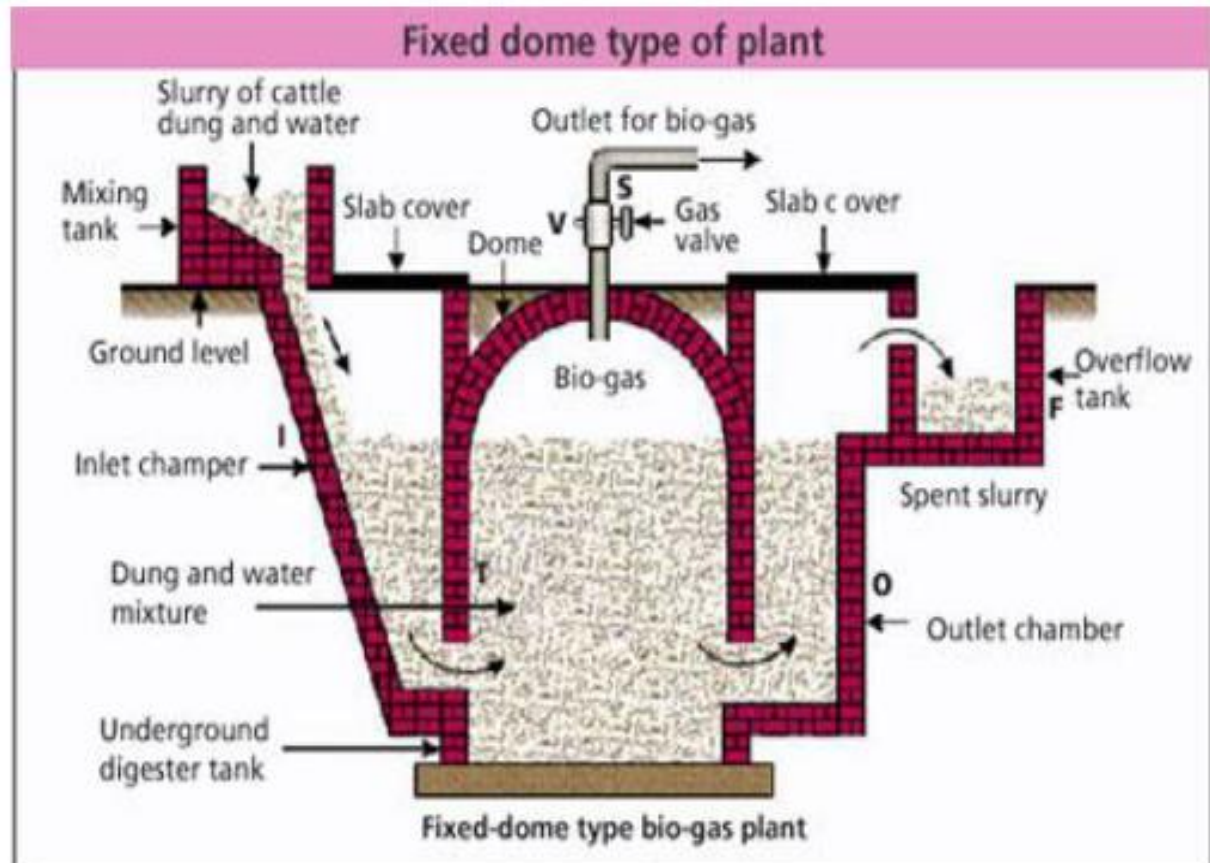
1. Floating Dome Digester plant

A well is made out of concrete called the digester tank T, which is divided into two parts. One part is an inlet, from where the slurry is fed to the tank. The cylindrical dome H of the tank is made out of stainless steel that floats on the slurry and collects the gas generated. Hence it is called floating gas-holder type of bio gas plant. The slurry is fermented for about 50 days. As more gas is made by the bacterial fermentation, the pressure inside H increases. The gas can be taken out from outlet pipe V. The decomposed matter expands and overflows into the next chamber in tank T, which is removed by the outlet pipe to the overflow tank and used as manure for cultivation purposes.



2. Fixed Dome Digester plant

A well and a dome are made out of concrete called the digester tank T. This dome is fixed and thus it is called fixed dome type of bio gas plant. The function of the plant is similar to the floating holder type bio gas plant. The used slurry expands and overflows into the overflow tank. The bio gas is cleaned by supplying through water and then used in cooking or heating applications.



BIOGAS:

The biogas power plant works on fermentation concept. The feed is mixed with water and supplied to the digester and allowed there several days. The combustible gas contains methane comes out of it.

The typical composition of biogas is given below:

$\text{CH}_4 = 60\%$, $\text{CO}_2 = 35\%$, $\text{H}_2 = 3.5\%$, $\text{N}_2 = 1\%$, $\text{H}_2\text{S} = 0.3\%$, $\text{CO} = 0.2\%$.

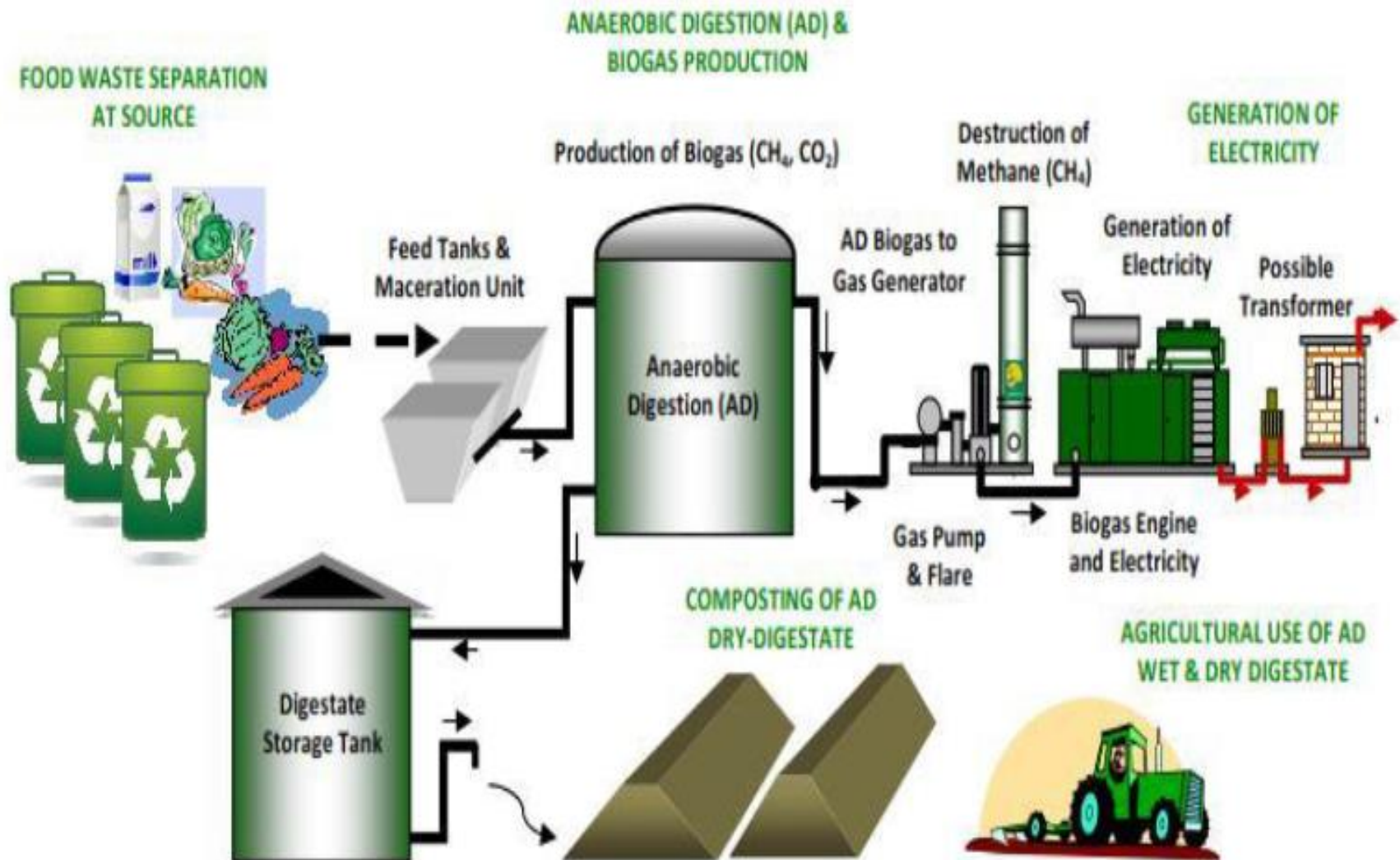
The percent of methane gas plays major role in combustion and the quality of gas depends on the methane only. Gross Calorific value: 23 MJ/m^3

Ignition temperature: 650°C .

FIXED DOME BIOGAS PLANT	FLOATING DOME BIOGAS PLANT
Completely masonry concrete structure	Masonry digester with steel or composite or plastic gas holder
Lower cost	Higher cost 20-30% more than fixed dome
Low maintenance	High maintenance
Low reliability	Highly reliable
High masonry skill is required	Low masonry skill is required
High supervision is required	Less fabrication skill is required
Gas pressure is variable so complicated appliance design	Gas pressure is constant so simple appliance design

BIOGAS POWER PLANT

The biogas power plant consists of more number of biogas plants are connected to produce large quantity of biogas to produce electricity using IC engines and the effluent is dewatered and converted as compost and manure. The major parts of the plants are fuel preparation systems, anaerobic digester, anaerobic digestrate storage, power generation unit and effluent treatment systems.



Anaerobic digester based biogas power plant (courtesy kznenergy.org.za)

Problems related to bio-gas plants operation:

All are controllable but reasons may be natural or man-made.

1. Handling of effluent slurry requires open space or compost pits to get the slurry dry.
2. Press filters and transportation are expensive.
3. Lack of proper training of biogas plant owners.
4. Addition of urea mixed water or soap or shampoo water mixing may leads to reduced bio-gas production.
5. pH level and volatile fatty acids play important role in gas production. Lime can be added to maintain pH level above 6-7.
6. Leakage of gas from gas holder. Quality construction is important.
7. Slurry preparation in correct water content and periodic effluent removal are important.

Selection of site for a biogas plant

Considerable site selection factors are given below:

1. **Distance** between the plant and gas consumption should be less to minimize gas leakage and pumping power. e.g. Optimum distance is 10m for 2 m³ plant capacity.
2. Preferred **minimum gradient** for conveying the gas is 1% for the line.
3. **Open space** is required for sun radiation to maintain temperature between 15 -30 °C.
4. **Water table** should not be less than 3 m. It leads to seepage of water into the plant and reduces the methane production.
5. Proper care is to be taken against **seasonal run-off**.
6. **Distance from wells** to avoid pollution of well water by entry of slurry. Keep 15 m distance from wells.
7. **Sufficient Space requirements.** 10-12 m² area required per m³ of gas capacity.
8. **Availability of water**

Digester design

Energy available from a biogas plant, $E = \eta H_b V_b$

η - Combustion efficiency of burner (around 60%)

H_b – Heat of combustion per unit volume in $\text{kJ/m}^3 = \text{CV of methane} \times$
Fraction of methane

V_b - Volume of the biogas, $\text{m}^3 = C \text{ md}$

Where C – Volume of biogas per unit dry mass ($0.2\text{-}0.4 \text{ m}^3$ per kg)

md – Mass of dry input (kg)

Volume of fluid in the digester, $V_f = m_d / \rho$

Where,

ρ - density of dry material in the fluid (around 50 kg/m^3)

Volume of the digester, $V_f = \text{Volume flow rate of digester fluid} \times \text{retention time}$

Retention time is usually 8 – 20 days.

Advantages of biomass energy

1. Versatile and renewable
2. No net CO₂ emissions (ideally) and emits less SO₂ and NO_x than fossil fuels
3. Production of alternate fuels like alcohol fuels.
4. Methanol and ethanol can be blended with diesel fuels for IC engine applications.

Disadvantages of biomass energy

1. Low energy density/yield
2. Land conversion (Biodiversity loss, possible decrease in agricultural food productivity)
3. Usual problems associated with intensive agriculture
 - Nutrient pollution,
 - Soil depletion,
 - Soil erosion,
 - Other water pollution problems etc.

THANK YOU