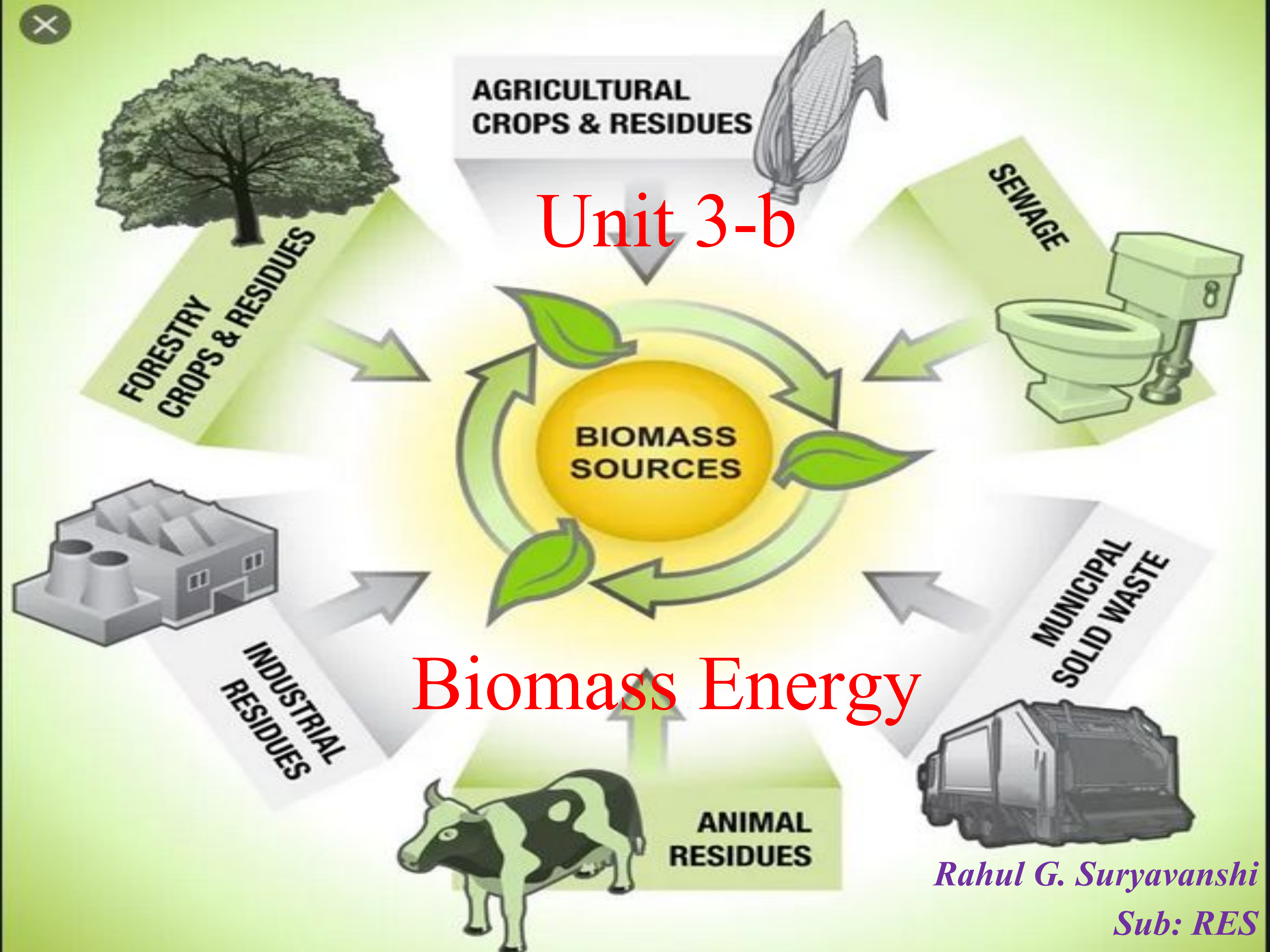
Unit 3-b



Biomass Energy

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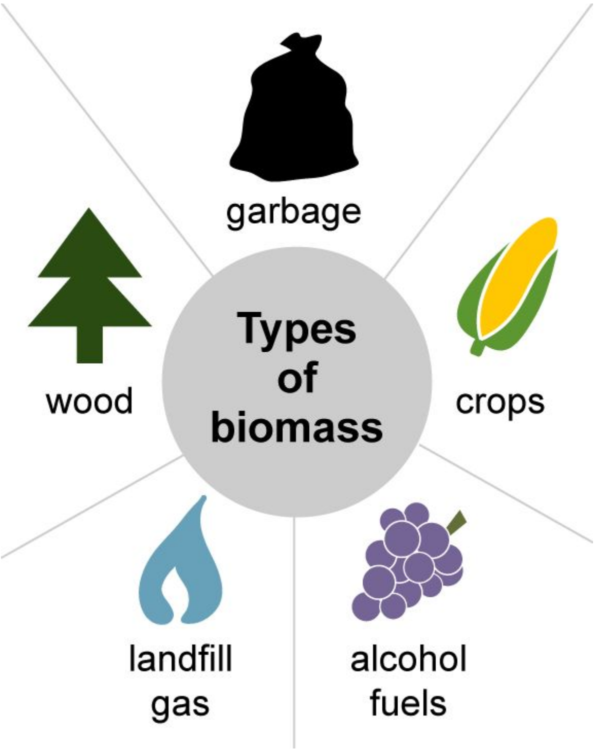
Sub: RES

Syllabus:

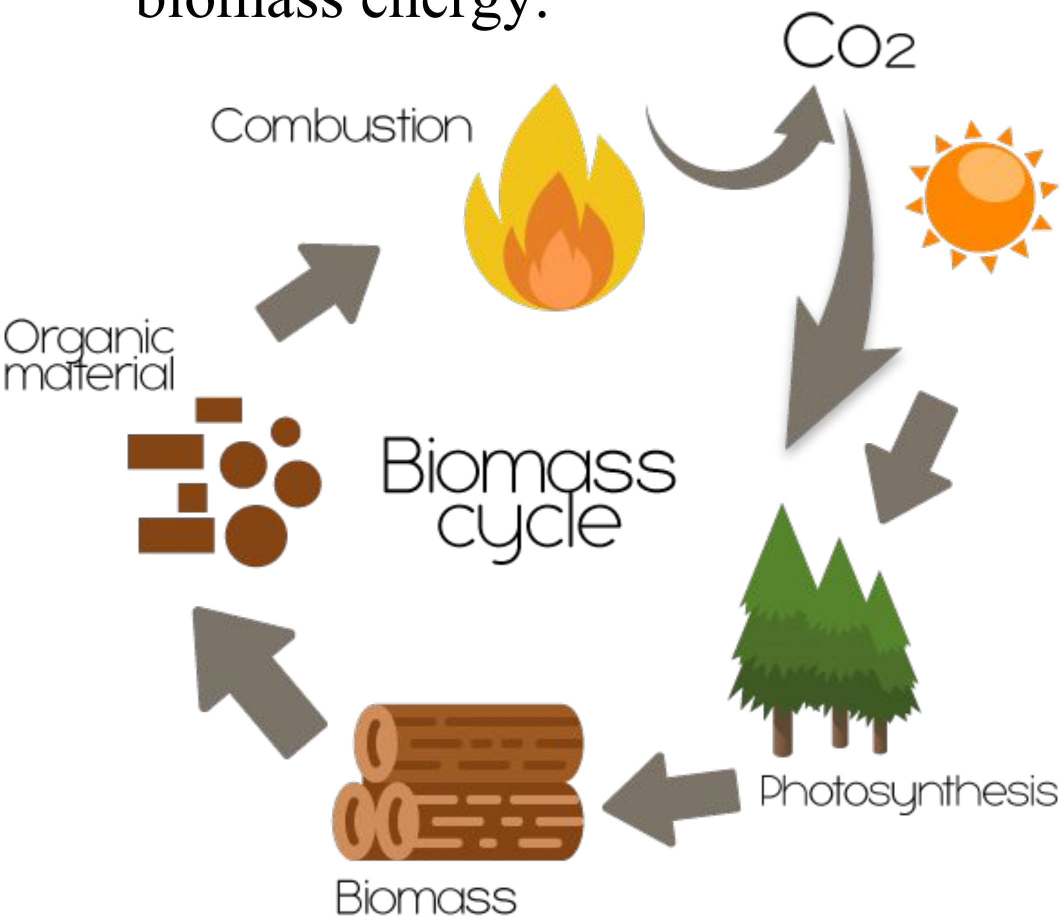
- Introduction,
- Photosynthesis process,
- biomass fuels,
- biomass conversion technologies,
- urban waste to energy conversion,
- biomass gasification,
- biomass to ethanol production,
- biogas production from waste biomass,
- factors affecting biogas generation,
- types of biogas plants:
  - KVIC and Janata model;
- Biomass program in India.

Introduction:

- Biomass is the energy obtained from organic matter which is derived from biological organisms (plants & animals).

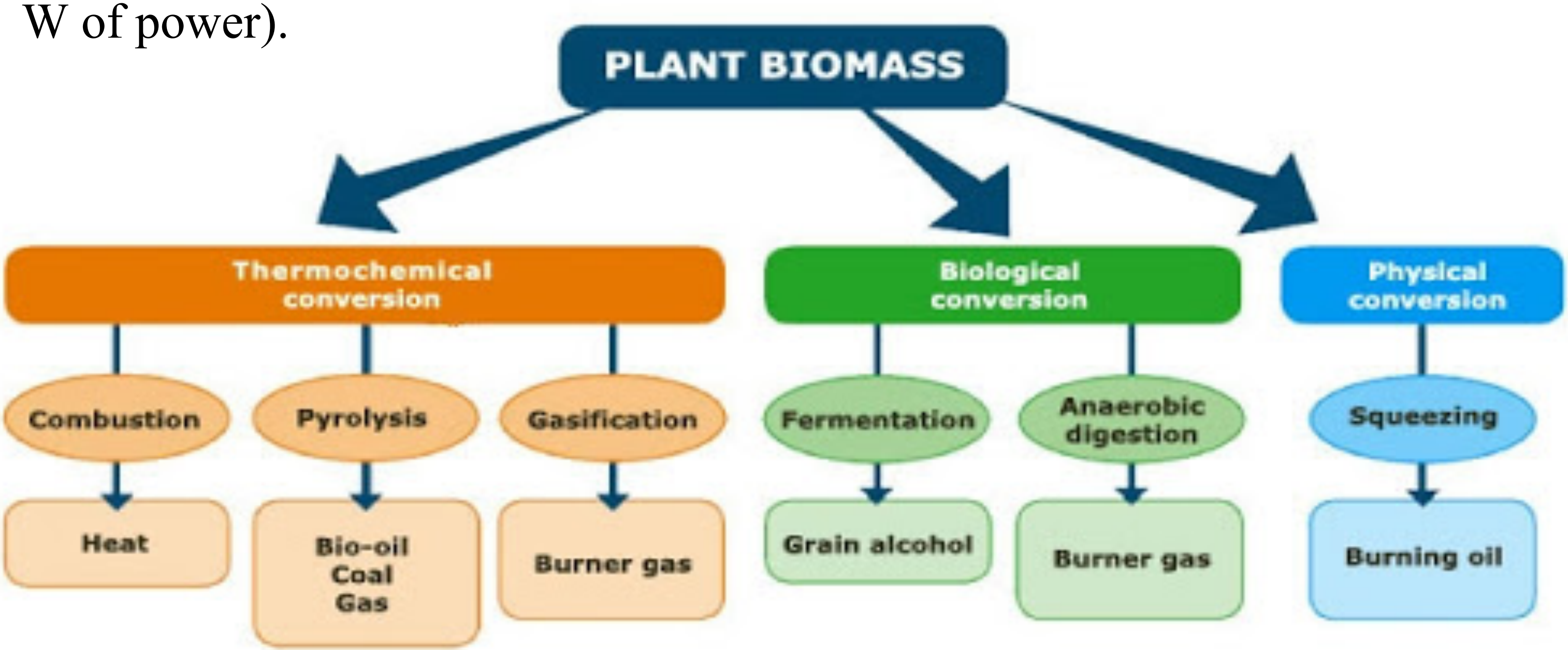


- Animals feed on plants and plants grow through photosynthesis process using solar energy, thus, photosynthesis is primarily responsible for the generation of biomass energy.



Average efficiency of photosynthesis conversion of solar energy into biomass energy is estimated to be 0.5 to 1%.

- Byproduct of biomass energy are methane, producer gas, ethanol and charcoal etc.
- On combustion it reacts with oxygen to release heat, but the elements of the material remain available for recycling in natural ecological or agricultural process.
- It is estimated that the biomass, which is 90% in trees, is equivalent to the proven current extractable fossil fuel reserves in the world.
- The dry matter mass of biological material cycling in biosphere is about 250×10^21 tons/ yr.
- The associated energy bound in photosynthesis is 2×10^21 J/yr (0.7×10^14 W of power).



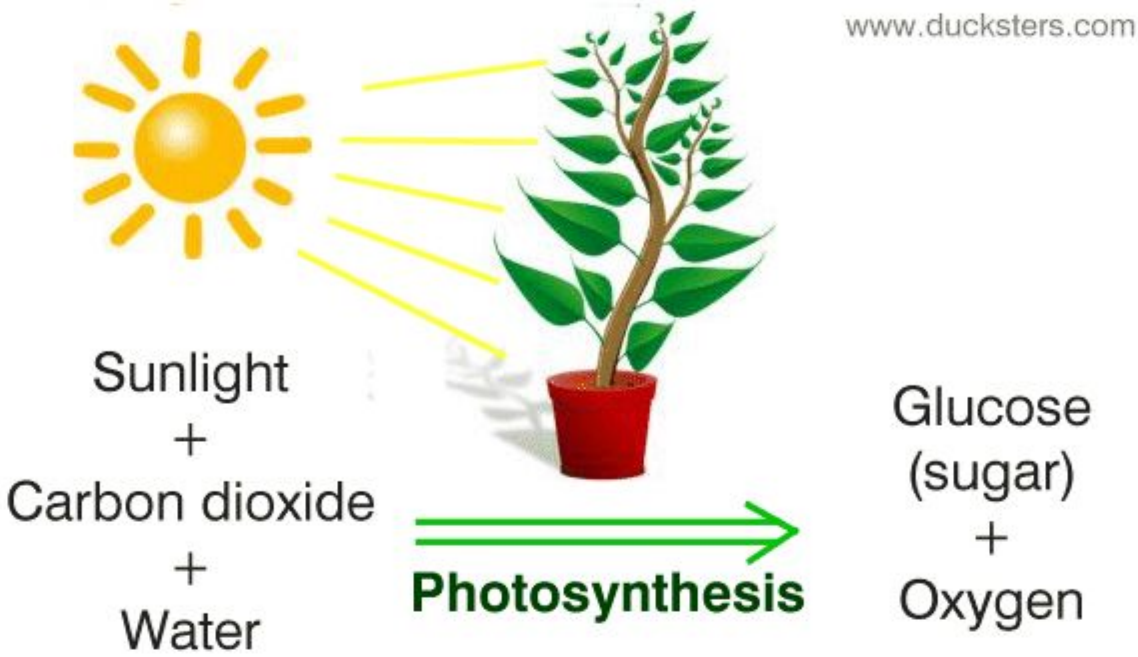
Advantages of biomass energy are:

1. It is **renewable** source.
2. Energy stored is a **inbuilt** feature of it.
3. It is an **indigenous** source requiring little or no foreign exchange.
4. The forestry and agricultural industries that supply feed stocks also provide **substantial economic development** opportunities in rural areas.
5. **Pollutant** emission from combustion of biomass are usually **lower** than those from fossil fuels.
6. Commercial use of biomass may avoid or **reduce** the problems of **waste disposal** in other industries, particularly municipal solid waste in urban centers.
7. Use of biogas plant apart from supplying green gas, also leads to **improved sanitation**, **better hygienic** conditions in rural areas as the harmful decaying biomass gets stabilized.
8. The nitrogen rich bio- digested **slurry** and **sludge** from biogas plant serves as a very good soil conditioner and improves the **fertility of the soil**.

Disadvantages :

1. It is a **dispersed** and land intensive source.
2. It is often of **low energy density**.
3. It is also **labor intensive**, and the cost of collecting large quantities for commercial application is significant.
4. Capacity is determined by availability of biomass and not suitable for varying loads.
5. Not feasible to set up at all corridors.

Photosynthesis process



$$xCO_2 + yH_2O + \text{light energy} \longrightarrow xO_2 + C_x(H_2O)y$$

$$6CO_2 + 6H_2O + \text{light energy} \longrightarrow 6O_2 + C_6H_{12}O_6$$

$C_x(H_2O)y$ □ Carbohydrates.

- More complex hydrocarbons (sucrose, starch, cellulose etc) are formed by chain of these simple structures.
- The reverse of this process is called Respiration.
- The energy produced by plants by respiration is used in several processes such as draw moisture and nutrients through its roots.
- In green plants, both photosynthesis and respiration takes place during day time and only respiration during night.
- The net energy absorbed from solar radiation during photosynthesis can be measured from its combustion

$$xCO_2 + yH_2O + \Delta Q \rightleftharpoons xO_2 + C_x(H_2O)y$$

Biomass fuels

Biomass is organic carbon based material that reacts with oxygen in combustion and natural metabolic process to release heat.

Some of the forms available to the users are:

1. Fuel wood.
2. Charcoal.
3. Fuel pellets.
4. Bio-ethanol.
5. Biogas.
6. Producer gas, etc

Fuel wood:

1. It is most obvious and oldest source of biomass energy.
2. This was the main source of energy used by mankind for centuries.
3. Direct combustion is the simplest way to obtain the heat energy.
4. Its energy density is 16-20MJ/kg.
5. Due to the inefficient use of fuel wood in conventional household stove, only 5% heat is utilized. Remaining is lost due to wind, incomplete combustion, radiation losses etc.
6. There is a little control over the rate at which wood is burnt.

<u>Charcoal</u>:

1. It is clean (smokeless), dry, solid fuel of black color.
2. It has 75-80% carbon content and has energy density of about 30MJ/kg.
3. It is obtained by carbonization process of woody biomass to achieve higher energy density per unit mass, thus making it more economical to transport.
4. It has high carbon and low Sulphur content.
5. Used for making high quality steel.

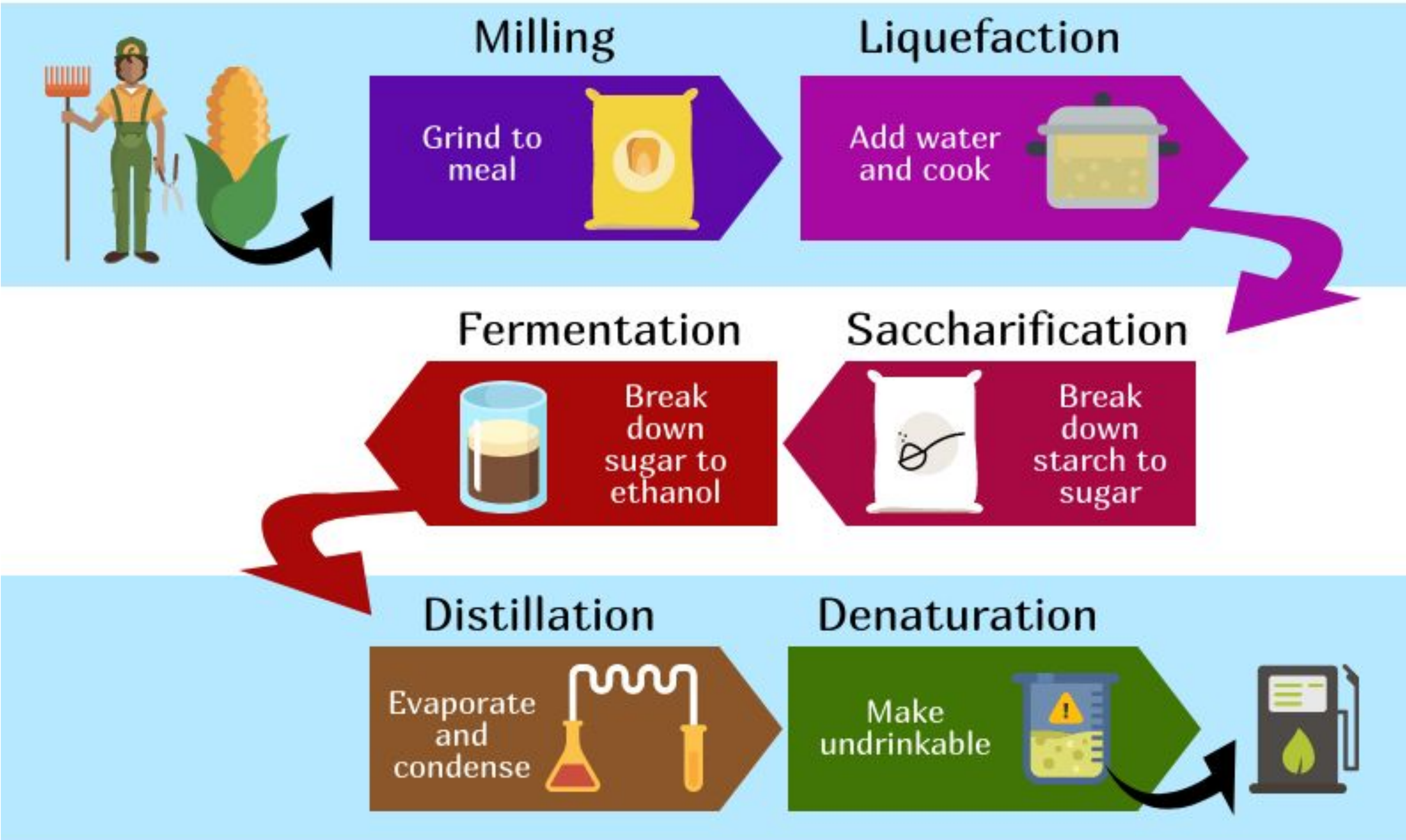
Fuel pellets:

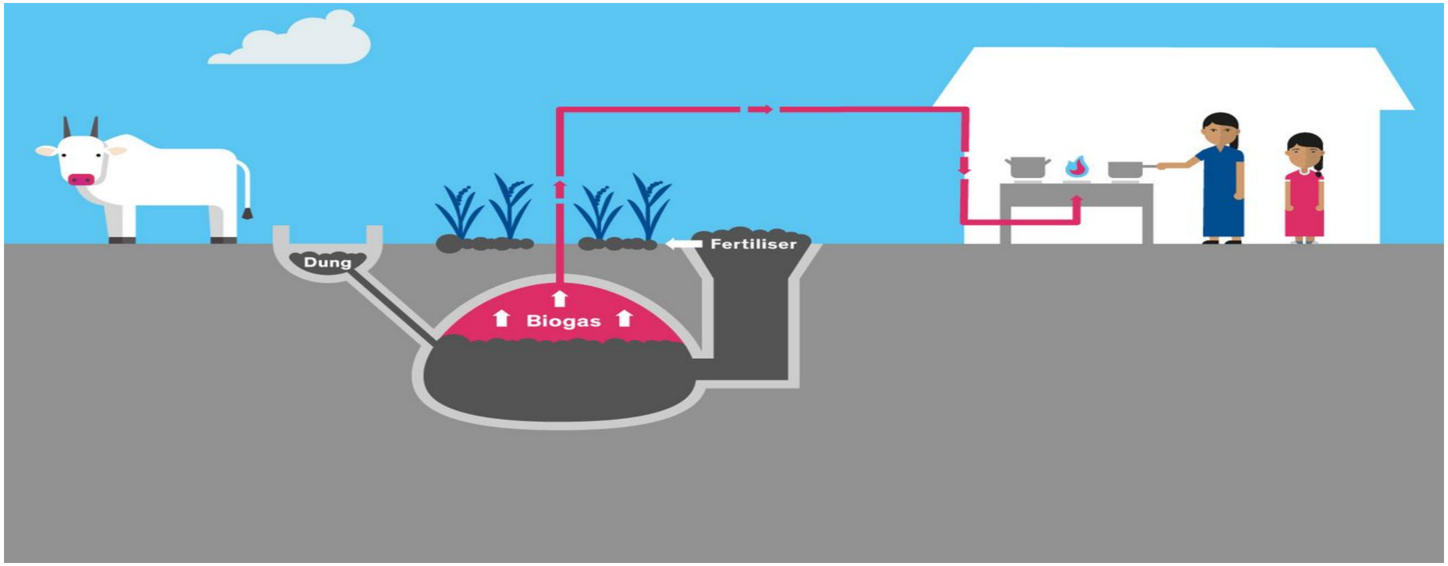
Crop residues such as straw, rise husk, etc. are pressed to form lumps, known as fuel pellets and used as solid fuel.

Bio-ethanol:

1. It is colorless liquid biofuel.
2. Its boiling point is 78°C and energy density is 26.9 MJ/kg.
3. It can be derived from wet biomass containing sugars (e.g. Sugarcane, sweet sorghum, etc.), starches or cellulose (woody matter).
4. Main contents of woody matter are lignin (fibrous part) and cellulose (juicy part).
5. Ethanol are largely produced from sugarcane and corn.
6. Commercial ethanol is used in specially designed IC engines with 25% mileage penalty compared to conventional vehicles.

How to make ethanol using corn





Biogas:

1. Organic waste from plants, animals and humans contain enough energy to contribute significantly to energy supply in many areas.
2. Biogas is produced in biogas digester.
3. Nitrogen rich sludge is also produced as a byproduct with improved sanitation.
4. If the raw material is cow dung then the output biogas will contain 50-60% of Methane CH_4, 30-40% carbon dioxide CO_2, 5-10% Hydrogen H_2, 0.5-0.7% Nitrogen N_2 with trace amounts of O_2 and H_2S.
5. Its energy density is about 23 MJ/m^3.

Producer gas:

1. Woody matter such as crop residue, wood chips, bagasse, rise husk, coconut shell etc. can be transformed to producer gas by a method known as gasification of solid fuel.

2. The composition of gas produced depends upon the type of biomass and the design of gasifier.

3. For wood chips as input the typical gas composition is 19% CO, 18% H_2, 1% CH_4, 11% CO_2 and the rest N_2.

4. It has a typical energy density of 4-8 MJ/m^3 (5-10MJ/kg).

5. This can be used as a fuel for IC engines, irrigation pumps, motor vehicles etc.

Biomass conversion technologies

1. **Incineration**:

- It means direct combustion of biomass for immediate useful of heat.
- Can be used to produce heat or steam.
- It is used in the production of electricity as it reduces the mass of waste up to 96 percent.
- Furnace and boilers are used now a days.
- Moisture and other compositions reduces the efficiency.
- Cogeneration makes it an attractive adoption.

2. <u>Thermo-chemical:</u>

- Biomass $\xrightarrow{\textbf{(Pyrolusis)}}$ Valuable /convenient product.
- Biomass is heated either in absence of oxygen or by partial combustion of some of the biomass in restricted air or oxygen supply.
- Depending upon the type of biomass and heat, the products obtained are,
  - Gas mixture (H_2, CO_2, CO, CH_4, N_2)
  - Oil like Liquid (Acetic acid, Acetone, oil , tar, etc)
  - Carbon char (charcoal)

- *High temp (~1000 degree C)□ Gas (Gasification)*
- *Medium temp (upto 600 degree C)□ Char output (Carbonization)*
- *Low temp (250 to 450 degree C) □ Liquid (liquefaction)*

3. Biochemical:

- The process makes use of metabolic action of **microbial organism** on biomass to produce **liquid and gaseous fuel**. Two major biochemical processes are given below:

  i. Ethanol fermentation.

  ii. Anaerobic fermentation (Anaerobic Digestion)

- **Ethanol fermentation**:

Alcohol fermentation is the decomposition in the absence of air, of simple hexose sugars in aqueous solution by action of enzyme present in yeast, in acidic conditions (pH value 4 to 5).

$$C_6H_{12}O_6 \xrightarrow[\text{fermentation}]{32°C} 2C_2H_5OH + 2CO_2$$

The products are ethanol and carbon dioxide.

- **Anaerobic fermentation**:

this process converts decaying wet biomass and animal wastes into biogas through decomposition process by the action of anaerobic bacteria.

$$\text{Decaying wet biomass} \xrightarrow[\text{20 to 55°C}]{} \text{Biogas (largely } CH_4 \text{ and } CO_2\text{)}$$

Table 8.1 *Energy available from various biomass resources*

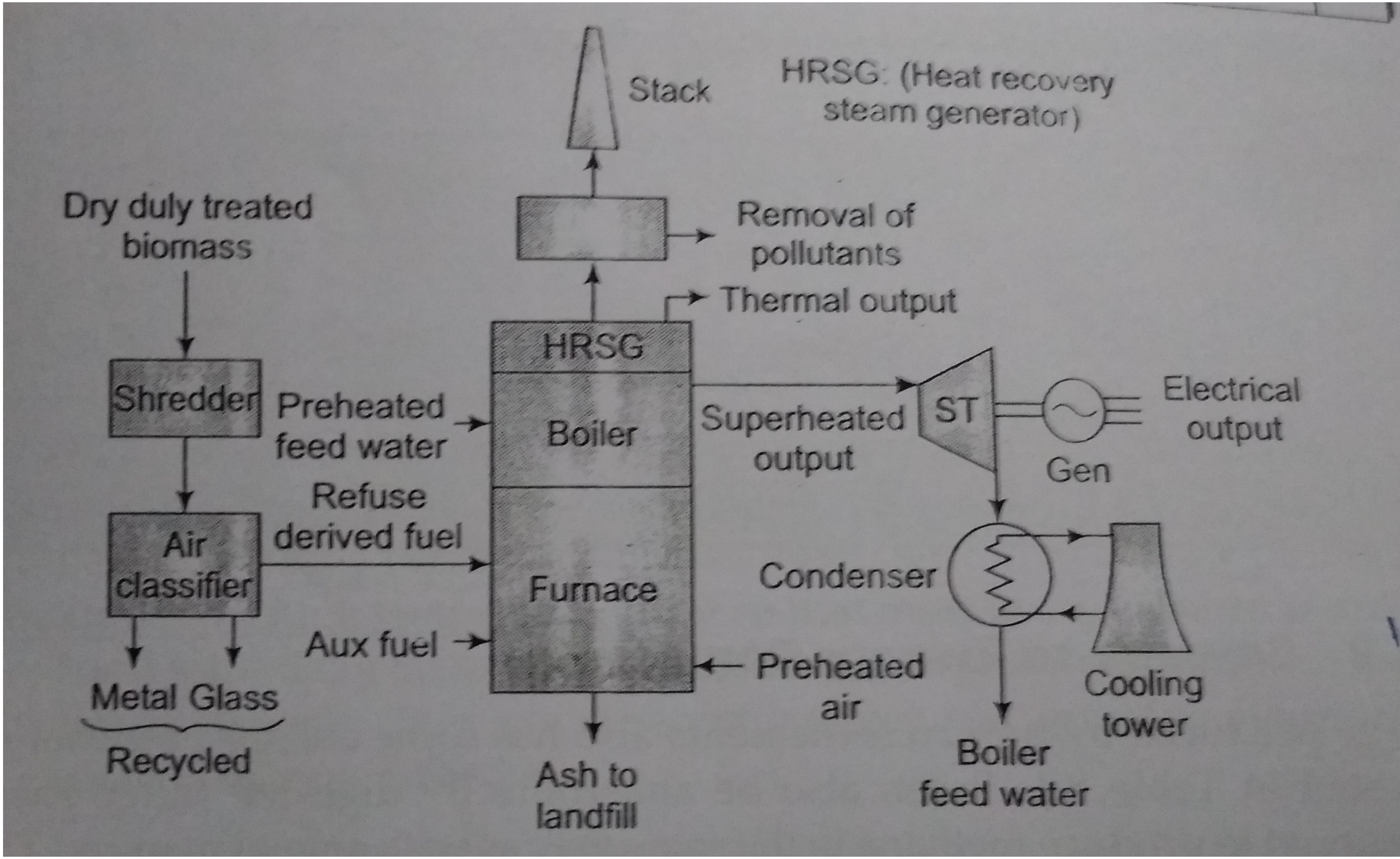
SN	*Biomass source*	*Biofuel produced*	*Conversion technology*	*Available energy (MJ/kg)*
1.	Wood chips, saw mill dust, forest residues	(Direct heat)	Incineration	16–20
2.	Wood chips, saw mill dust, forest residues	Gas Oil Char	Pyrolysis	40 (Nitrogen removed) 40 20
3.	Grain crops	Straw	Incineration	14–16
4.	Sugar-cane residue	Bagasse	Incineration	5–8 (fresh cane)
5.	Urban refuse	(Direct heat)	Incineration	5–16 (dry input)
6.	Sugar-cane juice	Ethanol	Fermentation	3–6 (fresh cane)
7.	Animal waste	Biogas	Anaerobic digestion	4–8 (dry input)
8.	Municipal sewage	Biogas	Anaerobic digestion	2–4 (dry input)

Urban waste to energy conversion

Table 8.2 *General composition of urban waste in USA*

SN	*Waste material*	*Percentage*
1.	Paper and paper board	39.2
2.	Food and yard waste	21
3.	Glass	6.2
4.	Metals	7.6
5.	Plastics, rubber	9.1
6.	Wood	7.1
7.	Others (including hazardous wastes e.g. chemicals, lead, insecticides, house hold cleaning chemicals etc.)	9.8

MSW to energy Incineration Plant:



Biomass Gasification

- **Biomass gasification** is a process of converting solid **biomass** fuel into a gaseous combustible gas (called producer gas) through a sequence of thermo-chemical reactions.
- Technology is from 1830 (Used during world war-II)
- Raw material used in gasifier: wood chips, wood waste from industry, rice husk, etc.

- Gasifier Combusts the biomass in restricted air and further reduces it.
- Here a large qty of fuel is fed to the gasifier.
- The moisture available in the biomass is converted to steam.
- Due to pyrolysis process, CO2, Water vapors, N2, CO & H2 are produced.
- These combustion products are passed through red hot charcoal.
- During this process, both CO2 and water vapour oxidize the char to form CO, H2 & CH4.

$$C + CO_2 \longrightarrow 2CO \quad \text{(Boudouard reaction, } -164.9 \text{ kJ/mole)} \tag{8.2}$$

$$C + H_2O \longrightarrow CO + H_2 \quad \text{(Water gas reaction, } -122.6 \text{ kJ/mole)} \tag{8.3}$$

$$CO + H_2O \longrightarrow CO_2 + H_2 \quad \text{(Water shift reaction, } 40.2 \text{ kJ/mole)} \tag{8.4}$$

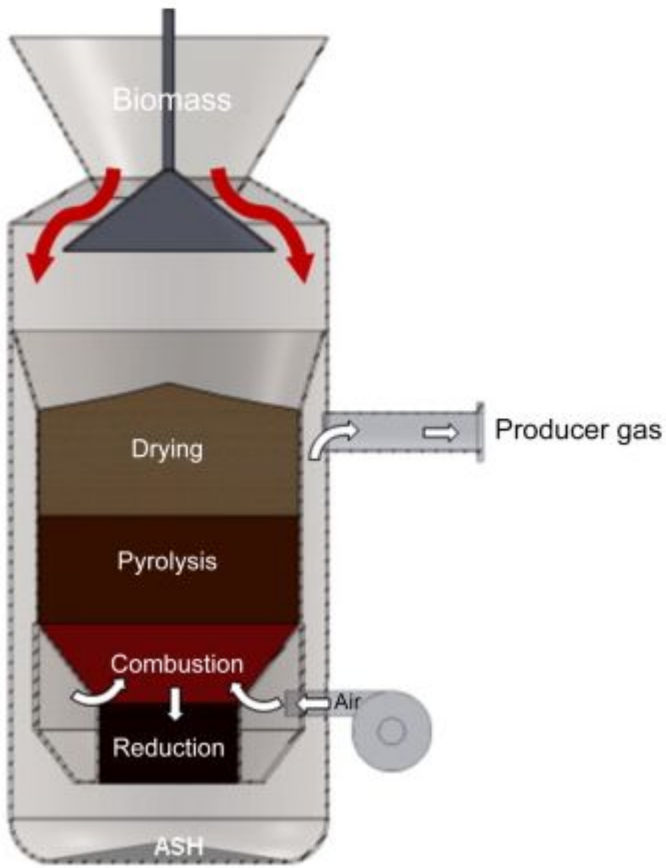
$$C + 2H_2 \longrightarrow CH_4 \quad \text{(Methane reaction, } 83.3 \text{ kJ/mole)} \tag{8.5}$$

- ***Types of gasifier***:

  - **Fixed Bed type**
    - *Downdrift Type*
    - *Updrift Type*
    - *Crossdrift Type.*

  - **Fluidized Bed type.**

- ***Downdrift Type***



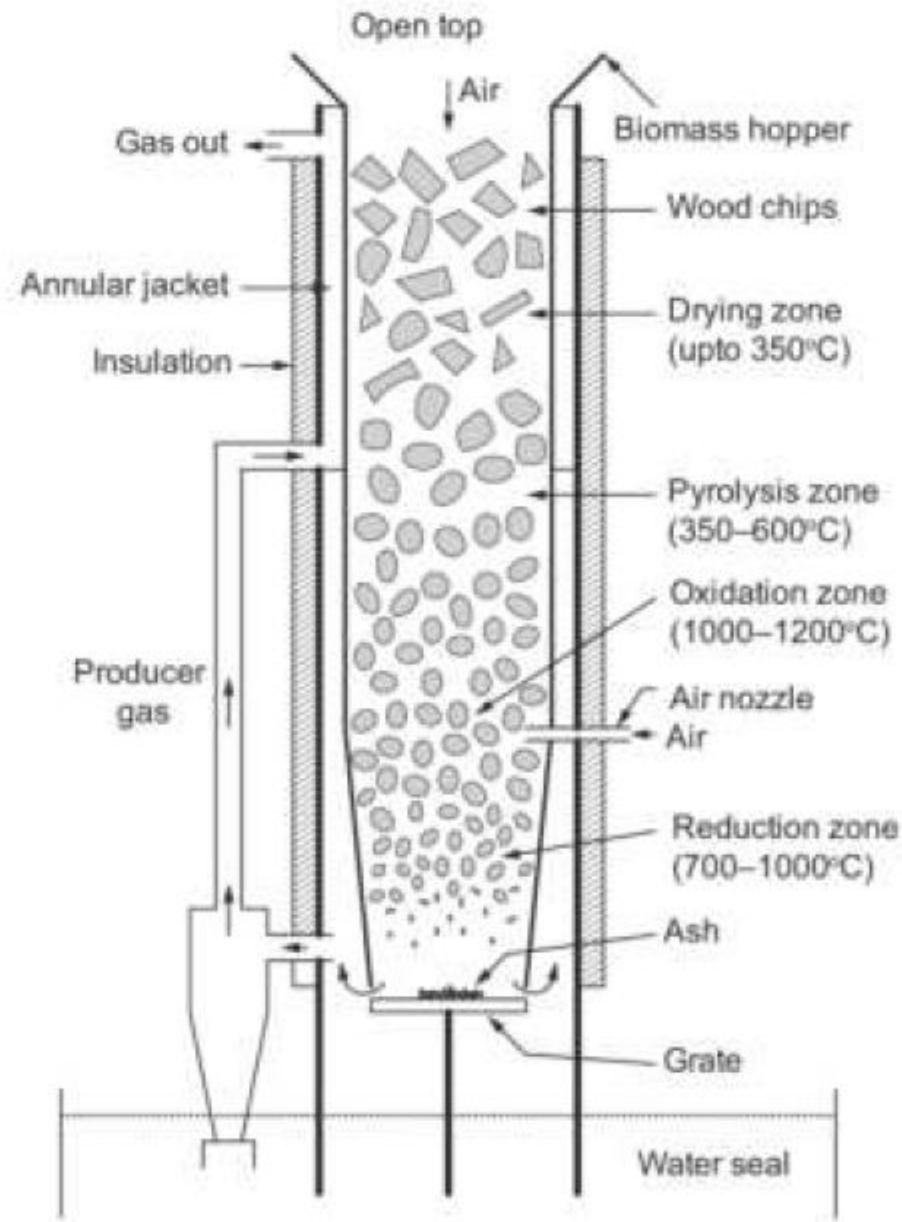


Fig. 8.4 *Downdraft biomass gasification plant*

Biomass to ethanol production

- Ethanol is manufactured by action of microorganism on carbohydrates (Hexoses). This process is known as alcoholic fermentation.
- The hexoses (Glucose / fructose) required for ethanol production are derived from:
  - Sucrose (sweet fruits/ sugarcane/beetroot)
  - Starch (Malt sugar)
  - Cellulose (Wood= 45 to 50% & Cotton= 90 to 95%)

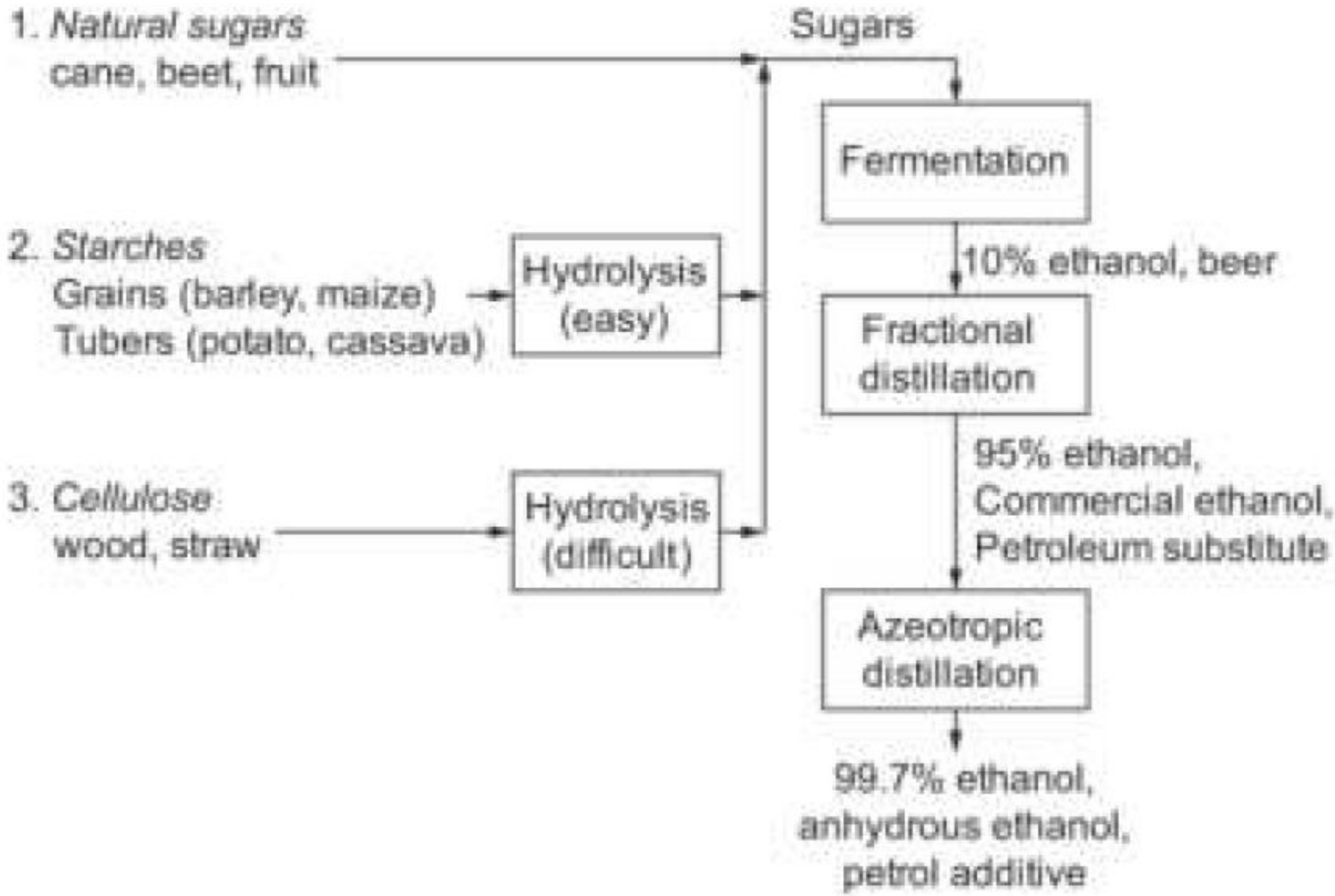
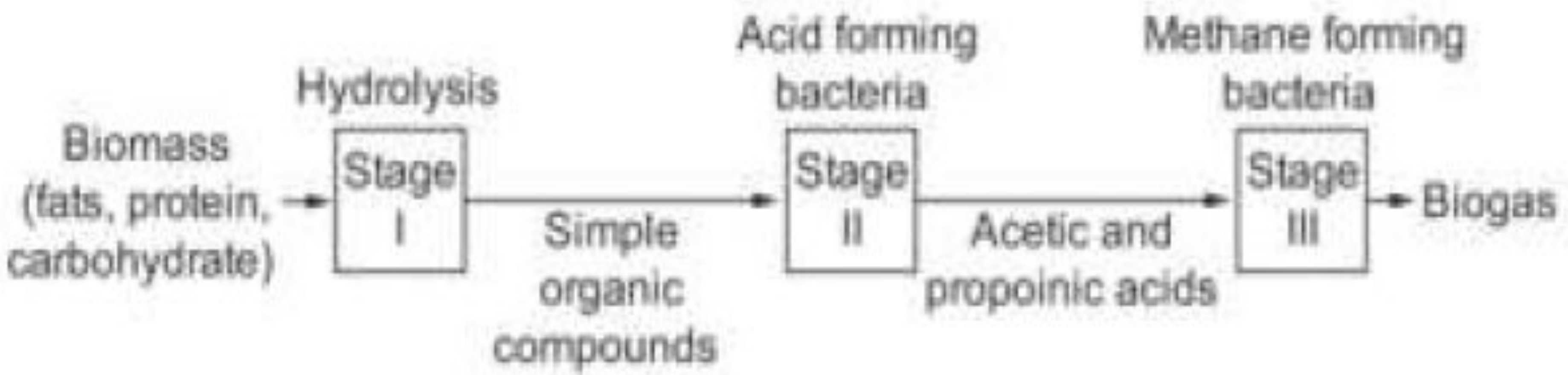


Fig. 8.8 *Ethanol production from various types of biomass*

Biogas production from waste biomass

- If biogas left in open air to decompose produces CO2 & NH3. (No fuel is produced)
- If biogas is produced with wet biomass by anaerobic bacteria produces CO2 & CH4.
- Various stages of anaerobic digestion process:



(i) *Stage I* First of all, the original organic matter containing complex compounds, e.g., carbohydrates, protein and fats is broken down through the influence of water (known as *hydrolysis*) to simple water-soluble compounds. The polymers (large molecules) are reduced to monomers (basic molecules).

The process takes about a day at 25°C in an active digester.

(ii) *Stage II* The micro-organisms of anaerobic and facultative (that can live and grow with or without oxygen) groups, together known as *acid formers*, produce mainly acetic and propionic acids. This stage also takes about one day at 25°C. Much of CO_2 is released in this stage.

(iii) *Stage III* Anaerobic bacteria, also known as methane formers slowly digest the products available from the second stage to produce methane, carbon dioxide, a small amount of hydrogen and a trace amount of other gases. The process takes about two weeks time to complete at 25°C. This third stage, i.e., methane-formation stage is carried out strictly by the action of anaerobic bacteria.

Factors affecting biogas generation

- ***Temperature***:
  - Methane forming bacteria work best in the temp range of 20 to 55ºC.
  - Gas yeald doubles with every 5ºC rise in temp.
  - In cold countries the digest needs to be heated till 35 ºC to start the gas generation.
  - The gas production sharply decreases below 20 ºC and stops at 10 ºC.

- ***Pressure***:
  - Min pressure of 6-10 cm of water column (i.e.1.2 bars) is considered as ideal for proper functioning of the plant.
  - Max pressure should be 40 -50 cm of water column. (to avoid gas leakages)
- ***Solid to Moisture ratio in biomass:***
  - Water is the most imp for survival and activities of microorganisms.
  - This helps in
    - better mixing of various content of biomass
    - Movement of bacteria's
    - Faster digestion.
  - If the water content is too high, then temp drops and gas production drops.
  - If water content is too low, acid accumulates and hinders fermentation.
  - Optimum solid concentration must be 7 to 9%

- ***pH Value:***
  - Initial stage pH is 6 or less (acid forming stage)
  - Methane forming stage pH is maintained between (6.5 to 7.5)

- ***Feeding rate:.***
  - If digest is fed with too much of raw material, acids will accumulate and digestion process stops.
  - Fast feeding results in undigested slurry.
  - Uniform feeding is required
  - i.e. if the retaintion period is 50 days then , the digest must be feed at a rate of 1/50 of the vol of the digest per day.

- ***<u>Carbon to Nitrogen (C/N) ratio and other nutrients in biomass:</u>***
  - Carbon (Carbohydrates) Nitrogen (Proteins, nitrates, etc) are the main nutrition for anaerobic bacteria.
  - Carbon supplies energy and Nitrogen is needed for cell building.
  - Anaerobic bacteria uses carbon 30 times faster than nitrogen.
  - Thus the optimum C/N ratio is 30:1

- ***Seeding of Biomass with bacteria***:
  - Small amount of digest slurry containing methane generation bacteria is added to the fresh plant.
  - Helps accelerates starting process.
- .***Mixing and steering:***
- ***Retention time:***

Availability of raw material and gas yield:

SN	Raw material	Production rate	Gas yield (m^3 per kg of dry matter)
1.	Cow dung	10–15 kg/day/head	0.34
2.	Poultry manure	0.06 kg/day/head	0.46–0.56
3.	Sheep manure	0.75 kg/day/head	0.37–0.61
4.	Night soil	0.75 kg/day/head	0.38
5.	Rice husk	1–1.3 tons/ha /year	5.67
6.	Algae	40 tons/ha /year	0.32
7.	Water hyacinth	60 tons/ha /year	0.42

- Only 70% of Cow dung produced can be collected
- Solid matter content in cow dung □ 18%
- Biogas required for cooking □ 0.227m3/person/day
- Gas required for lighting a 100 CP (Candle power) mantle lamp□ 0.126m3/hour
- Biogas plant production□ 2m3 gas/day (equivalent to 26 kg of LPG)
- Density of slurry□ 1090 kg/m3

Calculate the volume of a cow-dung based biogas plant required for cooking needs of a family of five adults and lighting needs with two 100 CP lamps for three hours daily. Also, calculate the required number of cows to feed the plant. Assume standard values of data where required.

Gas required for cooking for the family $= 5 \times 0.227 = 1.135$ m^3/day

Gas required for lighting $= 0.126 \times 2 \times 3 = 0.756$ m^3/day

Total daily gas requirement of the family $= 2.891 m^3$

Let n be the number of cows.

Cow dung produced $= 10\ n$ kg/day

Collectable cow dung (70%) $= 7\ n$ kg/day

Weight of dry solid mass (18%) in cow dung $= 0.18 \times 7\ n$ kg/day

Gas production per day $= 0.34 \times 0.18 \times 7\ n$ m^3/ day

Therefore,

$$0.34 \times 0.18 \times 7\ n = 1.891$$

$$n = 4.41 \approx 5$$

Thus, five cows are required to feed the plant.

Daily feeding of cow dung $= 7 \times 5 = 35$ kg

This will be mixed with equal quantity of water to make the slurry.

Thus, daily feed of slurry $= 70$ kg $= 70/1090 = 0.0642$ m^3 (slurry density $= 1090$ kg/m^3)

For a 50-day retention time, volume of slurry in the digester $= 50 \times 0.0642 = 3.21$ m^3

As about 90% volume is occupied by the slurry, the required volume of the digester $= 3.21/0.9 = 3.56$ m^3

Types of biogas plants:

- KVIC (*Floating Drum (Constant pressure) type biogas plant)*
- Janata model (*Fixed Dome (Constant volume) type biogas plant)*

Floating Drum (Constant pressure) type biogas plant:

- Below fig shows a KVIC (Khadi village industrial commission) model.
- Economical
- The partition wall provides optimum conditions for growth of acid formers and methane formers as both requires different ph levels.
- Provides good biogas yeald.

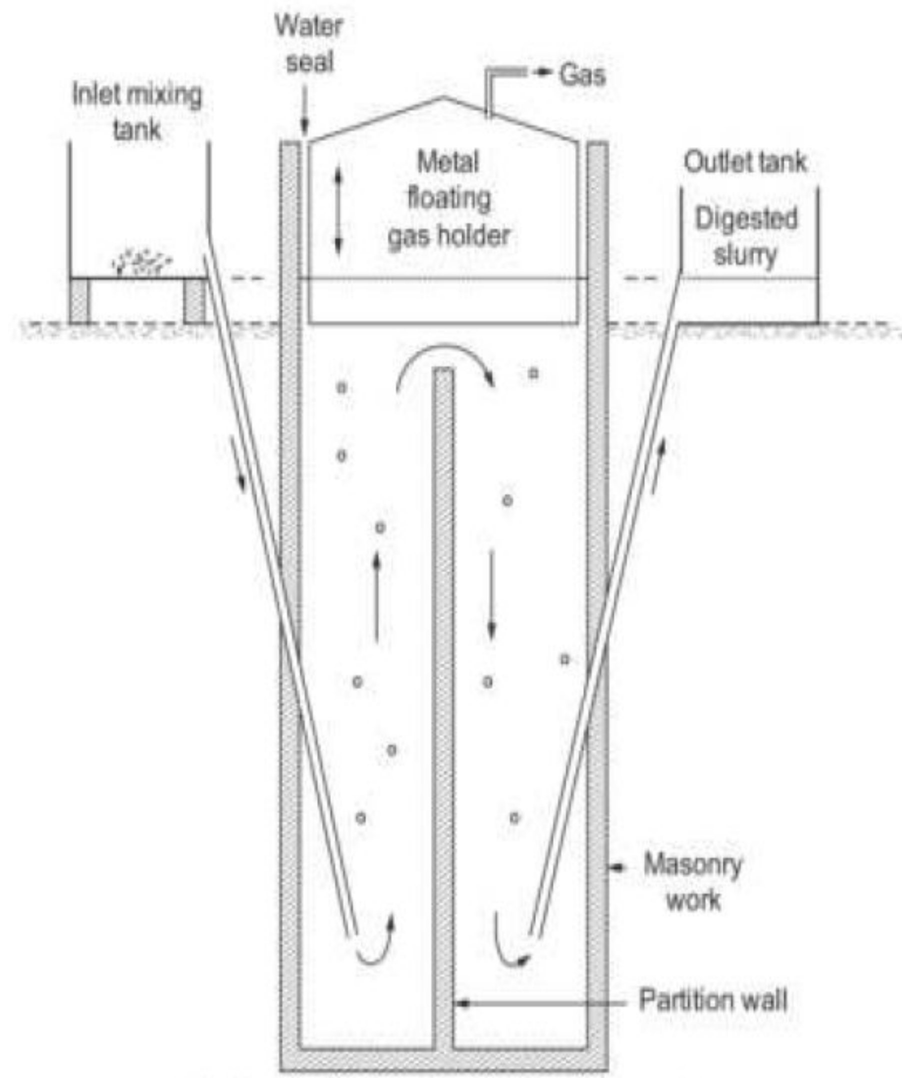


Fig. 8.12 Floating-drum-type biogas plant

Janata model (Fixed Dome (Constant volume) type biogas plant)

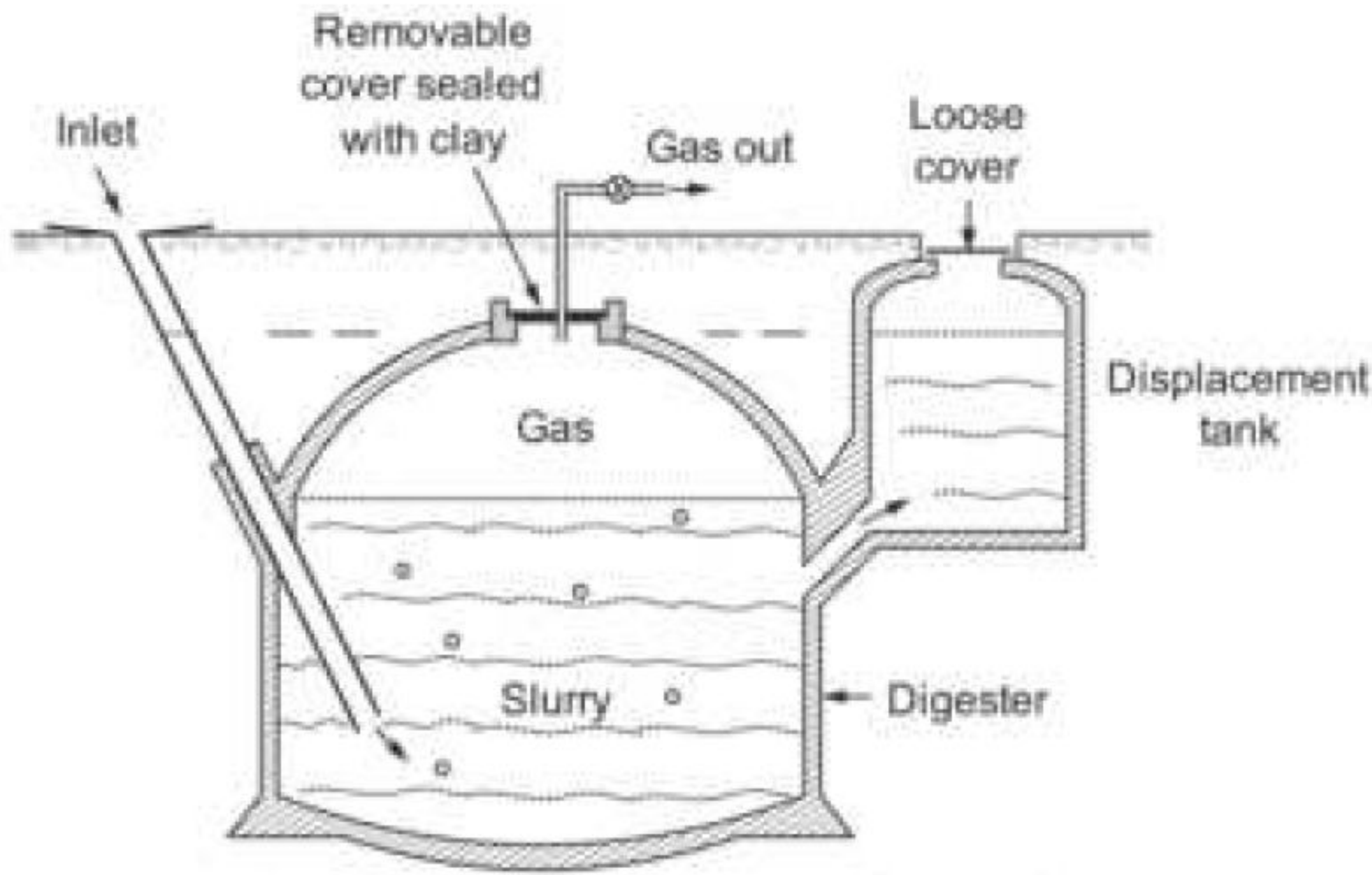


Fig. 8.13 *Fixed-dome-type biogas plant*

Comparison of KVIC and Janata model Biogas plant

S.No.	Feature	Floating drum	Fixed dome
1.	Cost	More (due to steel drum)	Less
2.	Corrosion	Yes (likely in steel drum)	No
3.	Maintenance	More • drum requires painting, once or twice a year • flexible gas pipe requires replacement	Less • no steel part is used • gas pipe is a fixed G.I. pipe
4.	Thermal insulation	Bad (heat loss due to steel drum)	Good (temperature will be constant due to complete underground construction)
5.	Scum troubles (layer of dirt)	Less likely (as solids are constantly submerged)	More likely
6.	Gas production per unit volume of digester	High (due to bifurcation, both acid and methane formers find better environment for growth)	Low
7.	Scum braking	By rotation of drum (no stirrer required)	External stirrer is required
8.	Leakage	Less likely	More likely
9.	Danger of mixing with oxygen due to leakage/cracks	No	More likely
10.	Gas pressure	Constant	Variable
11.	Masonry workmanship	Average skill	Specialized, skilled masonry work required