T. Y. B. Sc. (Physics) Semester: III

Elective-I : Renewable Energy Sources

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By Assistant Professor Wabale R.K.

MODULE IV : ENERGY FROM BIOMASS

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Introduction :

- The plant matter created by the process of photosynthesis is called biomass . The Biomass means organic matter .
- Photosynthesis is a naturally occurring process which derives its energy requirement from solar radiation .
- In its simplest form , the reaction of this process can be represented as follows ,

$$H_2O + CO_2 \xrightarrow{\text{Energy}} CH_2O + O_2$$

- It is seen that in the process , water and carbon dioxide are converted into organic material .
- The term ‘biomass’ includes all plant life that is trees , agricultural plants , bush , grass and algae and their residues after processing .
- The residues include crop residues (such as straw , stalks, leaves , roots , etc .) and agro-processing residues (such as oilseed shells , groundnut shells , husk , bagasse , molasses , coconut shells , saw dust , woodchips , etc .).
- The term biomass is also generally understood to include human waste and organic fractions of sewage sludge , industrial waste and household wastes .

Bio-mass conversion technologies :-

- There are variety of ways of **obtaining energy from biomass .**
- These may be classified into three groups , namely

    i) Thermochemical route .

    ii) Biochemical route .

    iii) Oil extraction .

i) Thermochemical route :

- The thermochemical conversion includes processes like combustion , gasification and pyrolysis .
- **Combustion :** It refers to the conversion of biomass to heat and power by directly burning it , as occurs in boilers.
- **Gasification :** It is the process of converting solid biomass with a limited quantity of air into producer gas .
- The producer gas is the mixture of combustible and non-combustible gases .
- **Pyrolysis :** It is the thermal decomposition of biomass in the absence of oxygen .

- The products of pyrolysis are charcoal , a condensable liquid and gaseous products , the relative proportions of these products depending on the chemical composition of biomass used and on the operating conditions .

- **ii) Biochemical route :**

- The biochemical conversion includes **anaerobic digestion** to produce biogas and **fermentation** to obtain alcohols fuels .

- **iii) Oil extraction :**

- An edible and non-edible oils can be extracted from a variety of grains and seeds .

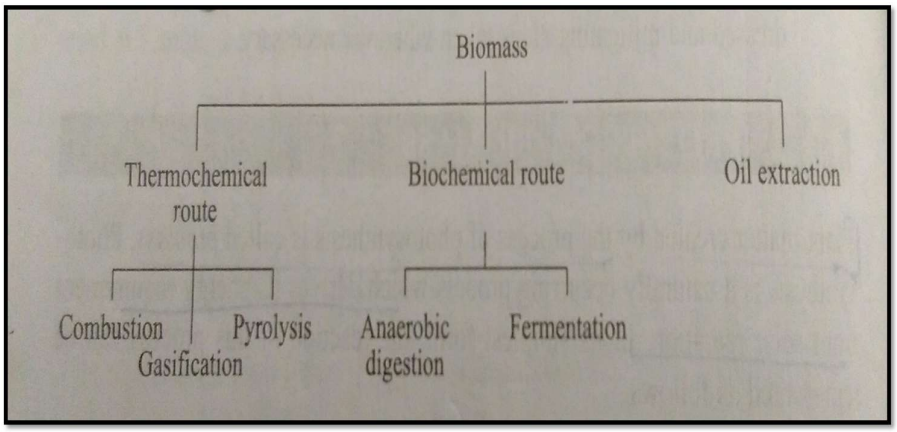

Figure : Biomass conversion routes .

- They can be directly used as liquid fuels or transesterified to produce biodiesel which is a good substitute for conventional diesel oil .

- The biomass is a sustainable source of energy . There is no net release of carbon dioxide in growing biomass and using it subsequently for energy conversion process .

Bio-gas generation :

- Biogas , a mixtures containing 55-65 % methane , 30-40 % carbon dioxide and the rest being the impurities (H_2 , H_2S and some N_2) , can be produced from the decomposition of animal , plant and human waste .

- It is clean but slow burning gas and usually the calorific value between 5000 to 5500 kcal/kg .

- It can be used directly in cooking , reducing the demand for firewood .

- Moreover , the material from which the biogas is produced retains its value as fertiliser and can be returned to the soil .
- Biogas has been popular on the name ‘Gobar Gas’ mainly because cowdung has been the material for its production .
- It is not only the excreta of the cattle but also the piggery waste as well as polutry droppings are very effectively used for biogas generation .
- A few other materials through which biogas can be generated are algae , crop residues (agro wastes) , garbage , kitchen wastes , paper wastes , waste from sugarcane refinery .
- Any cellulosic organic material of animal or plant origin which is easily bio-degredable is a potential raw material suitable for biogas production .
- Biogas is produced by digestion , pyrolysis or hydro-gasification .
- Digestion is a biological process that occurs in the absence of oxygen and in the presence of anaerobic organisms at ambient pressures and temperatures of 35-70 ^{0}C . This is also known as anaerobic digestion .
- This anaerobic digestion consists of three phases ,

i) Enzymatic hydrolysis :

- In this phase , the fats , starches and proteins contained in cellulosic biomass are broken down into simple compounds .

ii) Acid formation :

- In this phase the micro organisms of facultative and anaerobic group collectively called as acid formers , hydrolyse and ferment , are broken to simple compounds into acetic acids and volatiles solids .
- As a result complex organic compounds are broken down to short chained simple organic acids .

iii) Methane formation :

- Where these organic acids are then converted into methane (CH_4) and carbon dioxide (CO_2) by the bacteria which are strictly anarobs .
- These bacteria are called as methane fermentors .

- For efficient digestion these acid formers and methane fermentors , must remain in a state of dynamic equilibrium .
- This equilibrium is a very critical factor which decides the efficiency of generations .
- The container in which this digestion takes place is known as digester .

Factors affecting bio-digestion (List of factors) :

1. Temperature :

- The Methane forming bacteria work best in the temperature ranges 20-55 ^{0}C .
- Digestion at higher temperature proceeds more rapidly than at lower temperature .

2. Pressure :

- A minimum pressure of 6-10 cm of water column that is 12 bars is the ideal for proper functioning of plant .

3. Solid to moisture ratio :

- For various input materials the optimum ratio of solid to moisture should be adjusted by mixing extra water for best results .

4. pH value :

- During CH_4 formation stage , pH value of 6.5-7.5 is maintained .

5. Feeding rate :

- The uniform feed rate is maintained .
- The faster feeding rate will not help increase the gas production .

6. Carbon to Nitrogen ratio and other nutrients in the biomass :

- The optimum Carbon to Nitrogen ratio required for maximium microbiological activity is 30:1 .
- For optimal growth and activity of bacteria , it is essential that required nutrients are available in correct chemical form and concentration .

7. Seeding of biomass with bacteria :

- To start and accelerate fermentation process small amount of digested slurry containing methane forming bacteria is added to the freshly charged plant . This is known as seeding .

8. Mixing or stirring :

- Mixing prevents the deposition of solids at the bottom and it also minimizes the formation of scum at the surface .
- It maintains uniformity in concentration .

9. Retention time :

- Retention time is the time duration for which the slurry remains in the plant or the time that is available for bio- digestion .

10. Effect of toxic substances :

- High concentration of ammonia , antibiotics , pestisides , detergents , heavy metals like chromium , copper , nickel , zinc , etc . are toxic to bacteria responsible for bio-digestion .

Working of bio-gas plant :

Principle of the Biogas production :

- Biogas is produced through the "anaerobic fermentation" process in the "presence of water".

Construction :

- The biogas plant is a brick and cement structure having the following five sections:

Mixing tank : It is present above the ground level.

Inlet chamber : The mixing tank opens underground into a sloping inlet chamber .

Digester : The inlet chamber opens from below into the digester which is a huge tank with a dome like ceiling. The ceiling of the digester has an outlet with a valve for the supply of biogas.

Outlet chamber : The digester opens from below into an outlet chamber.

Overflow tank : The outlet chamber opens from the top into a small over flow tank.

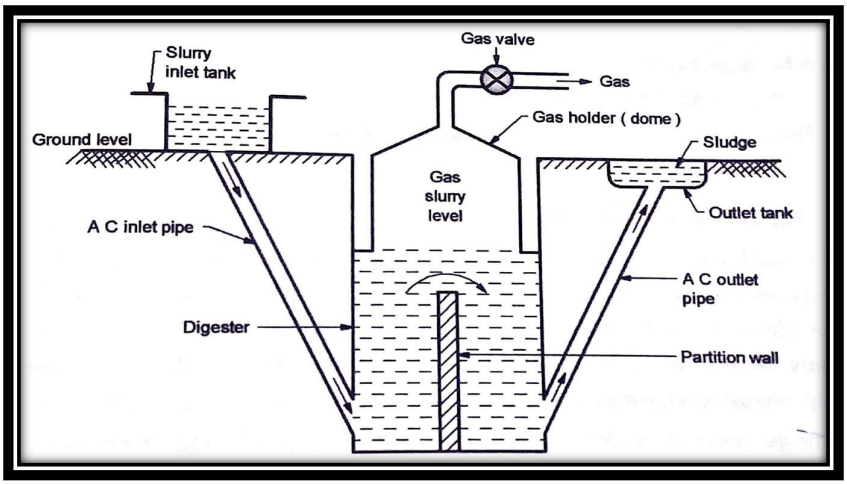

Fig : Schematic of bio-gas plant .

Working of the Biogas production :

- The various forms of biomass are mixed with an equal quantity of water in the mixing tank. This forms the slurry.
- The slurry is fed into the digester through the inlet chamber.
- When the digester is partially filled with the slurry, the introduction of slurry is stopped and the plant is left unused for about two months.
- During these two months, anaerobic bacteria present in the slurry decomposes or ferments the biomass in the presence of water.
- As a result of anaerobic fermentation, biogas is formed, which starts collecting in the dome of the digester .
- As more and more biogas starts collecting, the pressure exerted by the biogas forces the spent slurry into the outlet chamber .
- From the outlet chamber, the spent slurry overflows into the overflow tank .
- The spent slurry is manually removed from the overflow tank and used as manure for plants .
- The gas valve connected to a system of pipelines is opened when a supply of biogas is required .
- To obtain a continuous supply of biogas, a functioning plant can be fed continuously with the prepared slurry .

- **Advantages and dis-advantage of floating and fixed dome type plants :**

i) Floating [Constant Pressure or Khadi Village Industries Commission (KVIC)] type biogas plants :

Advantages :

1. Floating-drum plants are easy to understand and operate.
2. They provide gas at a constant pressure, and the stored gas-volume is immediately recognizable by the position of the drum.
3. Gas-tightness is no problem, provided the gasholder is de-rusted and painted regularly.
4. It has less scum(Floating matter) troubles because solids are constantly submerged.
5. No seperate pressure equlizing device needed , when fresh waste is added to the tank or digested slurry is withdrawn .
6. In this type there is no requirement of external stirrer , because scum breaking takes place by rotation of drum .
7. The gas production per unit volume of the digester is high as comparative to fixed dome type biogas plant .
8. The leakage through this type is less likely and average skill masonry work required for construction of plant .
9. In this type , the danger of mixing of oxygen with the gas to form explosive mixture is minimized .

Disadvantages :

1. The steel drum is relatively expensive and maintenance-intensive.
2. Removing rust and painting has to be carried out regularly.
3. The life-time of the drum is short (up to 15 years; in tropical coastal regions about five years).
4. If fibrous substrates are used, the gas-holder shows a tendency to get "stuck" in the resultant floating scum.

5. The thermal insulation is bad ,that is heat loss due to steel drum .
6. The cost of the this plant is high as compair to fixed dome type biogas plant .
7. Because of steel drum , it may suffers through the corrosion and sometimes gas pipes needs replacement .

ii) Fixed dome [Constant Volume or Janta model] type biogas plants :

Advantages :

1. Advantages are the relatively low construction costs, the absence of moving parts and rusting steel parts.
2. If well constructed, fixed dome plants have a long life span.
3. The underground construction saves space and protects the digester from temperature changes.
4. The construction provides opportunities for skilled local employment .
5. The thermal insulation is good ,because there is no steel part is used that is due to underground construction .
6. The gas pipes are fixed , therefore there is no needs replacement regularly .

Disadvantages:

1. Disadvantages are mainly the frequent problems with the gas-tightness of the brickwork gas holder (a small crack in the upper brickwork can cause heavy losses of biogas).
2. Fixed-dome plants are, therefore, recommended only where construction can be supervised by experienced biogas technicians.
3. The gas pressure fluctuates substantially depending on the volume of the stored gas.
4. Even though the underground construction buffers temperature extremes, digester temperatures are generally low.
5. Fixed dome plants can be recommended only where construction can be supervised by experienced biogas technicians.

6. A specific environmental disadvantage is methane emission from the expansion chamber.
7. For scum breaking , the external stirrer is required .
8. The gas production per unit volume of digester is low as comparative to floating type biogas plant .
9. In this type , the danger of mixing of oxygen with the gas to form explosive mixture is not minimized due to leakage through cracks .

Bio-gas from plant wastes :

- Wood biomass includes wood chips from forestry operations, residues from lumber, pulp/paper, and furniture mills, and fuel wood for space heating .
- The largest single source of wood energy is “black liquor,” a residue of pulp, paper, and paperboard production .
- Burning wood is nothing new, it is the most common form of biomass .
- For thousands of years people have burned wood for heating and cooking .
- Wood was the main source of energy in the world until the mid-1800s.
- Wood continues to be a major source of energy in much of the developing world.
- Its combustion produces heat and steam which can be further used to produce electricity .
- All forms of wood that include wood chips, wood pallets, logs, sawdust and even tree bark can be used to produce the biogas .
- Agricultural waste is a huge source of raw material to the biomass industry.
- Different types of agricultural waste can be utilized to create biogas.
- Waste can be in the form of leaves, husk, shells .
- All these come under renewable energy source that are even beneficial to the environment.

- Another important characteristic of this agricultural waste is that it can be used for organic farming as manure and used for cooking and heating purposes.
- **Biomass crops :** The certain crops are grown so that it can be further used for biomass energy.
- Some of the commonly grown biomass crops are corn varieties for ethanol production and soybean oil for the production biodiesel.

• Methods for obtaining the energy from bio-mass :

- The methods of generating energy can be split in two different groups .
- There are the dry processes and the wet processes .
- The dry processes are : Combustion and Pyrolysis .
- The wet processes are : Anaerobic Digestion , Gasification and Fermentation .

i) Dry processes :

• A) Combustion :

- The most obvious way of extracting energy from biomass , the technology of direct combustion is well understood , straightforward and commercially available .
- Combustion systems come in a wide range of shapes and sizes burning virtually any kind of fuel , from chicken manure and straw bales to tree trunks , municipal refuse and scrap tyres .
- Some of the ways in which heat from burning wastes is currently used include space and water heating , industrial processing and electricity generation .
- One problem with this method is its very low efficiency .
- With an open fire most of the heat is wasted and is not used to cook or whatever .
- One method of improving this in developing countries is to build stoves out of mud and scrap iron .

B) Pyrolysis :

- A wide range of energy-rich fuels can be produced by roasting dry woody matter like straw and woodchips .
- The process has been used for centuries to produce charcoal .
- The material is shredded then fed into a reactor vessel and heated in the absence of air .
- Pyrolysis can also be carried out in the presence of a small quantity of oxygen ('gasification'), water ('steam gasification') or hydrogen ('hydrogenation') .
- One of the most useful products is methane , which is a suilable fuel for electricity generation using high-efficiency gas turbines.

ii) Wet Processes :

a) Anaerobic Digestion :

- Biogas is produced when wet sewage sludge , animal dung or green plants are allowed to decompose in a sealed tank under anaerobic (oxygen-free) conditions .
- Feedstocks like wood shavings , straw and refuse may be used , but digestion takes much longer time.
- Each kilogram of organic material (dry weight) can be expected to yield 450-500 litres of biogas .
- The residue left after digestion is a potentially valuable fertilizer or compost .

b) Fermentation :

- Ethanol (ethyl alcohol) is produced by the fermentation of sugar solution by natural yeasts .
- Suitable feedstocks include crushed sugar beet and fruit .
- Sugars can also be manufactured from vegetable starches and cellulose by pulping and cooking , or from cellulose by miling and treatment with hot acid.
- After about 30 hours of fermentation , the brew cantains 6-10 per cent alcohol , which can be removed by distillation as a fuel .

- If the biomass used is (or can be converted into) mostly sugar , then yeast can be added.
- The fermentation that follows produces alcohol which is a very high energy fuel that makes it very practicle for use in cars . This has been tried succesfully in Brazil .

c) Gasification :

- This process , usually using wood produces a flammable gas mixture of hydrogen , carbon monoxide , methane and other non flammable by products .
- This is done by partially burning and partially heating the biomass (using the heat from the limited burning) in the presence of charcoal (a natural by-product of burning biomass) .
- The gas can be used instead of petrol and reduces the power output of the car by 40% .
- It is also possible that in the future this fuel could be a major source of energy for power stations .

Thermal gasification of biomass :

- The biomass gasification is a process of partial combustion in which solid biomass usually in the form of pieces of wood or agricultural residue is converted into a combustible gas mixture .
- The partial combustion occurs bacause the air supply , is intentionally kept less than the amount required for the full combustion of biomass .
- As a result , a gaseous mixture of carbon dioxide ,carbon monoxide , hydrogen , and nitrogen called **producer gas** is obtained .
- The **Gasifier** is the equipment that converts biomass into producer gas .
- The gasifier is a chemical reactor where various complex and physical as well as chemical processes take place .
- Biomass gets dried , heated , pyrolysed , partially oxidized and reduced in this reactor as it flows through it .
- The essence of gasification process is the conversion of solid carbon fuels into carbon monoxide and hydrogen by thermochemical process .

The gasifier is classified based on the types of bed used in it .

There two types namely ,

i) **Fixed Bed Gasifier**

ii) **Fluidized Bed Gasifier**

The three main designs of fixed bed gasifiers are ,

A)Up Draft Type Gasifier

B) Down Draft Type Gasifier

C) Cross Draft Type Gasifier

B) Down Draft Type Gasifier :

- It is also called as **co-current gasifier** . The schematic of down draft type gasifier is shown in figure .
- Typically the gasifier is a vertical cylindrical vessel of varying cross section .
- The biomass is fed in at the top at regular intervals of time and is converted through a series of processes into producer gas and ash as it moves down slowly through various zones of the gasifier .

i) Drying zone :

- The first zone is the drying zone in which the moisture content in the upper layers of the biomass is removed by evaporation .
- The temperature in this zone is about 120 ^{0}C .
- This temperature is acquired by heat transfer from the lower zones which are at much higher temperatures .

ii) Pyrolysis zone :

- The dried biomass moves down to the second zone called the pyrolysis zone which is at temperatures ranging from 200 ^{0}C to 600 ^{0}C from top to bottom .

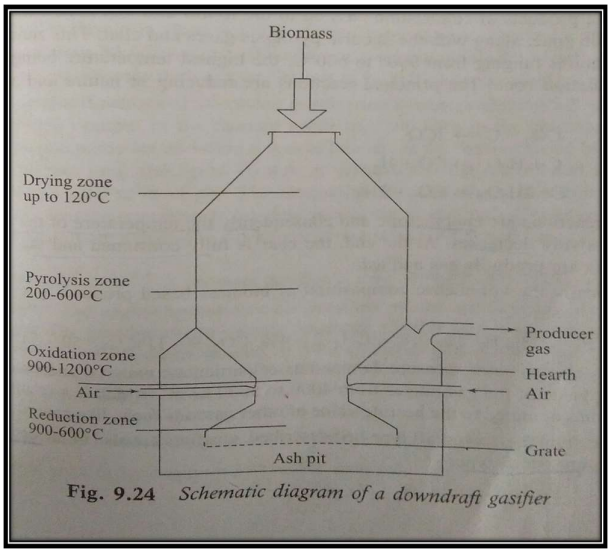

Fig. 9.24 *Schematic diagram of a downdraft gasifier*

- Throughout this zone , the biomass loses its volatiles .
- In addition , in the lower part of this zone , when the temperature reaches 400 ^{0}C , a self sustaining exothermic reaction takes place , in which the structure of the biomass breaks down .
- As a results , water vapour , methanol , acetic acid and significant amounts of hydrocarbon tars are evolved .
- The remaining solid is called char (carbon).
- All the products , gaseous and solid , pass on to the zone below .

iii) Oxidation or Combustion zone :

- The third zone is called as oxidation or combustion zone .
- A predetermined quantity of air is drawn into this zone through nozzles and temperatures ranging from 900 ^{0}C to 1200 ^{0}C are attained .
- The combustion reactions similar to those occuring in a normal stove or furnace take place in this zone and a portion of the char and pyrolysed gases coming from the second zone are burnt .
- The principal reactions taking place are exothermic and oxidising in nature , and the reultant products are carbon dioxide and water vapour .

iv) Reduction zone :

- The reultant products are carbon dioxide and water vapour of combustion pass on to the fourth and last zone called the reduction zone , along with the unburnt pyrolysis gases and char .
- This zone is at temperatures ranging from 900 ^{0}C to 600 ^{0}C , the highest temperature being near the oxidation zone .
- The principal reactions in nature and are as follows :

$$CO_2 + C \rightarrow 2CO$$

$$C + H_2O \rightarrow CO + H_2$$

$$C + 2H_2O \rightarrow CO_2 + 2H_2$$

- These rections are endothermic and consequently the temperature of the zone progressively decreases .
- At the end , the char is fully consumed and the final products are producer gas and ash .

• Down Draft Type Gasifier :

- Typically the volumetric composition of biomass based producer gas is as follows :

CO : 20-22 %

H_2 : 15-18 %

CH_4 : 2-4 %

CO_2 : 9-11 %

N_2 : 50-54 %

- The gas also contains measurable amounts of particulate material and tar .

• Conversion efficiency of a gasifier :

- The conversion efficiency of a gasifier is defined as the ratio of the heat content in the producer gas to the heat content in the biomass supplied and is usuallly around 75 % .

- The output of a biomass gasifier can be used for a variety of direct thermal applications such as cooking , drying , water heating , generating steam , etc .
- It can be also used as a fuel for internal combustion engines to obtain mechanical shaft power or electrical power .

Advantages Of Downdraft Gasifier :

- This type is more suitable with some thermal applications .
- It has minimum bulk density of 250 kg/m^3.
- The gas comes out of the gasifier at 250 - 450 ^0C .
- The downdraft fixed-bed gasifier is that the tars are cracked down in the oxidation zone , thus the producer gas has lower tar content compared to other types of gasifiers .

Disadvantages Of Downdraft Gasifier :

- High amounts of ash and dust particles remain in the gas because the gas has to pass the oxidation zone, where it collects small ash particles
- Fuel requirements are relatively strict; fuel must be uniformly sized from 4 to 10 cm so as not to block the throat and allow pyrolysis gases to flow downward and heat from the hearth zone to flow upward; therefore, pelletization or briquetting of is often necessary.
- 3. The moisture content of the biomass must be less than 25 percent (on a wet basis) .
- 4. The relatively high temperature of the exit flue gas results in lower gasification efficiency .

• Advantages and disadvantages of biological conversion of solar energy :-

- **Advantages :**
- The only major input to the system would be solar energy, which is free of cost.
- The production of energy would involve the less formation of pollutants .

- The techniques for raising such plants are simple and similar to conventional agricultural . Hence they can be used in the rural areas of the developing countries .
- 4. The by-products of such a system can be fully recycled .
- 5. Biogas can be distributed through pipes for domestic use .
- 6. It can be stored in container which can be transported to consumers .
- 7. It reduces the overreliance of fossil fuels.
- 8. Biomass energy produces less carbon than fossil fuel energy. Levels of the greenhouse gases methane and carbon dioxide could also be reduced .
- **Disadvantages :-**
- 1. It can be expensive when taking into account the cost of harvesting , extracting, transporting and handling biomass .
- 2. It uses a lot of wood from natural forests which can lead to deforestation, and if wood is not fully burnt it can release soot-like particles that may cause widespread air pollution .
- 3. The land area required is relatively large and hence this method is ruled out for areas where land cost is high .
- 4. Ordinarly there is storage problems , it can not be liquified hence cannot be bottled like LPG into cylinder .
- 5. It is generally a more expensive energy source compared to fossil fuels, because it requires more fuel to produce the same amount of energy.
- 6. A great deal of land and water are needed for some biomass crops to be produced and, when they have grown, the product requires a large amount of storage room before being converted into energy.
- 7. Another disadvantage is that biomass energy is not entirely clean.
- Some greenhouse gases are still produced; although the levels of these gases are far less than those produced by fossil fuels.
- 8. The constant and continues supply of biomass is required for the generation of biomass energy.

- 9. Compared to the input of raw materials, the outcome is comparatively less.
- 10. All the raw materials used are waste products that can cause pollution and foul smell.
- 11. More and more biomass crops are grown which in turn reduces the fertility of the soil.