BMM4753 RENEWABLE ENERGY RESOURCES

Chapter 6. Biomass Energy

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Energy Sustainability Focus Group

Chapter 6. Biomass Energy

Summary

6.1 Introduction

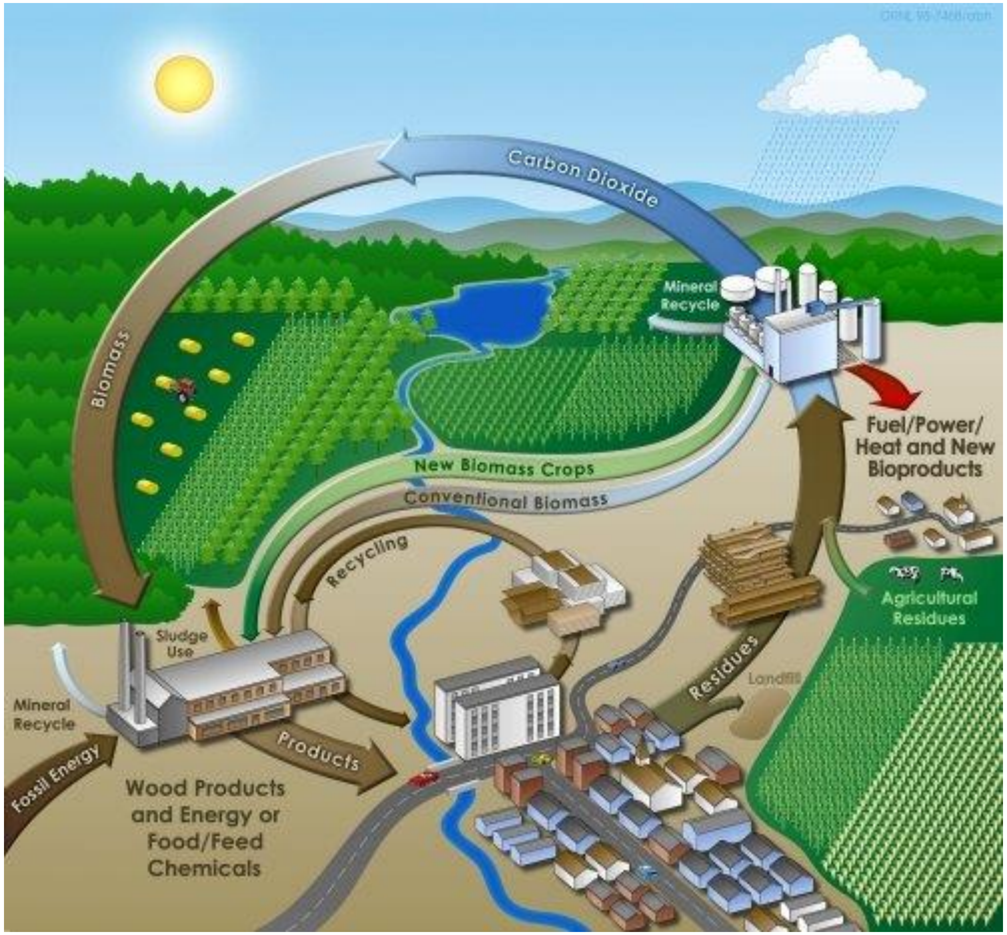
Biomass refers to solid carbonaceous material derived from plants and animals. These include residue of agriculture and forestry, animal waste and discarded material from food processing plants. Biomass being organic matter from terrestrial and marine vegetation, renews naturally in a short span of time, thus classified as a renewable source of energy. It is a derivative of solar energy as plants grow by the process of photosynthesis by absorbing CO_2 from the atmosphere to form hexose (dextrose, glucose, etc.) expressed by the reaction:

$$6CO_2 + H_2O \xrightarrow[\text{photosynthesis}]{\text{sunlight}} C_6H_{12}O_6 + 6O_2$$

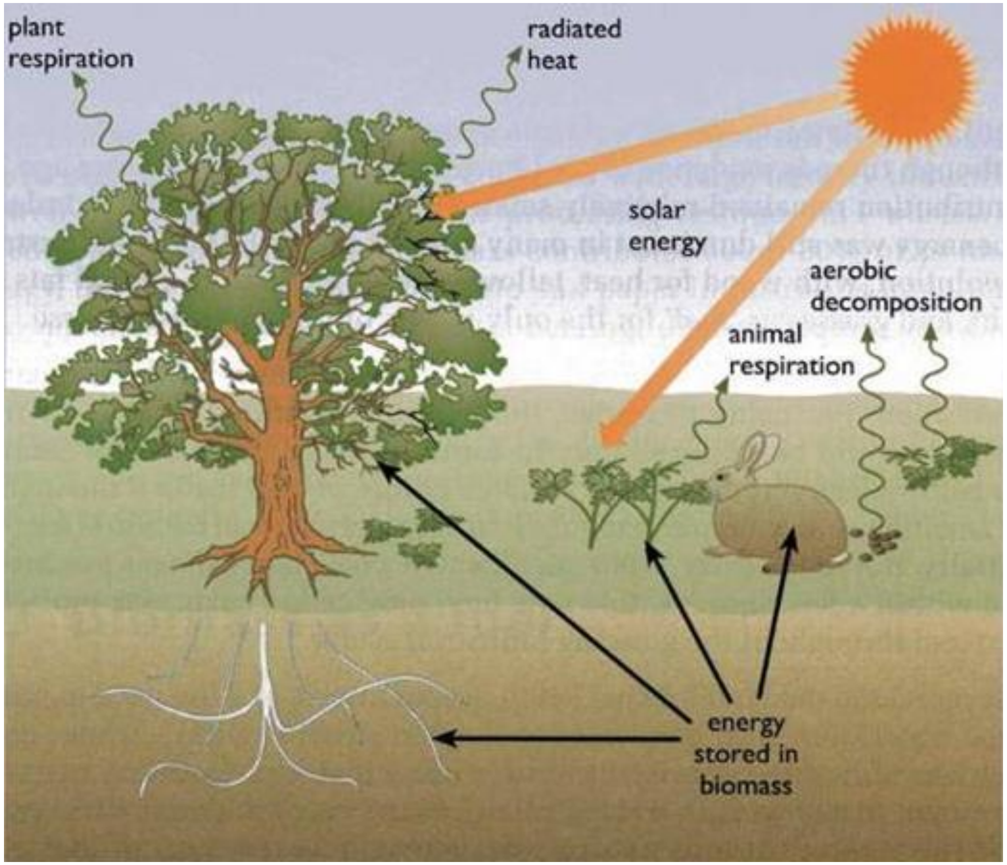
Biomass does not add CO_2 to the atmosphere as it absorb the same amount of carbon in growing the plants as it release when consumed as fuel. It is a superior fuel as the energy produced from biomass is ‘carbon cycle neutral’.

Biomass fuel is used in over 90% of rural household and in about 15% urban dwellings. Agriculture products rich in starch and sugar like wheat, maize, sugarcane can be fermented to produce ethanol (C_2H_5OH) is also produce by distillation of biomass that contains cellulose like wood and bagasse. Both these alcohols can be used to fuel vehicles and can be mixed with diesel to make biodiesel.

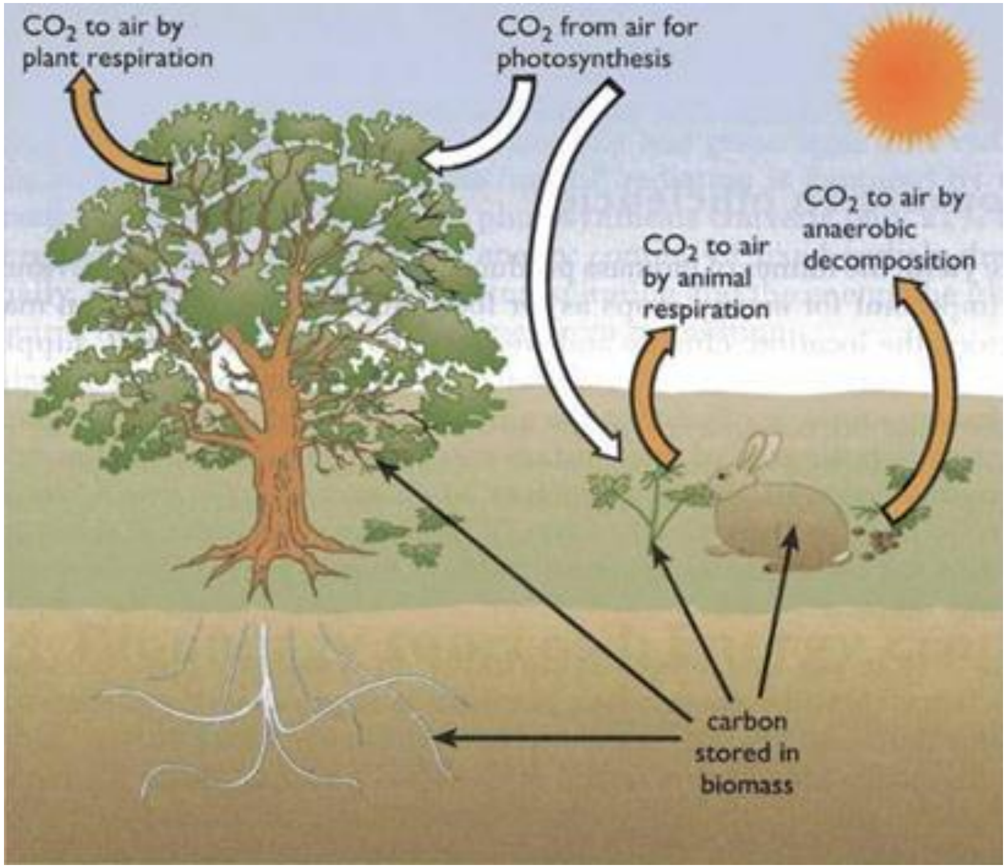
6.1 Introduction – Bioenergy Cycle



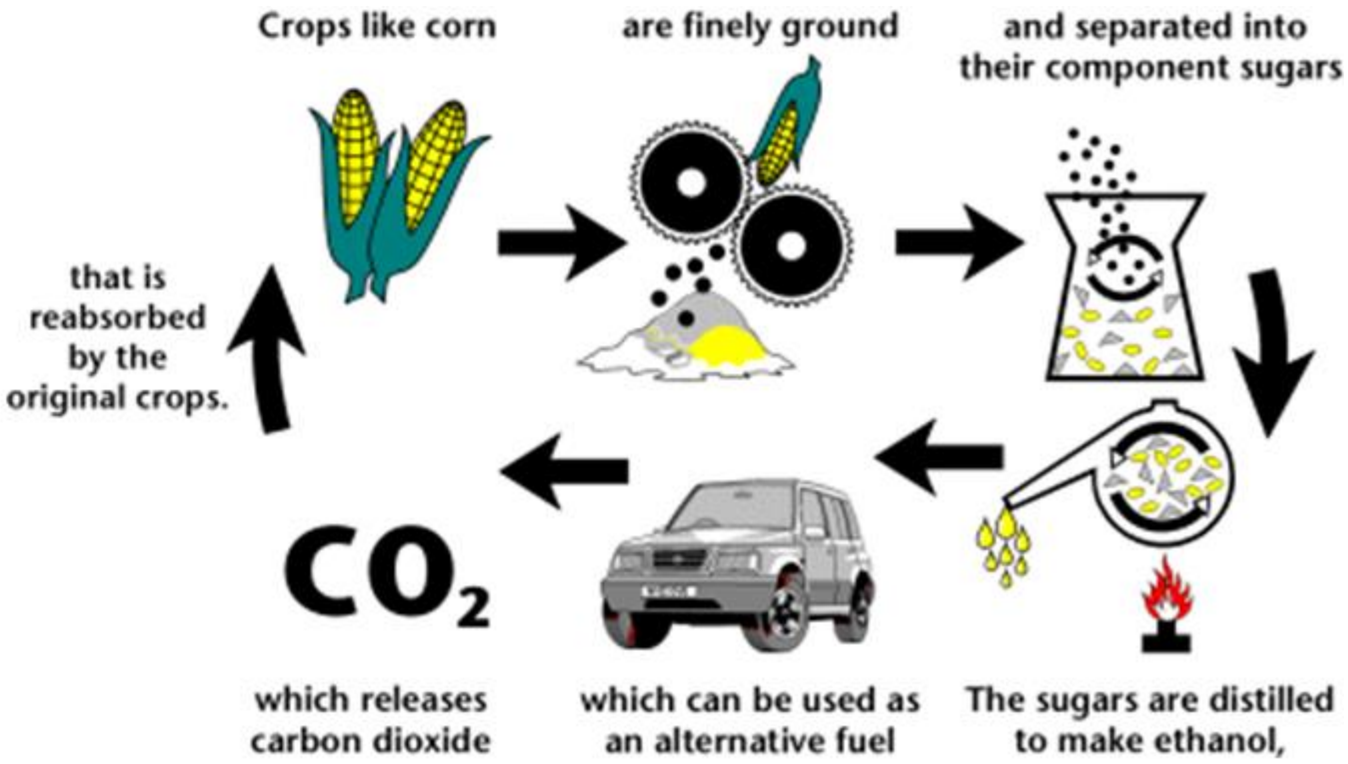
6.1 Introduction – Bioenergy Cycle, energy



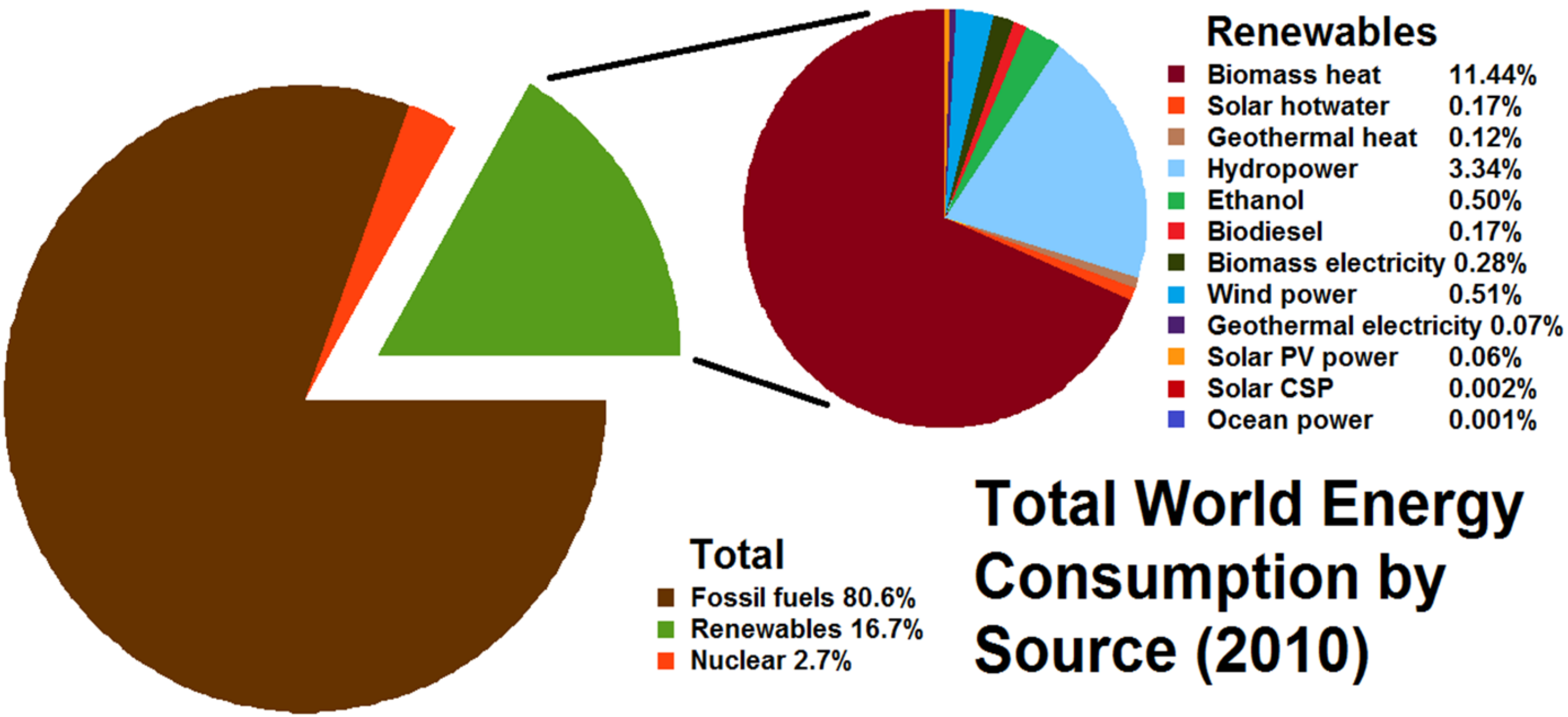
6.1 Introduction – Bioenergy Cycle, carbon dioxide



6.1 Introduction – Bioenergy Cycle, carbon



6.2 Biomass Resources – World Energy Consumption 2010



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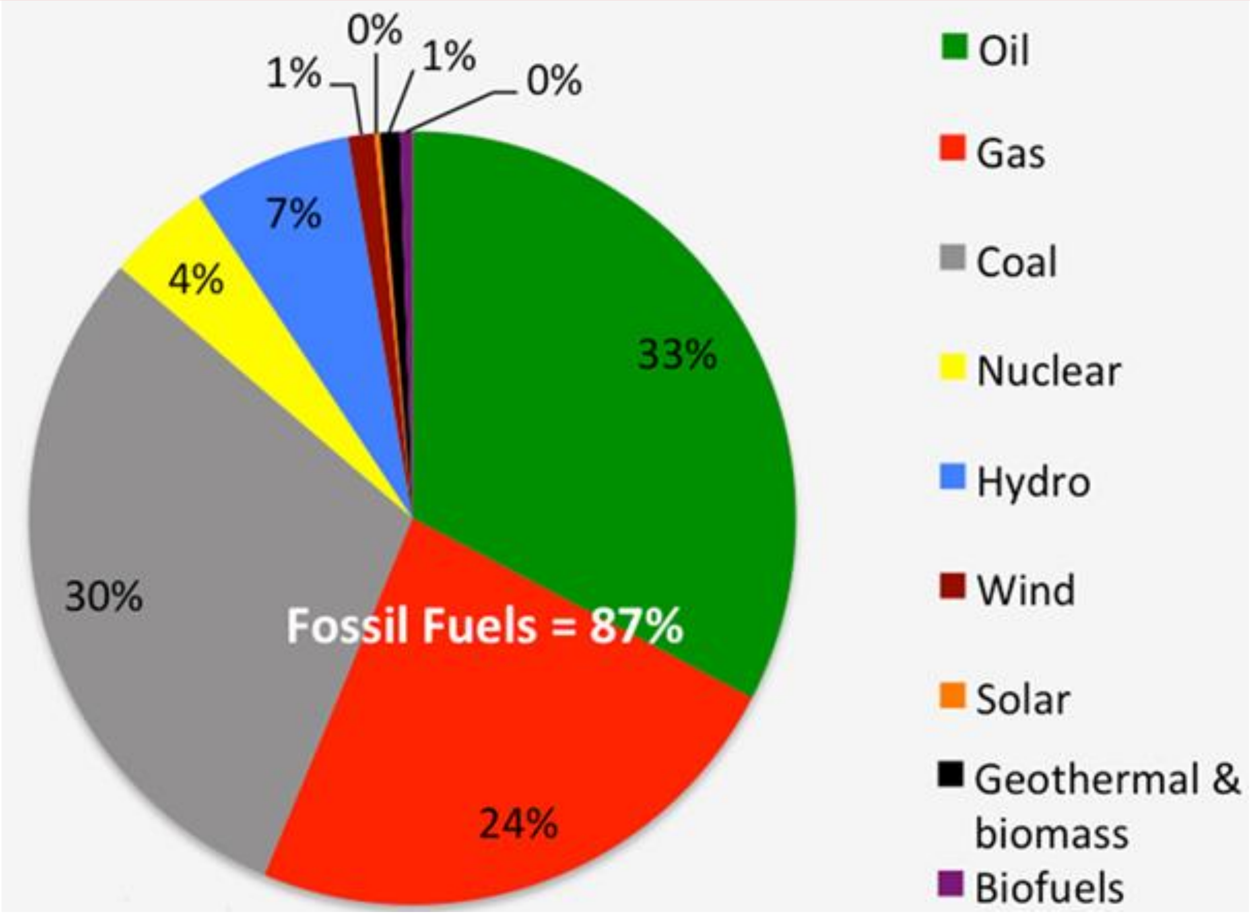
6.2 Biomass Resources – World Energy Consumption 2013



6.2 Biomass Resources – Basic data

World Totals		World Energy Comparisons	
Total mass of living matter (including moisture)	2000 bil. tonnes	Rate of energy storage by land biomass	3000 EJy^{-1} (95 TW)
Total mass in land plants	1800 bil. tonnes	Total primary energy consumption (2002)	451 EJy^{-1} (14.3 TW)
Total mass in forest	1600 bil. tonnes	Biomass energy consumption	56 EJy^{-1} (1.6 TW)
World population (2012)	7 bil.	Food energy consumption	16 EJy^{-1} (0.5 TW)
Per capita terrestrial plant biomass	300 tonnes		
Energy stored in terrestrial biomass	25 000 EJ		
Net annual production of terrestrial biomass	400 000 Mty^{-1}		

6.2 Biomass Resources – Conversion of Solar Energy

Consider one hectare (ha) of land, in an area such as southern England where the annual energy delivered by solar radiation is 1000 kWh m^{-2} y^{-1}. 1000 kWh is 3.6 GJ and 1 ha is 10, 000 m^2, so the total annual energy is 36, 000 GJ

After losses about an eight of this reaches the crop at the right time. Say….

12%	of the annual energy reaches growing leaves	4320 GJ
50%	of this is photosynthically active radiation	2160 GJ
85%	of which is captured by the growing leaves	1836 GJ
21%	of which is converted into stored energy	386 GJ
40%	of which is lost in photorespiration or in respiration to sustain the plant, leaving	231 GJ

E = exa E 10^{18}
P = peta 10^{15}
T = tera 10^{12}
G = giga 10^{9}
1 hectare = 2.5 acres

This amount represent 5.3% of the solar radiation reaching the growing plant, and 0.64% of the original total annual energy.

6.2 Biomass Resources – Boiling a liter of water

How much wood is needed to bring one liter of water to boil?

Data

Specific heat capacity of water	= 4200 J kg^{-1} K^{-1}
Mass of 1 liter of water	= 1 kg
Heat value of wood	= 15 MJ kg^{-1}
Density of wood	= 600 kg m^{-3}
1 cubic centimeter (1 cm^3)	= 10^{-6} m^3

Calculation

Heat energy to heat 1 liter of water from 20 ^oC to 100 ^oC = 80 × 4200 J = 336 kJ

Heat energy released in burning 1 cm3 of wood = 15 × 600 × 10^{-6} MJ = 9.0 kJ

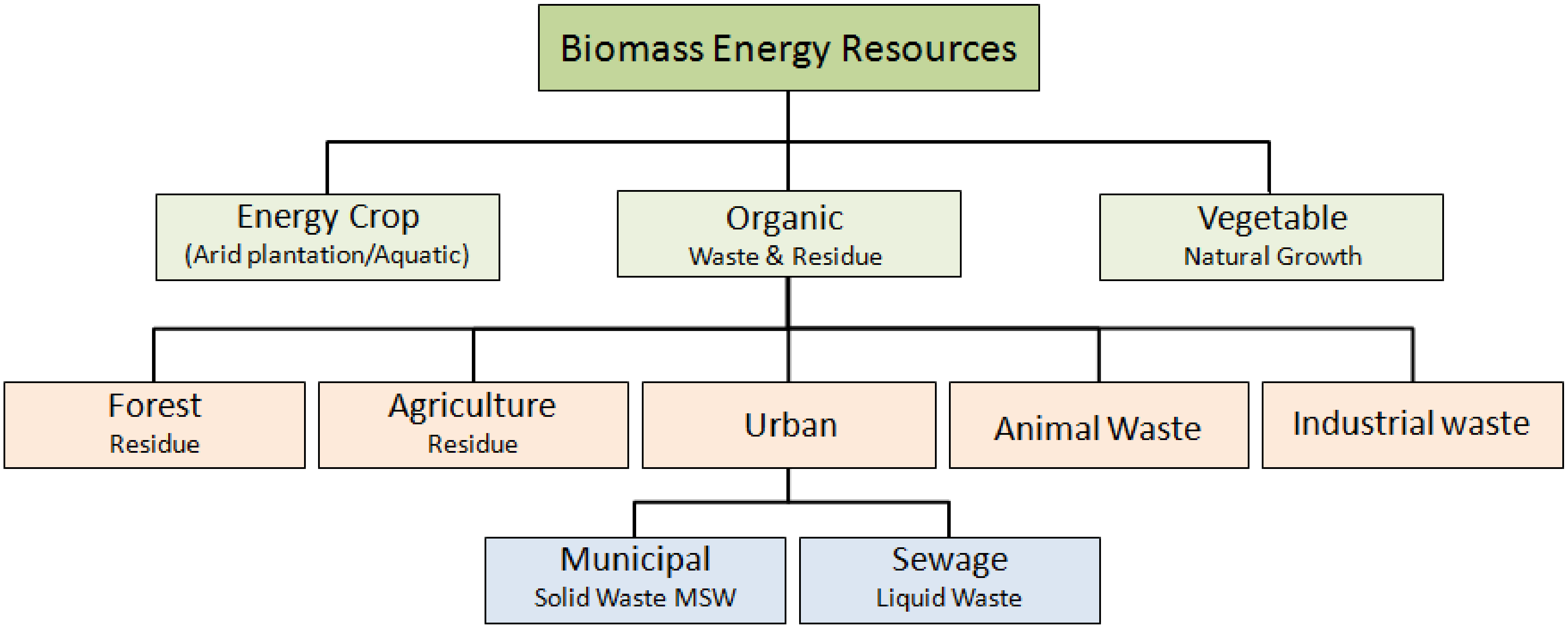
Volume of wood required = 336 ÷ 9.0 = 37 cm^3

Experience suggest that on an open fire much more than two thin 20 cm sticks would be needed. But a well-designed stove using small pieces of wood could boil the water with as little as four time this 'input' – an efficiency of 25%

6.2 Biomass Resources – Biomass Energy Production

Sector/Source	2000	2001	2002	2003	2004
Total	**2,907**	**2,640**	**2,648**	**2,740**	**2,845**
Wood Energy Total	**2,257**	**1,980**	**1,899**	**1,929**	**1,989**
Residential	433	370	313	359	332
Commercial	53	40	39	40	41
Industrial	1,636	1,443	1,396	1,363	1,448
Electric Power[a]	134	126	150	167	168
Waste Energy Total	**511**	**514**	**576**	**571**	**560**
MSW/Landfills Gas	400	419	467	440	443
Commercial	41	35	37	42	43
Industrial	64	74	87	85	88
Electric Power[a]	295	310	343	314	312
Other Biomass[b]	111	95	108	131	117
Commercial	6	4	5	6	5
Industrial	81	76	81	85	84
Electric Power[a]	23	14	22	41	28
Alcohol Fuels[c]	**139**	**147**	**174**	**239**	**296**
Transportation	139	147	174	239	296

6.2 Biomass Resources – Biomass Classification



6.2 Biomass Resources – Biomass Classification

A. Organic Waste and Residues

Forest residues

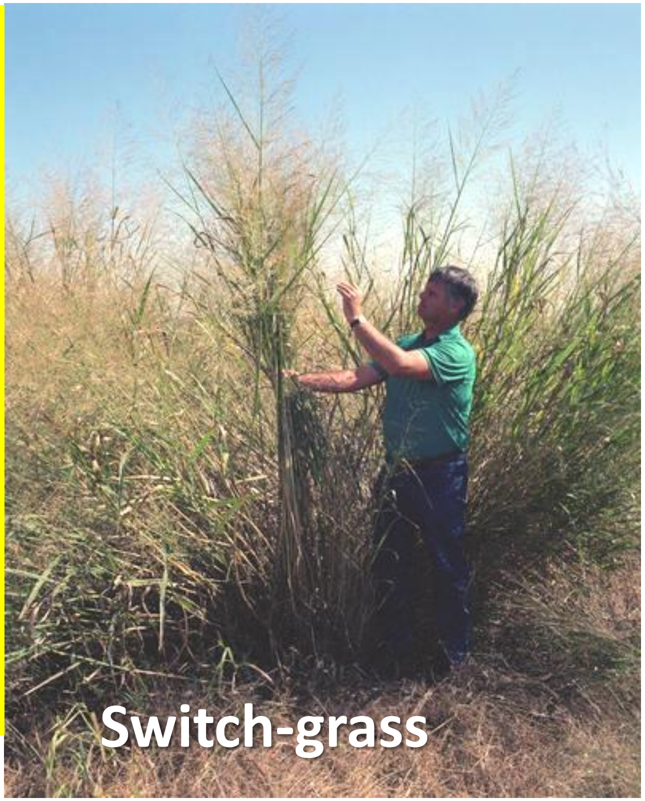
Forest, naturally or cultivated are a rich source of timber, fuel wood, charcoal and raw material for paper mills and other industries. Fast growing trees like Eucalyptus, Neem, Kikar and Gulmohar are grown along canals, railway and on land of marginal quality. Wood, saw, dust, and bark residue are generated in sawmills. Forest also provide foliage and logging residues. An important characteristic of forest residue is its calorific value, which is 4399 to 4977 kcal/kg for softwood foliage and 3888 to 5219 kcal/kg for hard wood species.

6.2 Biomass Resources – Biomass Classification

A. Organic Waste and Residues

Forest residues

- Switch-grass, found in remnant of the prairies, along roadsides, pastures and as wind breakers around farms.
- Hardy, perennial grass can grow up to 1.8-2.2 m
- Forage for livestock, in wildlife areas, or as a ground cover for erosion control.
- Can produce of up to 1000 gallon ethanol/acre.
- Not currently viable alternative, requires 45% fossil energy than the fuel produced.
- More research for more efficient conversion process



6.2 Biomass Resources – Biomass Classification

A. Organic Waste and Residues

Forest residues

Wood Chips & Sawdust

6.2 Biomass Resources – Biomass Classification

A. Organic Waste and Residues

Agricultural crop residues

Crop residues are available in abundance as natural resource, easily collected and stored. These are, rice husk, wheat straw, corn cobs, cotton stick, sugarcane bagasse, groundnut and coconut shells. These are converted into briquettes or pallets for use as clean fuel. These are called ‘biofuels’ which are high efficiency solid fuels.

The total energy content of the annual residues of the world's two main tropical food crops, sugar and rice, is estimated at about 18 EJ similar to the total for temperate crops. Significant quantities are already being used as fuels.

- Bagasse, the fibrous residue of sugar cane, is used in sugar factories as a fuel for raising steam, and to produce electricity for use in the plant. Facts:-
  i. Transporting the bagasse may not be economic.

6.2 Biomass Resources – Biomass Classification

A. Organic Waste and Residues

Agricultural crop residues

ii. Increased recovery of wastes, combined with improved efficiency of conversion to electricity, could result in up to 50 GW of generating capacity from the sugar industry world-wide.

iii. The use of bagasse to produce ethanol is another possibility.

- Rice husks are the most common agricultural residues in the world, constitute one-fifth of un-milled rice dry weight. Although they have high silica, ash content compared with other biomass fuels, their uniform texture makes them suitable for technologies such as gasification. Rice husk gasifiers have been successfully operated in many countries including Indonesia, China and Mali.

6.2 Biomass Resources – Biomass Classification

A. Organic Waste and Residues

Agricultural crop residues

Sugarcane Bagasse

6.2 Biomass Resources – Biomass Classification

A. Organic Waste and Residues

Agricultural crop residues

Soybeans

6.2 Biomass Resources – Biomass Classification

A. Organic Waste and Residues

Agricultural crop residues

Sorghum

6.2 Biomass Resources – Biomass Classification

A. Organic Waste and Residues

Agricultural crop residues

Corn Stover

6.2 Biomass Resources – Biomass Classification

A. Organic Waste and Residues

Agricultural crop residues

Corn

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6.2 Biomass Resources – Biomass Classification

A. Organic Waste and Residues

Urban waste

Two types of urban waste :

i. Municipal Solid Waste (MSW) which includes human excreta, household garbage and commercial waste.

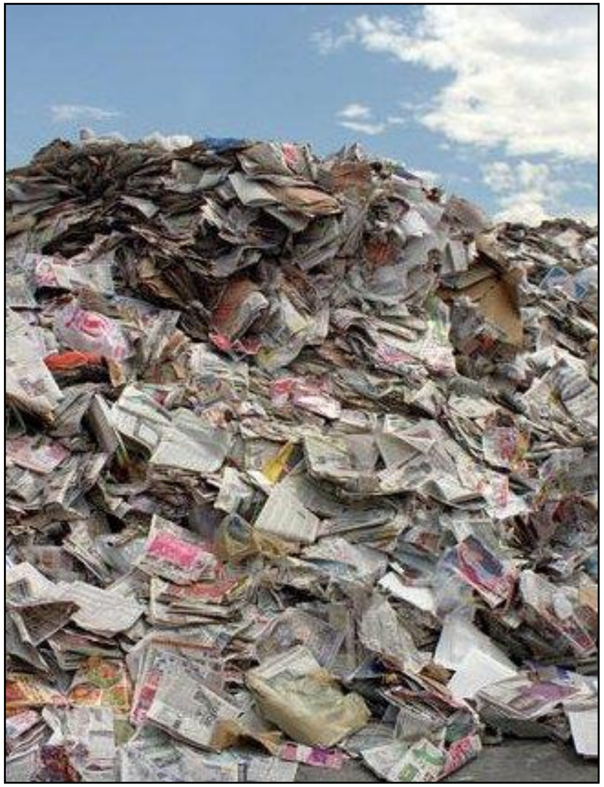
ii. Liquid Waste (LW) from domestic sewage effluents from institutional activities.

At present MSW is dumped in sanitary landfills, where fuel gas is produced which is a valuable source of renewable energy. Sewage is suitably processed to produce biogas.

6.2 Biomass Resources – Biomass Classification

A. Organic Waste and Residues

Urban waste – Municipal Solid Waste



6.2 Biomass Resources – Biomass Classification

A. Organic Waste and Residues

Urban waste – Sewage liquid waste

- Sewage is a water-carried waste, in solution or suspension, that is intended to be removed from a community.
- Also known as domestic or municipal wastewater, it is more than 99% water and is characterized by volume or rate of flow, physical condition, chemical and toxic constituents, and its bacteriologic status (which organisms it contains and in what proportions).
- Consists mostly of greywater (from sinks, tubs, showers, dishwashers, and clothes washers), blackwater (the water used to flush toilets, combined with the human waste that it flushes away); soaps and detergents; and toilet paper (less so in regions where bidets are widely used instead of paper).
- Depends on the design of its route back to the environment, may contains surface runoff .

6.2 Biomass Resources – Biomass Classification

A. Organic Waste and Residues

Animal waste

Organic material with combustible property and a rich source of fuel. Dung cakes prepared with animal waste are used for cooking in rural and semi-urban areas. It is also a raw material for biogas plants. Farmers frequently use animal waste as fertilizer and need proper management. As it decays and ferments, it creates gases and can cause toxic reactions in people or animals, oxygen depletion, asphyxiation, and even death. Animal waste can generate four potentially deadly gases:

- ammonia,
- carbon dioxide,
- hydrogen sulfide, and
- methane.

The gases can also cause explosions. It can also contain bacteria and nitrates, which can contaminate drinking water and cause human illnesses.

6.2 Biomass Resources – Biomass Classification

A. Organic Waste and Residues

Industrial waste

Energy recovery from industrial waste was taken up. Projects are implemented with technical assistance of national laboratories. Projects developed under this program are:

i. Pulp & Paper Industry Effluent
ii. Starch and Glucose Industry Waste
iii. Palm Oil Industry
iv. Distillery Waste and Tanneries Waste

Each project is aimed to treat its waste for the production of bio-energy which in turn can be used for power generation.

6.2 Biomass Resources – Biomass Classification

B. Energy Crops

Energy farming refers to the cultivation of fast growing plants which supply fuel wood, biomass that can be converted into gaseous and liquid fuels like biogas, vegetable oil and alcohol. To harvest biomass for power generation, energy plantation is done on degraded or wastelands which are saline, wind eroded lands in arid areas and water logged lands.

Aquatic crop

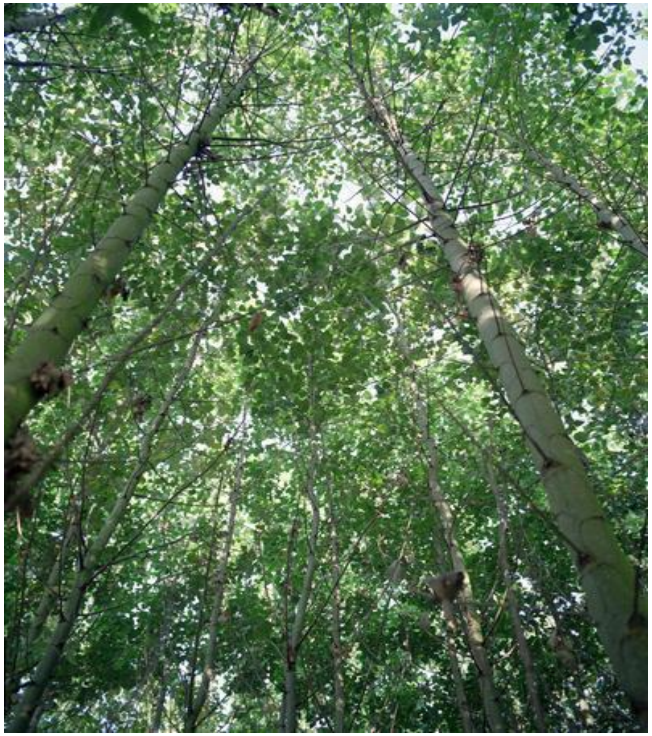
Aquatic crop constitutes three water plants, namely algae, water hyacinth and sea weed. These plants grow abundantly in water bodies and provide organic matter for biogas plants. Energy plantation program is directed to bring sub-standard soil under cultivation. It restores the fertility of lands, halts desertification, prevent soil erosion, reduce flooding and improves microclimate.

6.2 Biomass Resources – Biomass Classification

B. Energy Crops

Arid Plantation - Hybrid Poplar

- Fastest-growing trees in North America , well suited for the production of bioenergy (e.g., heat, power, transportation fuels), fiber (e.g., paper, pulp, particle board, etc.) and other biobased products (e.g., organic chemicals, adhesives). With the exception of the more arid regions, hybrid poplars can be produced throughout most of the continental U.S.
- Poplars were used as windbreaks



6.2 Biomass Resources – Biomass Classification

C. Vegetable oil crops

Oil can be extracted from fertile area crops such as sunflower, cotton seed, groundnut, rapeseed, palm and coconut. These oils after purification can be blended with diesel as engine fuel.

Jatropha (Pokok Jarak)

- Abundance as succulent plants, shrubs and trees
- Produce male/female flowers containing highly toxic compounds
- Use as oil and reclamation plants
- One of the best candidates for future biodiesel production
- Resistant to drought and pests,
- Produces seeds containing 27-40% oil, averaging 34.4%
- Jatropha seeds press cake recycled for energy production
- Currently properly domesticated and their productivity is variable

6.3 Biofuels

Biomass is an organic carbon-based matter obtained from plants. Biomass is a source of energy from wood, crop residues, cow dung, etc. for cooking and various domestic uses. Dry biomass gives heat energy by direct combustion.

Direct burning of firewood in traditional stove utilizes only 10% heat. Besides inefficient burning, smoke discharge in kitchens is a health hazard. To harness fuel value, technologies - are required to convert biomass into a high quality usable solid, liquid and gaseous fuels called biofuels.

Biomass charcoal is a smokeless dry solid fuel with high energy density. Modern charcoal retorts (furnaces) operate at about 600°C to produce charcoal from 25-35% of dry biomass feed. contains 75-80% carbon and is useful as a compact fuel. It can be burnt to provide heat for domestic, commercial and industrial applications.

6.3 Biofuels

Biomass briquetting is densification of loose biomass into a high density solid fuel. Biomass of any form such as cotton sticks, rice husk, coconut shells, saw dust and wood chips can be converted into briquettes. It reduces the volume-to-weight ratio, thus making transportation easy for efficient commercial and industrial use. The calorific value is about 3500 kcal/kg. Biomass briquettes can replace 'C' grade coal used in industrial boilers.

Vegetable oils such as rapeseed, palm, coconut and cotton seed oil can substitute diesel as engine fuel. Jojoba trees cultivated in marginal lands produce oil seeds. Jojoba oil is considered liquid gold like crude oil as it can be processed into a wide range of products like motor oil, lubricants, mono-unsaturated alcohols and oil of cosmetic value. Euphorbia species produce latex which after water removal give light hydrocarbon oil.

6.3 Biofuels

Biogas can be produced by digestion of animal, plant and human waste. Digestion is a biological process that takes place in a digester with anaerobic organism in absence of oxygen at a temperature between *35°C* and 70°C. In rural areas, household biogas plants operate from cow and buffalo dung which provide gas for cooking and lighting. Biogas is a mixture of CH (55 to 65%), CO_2 (30 to 40%) H_2, H_2S and N2 « 10%) having a calorific value between 500 and 5500 kcal/kg.

Gas fuel, producer gas is obtained by partial combustion of wood or any cellulose organic material of plant origin. It is a mixture of a few gases and its constituents are CO_2 (19%), CH_4 (1 %), H2 (18%), CO_2 01%) and N2 (45-60%). Hydrogen and methane keep heating value between 4.5 MJ/m^3 and 6 MJ/m^3 depending upon the volume of its constituents. Producer gas can be burnt to generate steam in a boiler. It is used as fuel in IC engines used for irrigation pumps, in spark ignition engines and gas turbines for power generation.

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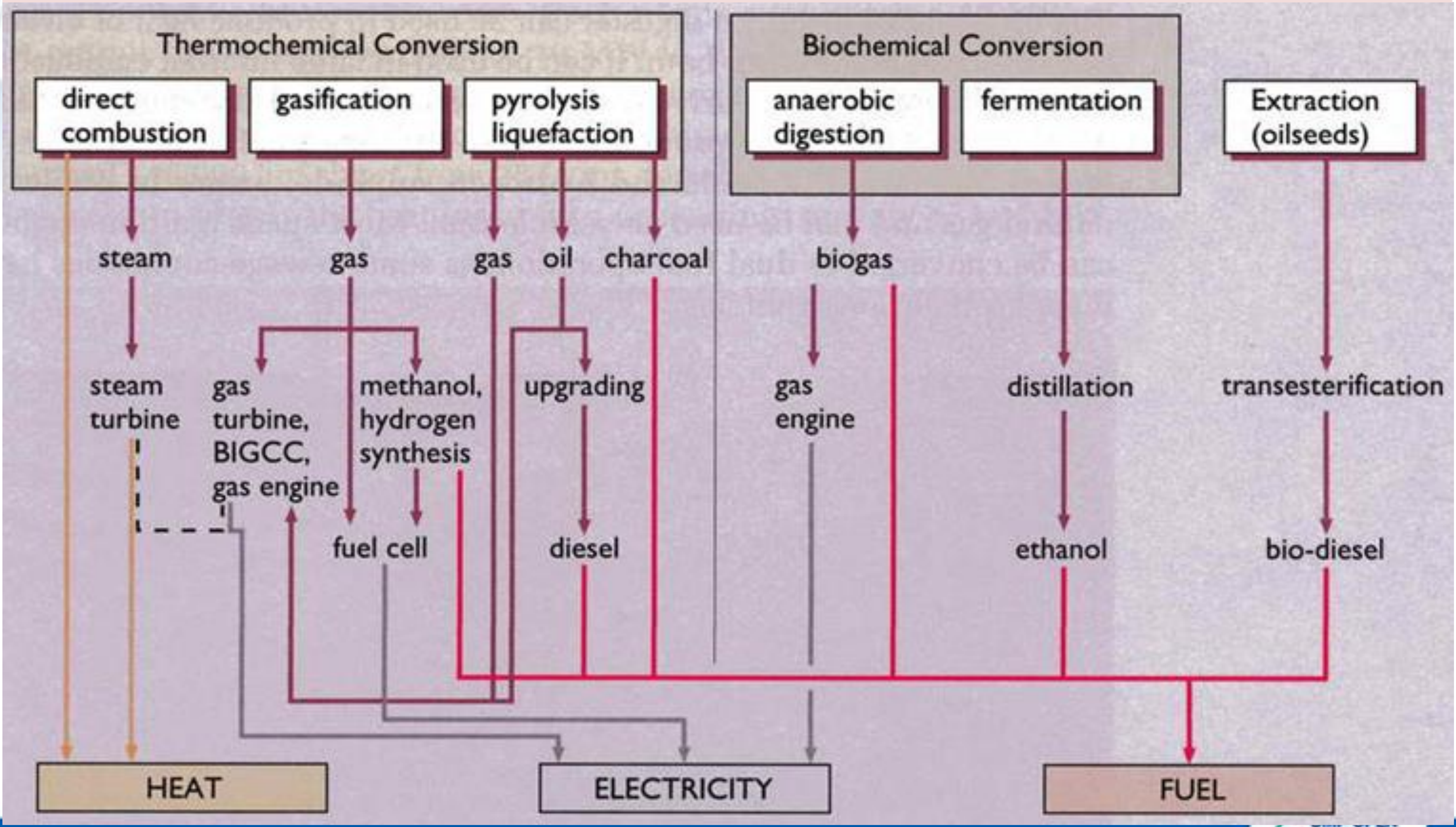
6.3 Biofuels

Liquid fuel, ethanol (C_2H_sOH) is a flammable colorless biofuel. It can be produced by fermentation of any feedstock which contains sugar or starch and even cellulose material. Biomass containing sugar are: sugar-beets, sugarcane, sweet sorghum; starch crop covers corn, wheat, cassava and potato. Cellulose is found in all plant tissues, is available in wood, solid waste and agriculture residues. Ethanol is suitable for use as a fuel additive to cut down carbon monoxide and other smog-causing emissions. In nine sugar producing Indian states, petrol blended with 5% ethanol is supplied.

NB: Methanol (CH_3OH) or methyl-alchohol

- ❑ Liquid at normal pressure and temperature, colourless, extremely flamable
- ❑ Highly poisonous and if consume can cause blidness and fatal
- ❑ Use in industry for shellack, lacquer, paint, chemical, formaldihyde
- ❑ Produce from fossil fuels, biomass
  - ➢ Gasification of coal
  - ➢ Burning natural gas (mainly methane) in excess of water and carbon dioxide
  - ➢ Biogas from organic waste/biomass is process further to produce methanol

6.4 Biomass Energy Conversion Technologies



6.4 Biomass Energy Conversion Technologies

Biomass material from a variety of sources can be utilized optimally by adopting efficient and state-of-the-art conversion technologies such as:

- Densification of biomass
- Combustion and incineration
- Thermo-chemical conversion
- Bio-chemical conversion

Densification: Bulky biomass is reduced to a better volume-to-weight ratio by compressing in a die at a high temperature and pressure. It is shaped into briquettes or pellets to make a more compact source of energy, easy to transport and store than the natural biomass. Pellets and briquettes can be used as clean fuel in domestic chulhas, bakeries and hotels.

NB: **Briquetting** is done at high temp and pressure with a ram type or screw press from paddy husk or sawdust using a binder.
Pelletization is formation of wood waste in the form of rods (12 x 12 mm) by removing moisture after pulverization and forcing it through an extrusion device.

6.4 Biomass Energy Conversion Technologies

Combustion is the most common process adopted for utilizing biomass energy. It is burnt to produce heat utilized for cooking, space heating, industrial processes and for electricity generation. This utilization method is very inefficient with heat transfer losses of 30-90% of the original energy contained in the biomass. The problem is addressed through the use of more efficient cook-stove for burning solid fuels.

Incineration is the process of burning completely the solid biomass to ashes by high temperature oxidation. The terms incineration and combustion are synonymous, but the process of combustion is applicable to all fuels, i.e. solid, liquid and gaseous. Incineration is a special process where the dry Municipal Solid Waste (MSW) is incinerated to reduce the volume of solid refuse (90%) and to produce heat, steam and electricity. Waste incineration plants are installed in large cities to dispose off urban refuse and generate energy. It constitutes a furnace with adequate supply of air to ensure complete combustion up to a capacity of 1000 tonnes/day.

6.4 Biomass Energy Conversion Technologies

Thermo-chemical Conversion is the process of decomposing biomass at various combinations of pressure and temperature to obtain biofuel in solid, liquid and gaseous form and the process is referred respectively as, **i. Pyrolysis ii. Gasification iii. Liquefaction**

i. Pyrolysis: Biomass is heated at high pressure at temperatures 500-900°C in absence of oxygen, or partially combusted in a limited oxygen supply, to produce a hydrocarbon, rich in **gas** mixture (H_2, CO_2, CO CH_4 and lower hydrocarbons), an **oil-like** liquid and a carbon rich solid residue, **charcoal**.

The pyrolitic or 'bio-oil' produced can easily be transported and refined into a series of products similar to refining crude oil. There is no waste product, the conversion efficiency is high (82%) depending upon the feedstock used, the process temperature in reactor and the fuel air ratio during combustion.

6.4 Biomass Energy Conversion Technologies

Thermo-chemical Conversion

ii. Gasification of biomass. If the pyrolysis of organic materials is to produce combustible gases, the process is called gasification and the output is known as **producer gas**, , a mixture of H2 (15-20%), CO (10-20%), CH_4 (1-5%), CO_2 (9-12%) and N_2 (45-55%).

a. Wood, wood-type residues, waste straw and other agricultural waste is used in thermal gasification.
b. The process of gasification is carried out in **fixed or fluidized bed** gasifier. Particulate removal equipment such as fabric filters or wet scrubbers is used in cleaning the gas for use in gas fired engines or gas turbines.
c. The gas has a low calorific value of 3-5 MJ/m^3.

6.4 Biomass Energy Conversion Technologies

Thermo-chemical Conversion

iii. Liquefaction of Biomass

Process through 'fast' or 'flash' pyrolysis or methanol synthesis. Pyrolysis liquid is a good substitute for heating oil.

a. Pyrolysis of organic materials produces combustible gases, including CO, H_2 and CH_4, and other hydrocarbons.
b. If the off-gases are cooled, liquids condense producing an oil/tar residue and contaminated water.
c. Fast pyrolysis of biomass feed stocks is required to achieve high yields of liquids. It is characterized by rapid heating of biomass particles and short residence time of product vapors (0.5 to 2 s). Rapid heating requires biomass to be ground into fine particles and the insulating char layer that forms at the surface of the reacting particles must be continuously removed.

6.4 Biomass Energy Conversion Technologies

Biochemical Conversion consist of two forms,

i. Anaerobic digestion: Biogas originates from bacteria in the process of bio-degradation of organic material (biomass) under anaerobic condition in which the cattle dung, human wastes and other organic waste with high moisture content are converted into biogas through anaerobic fermentation in absence of air. Fermentation occurs in two stages by two different metabolic groups of bacteria.

- Initially the organic material is hydrolyzed into fatty acids, alcohol, sugars, H_2 and CO_2.
- Methane forming bacteria then converts the products of the first stage to CH_4 and CO_2 in the temperature range 30-55°C.

Biogas produced can be used for heating, or for operating engine driven generators to produce electricity. Fermentation occurs in a sealed tank called 'digester' where the sludge left behind is used as enriched fertilizer.

6.4 Biomass Energy Conversion Technologies

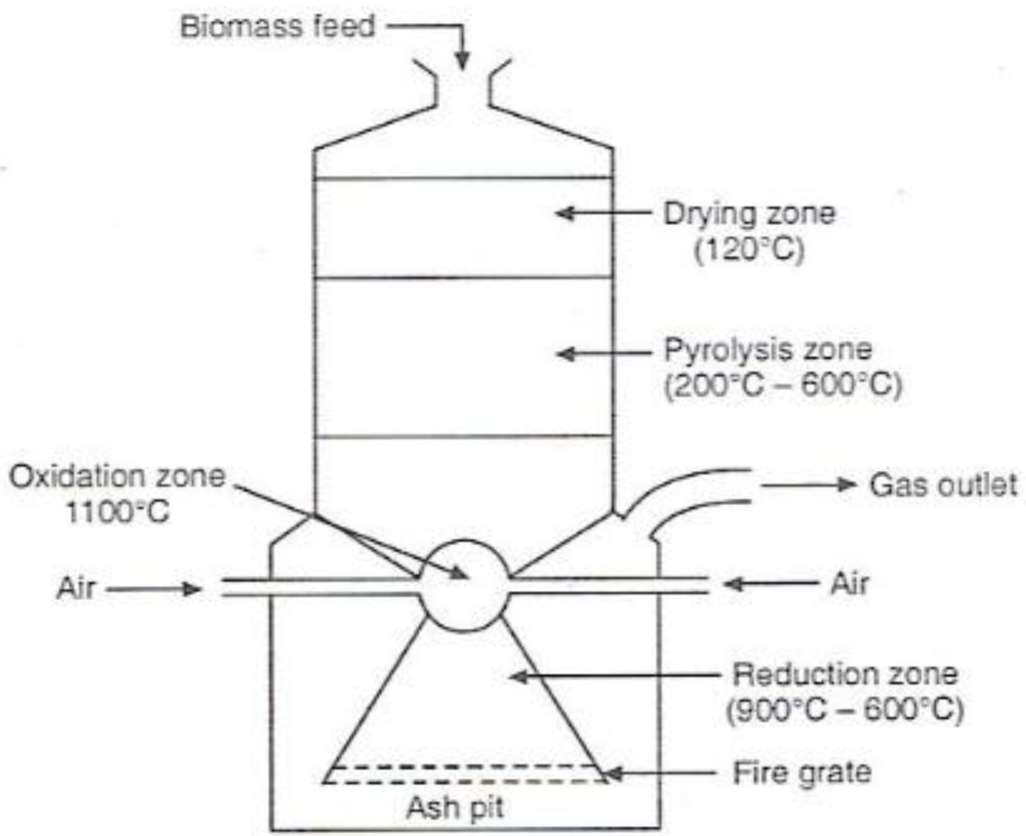
Biochemical Conversion consist of two forms,
ii. Ethanol Fermentation: Ethanol (C_2H_5OH) can be produced by decomposition of biomass containing sugar like sugarcane, cassava sweet sorghum, beet, potato, corn, grape, etc. into sugar molecules such as glucose ($C_6H_{12}0_6$) and sucrose ($C_{l2}H_{22}0_{ll}$). Ethanol fermentation involves biological conversion of sugar into ethanol and CO_2.

$$C_{12}H_{22}O_{11} + H_2O \longrightarrow 2C_6H_{12}O_6$$

$$C_6H_{12}O_6 \xrightarrow{\text{Fermentation}} 2C_2H_5OH + 2CO_2$$

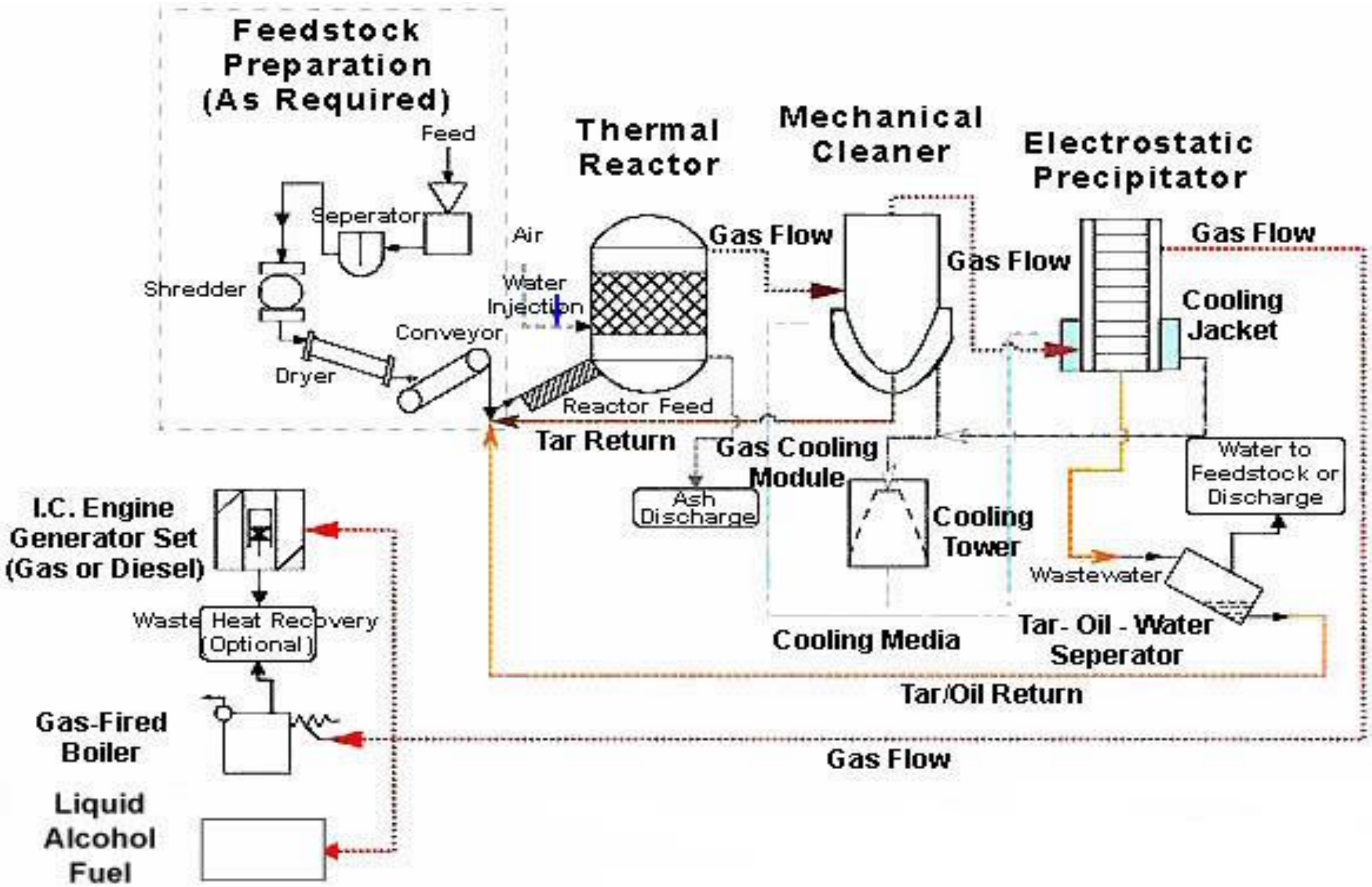
- Fermentation to create ethanol from yeast which feed on sugar, grapes, beer, or other substances.
- Ethanol mixed with water is distilled and the resulting ethanol can be used to power turbines or mixed with gasoline to power cars.
- Ethanol fermentation process produces considerable quantities of carbon dioxide.

6.5 Gasification of Biomass – Fixed bed gasifier



Downdraft gasifier.

6.5 Gasification of Biomass – Fixed bed gasifier, process



6.5 Gasification of Biomass – Fixed bed gasifier, process

Biomass gasification is thermo-chemical conversion of solid biomass into a combustible gas fuel through partial combustion with no solid carbonaceous residue. Gasifiers use wood waste and agriculture residue

Gasifiers (fixed bed type) can be of 'updraft' or 'downdraft' type depending upon the direction of the air flow but same basic reaction.

- Downdraft gasifier, fuel and air move in a co-current manner.
- Updraft gasifier, fuel and air move in a countercurrent manner.

Fuel is loaded in the reactor from the top. Fuel moves down is subjected to drying (l20°C) then pyrolysis (200-600°C) where solid char, acetic acid, methanol and water vapor are produced. Descending volatiles and char reach the oxidation zone where air is injected to complete the combustion. It is the reaction zone and the temperatures rises to 1100°C. which break down the heavier hydrocarbons and tars. As these products move downwards, they enter the 'reduction zone' (900-600°C, reaction being endothermic) where producer gas is formed by the action of CO_2 and water vapor on red hot charcoal.

6.5 Gasification of Biomass – Fixed bed gasifier, process

$$\text{Moist biomass} + \text{Heat} \longrightarrow \text{Dry biomass} + \text{Water vapour}$$

$$C + O_2 \longrightarrow CO_2 + 393.8\ \text{kJ/mole}\,; \quad \text{Combustion}$$

$$C + H_2O \longrightarrow CO + H_2 - 131.48\ \text{kJ/mole}\,; \quad \text{water gas reaction}$$

$$CO + H_2O \longrightarrow CO_2 + H_2 + 41.2\ \text{kJ/mole}\,; \quad \text{water shift reaction}$$

$$C + CO_2 \longrightarrow 2CO - 172.6\ \text{kJ/mole}$$

$$C + 2H_2O \longrightarrow CH_4 + 75.0\ \text{kJ/mole}\,; \quad \text{hydrogeneration reaction}$$

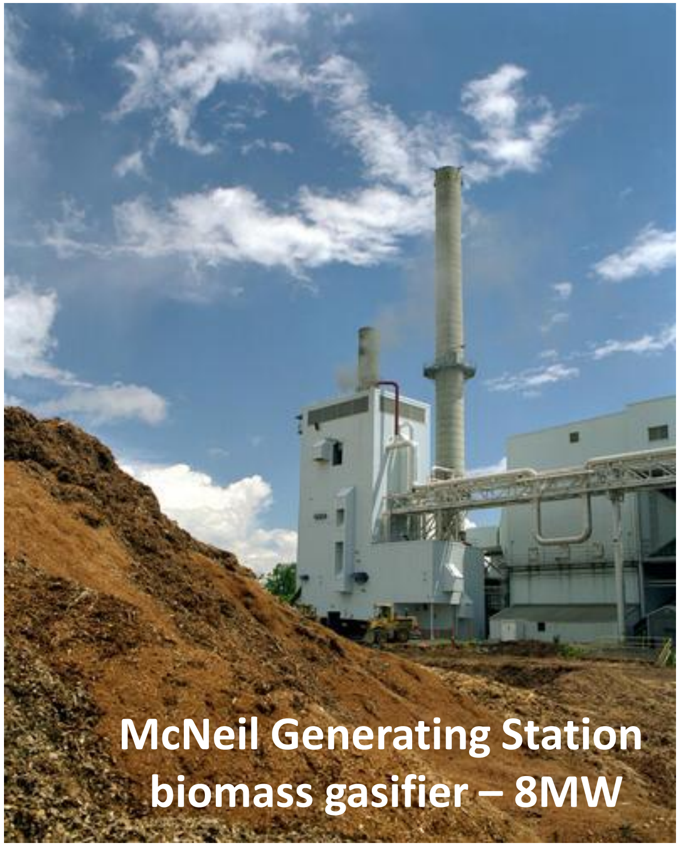
6.5 Gasification of Biomass – Fixed bed gasifier, process

- Producer gas formed in the reduction zone contains combustible products like CO, H2 and CH_4. Hot gas flowing out is usually polluted with soot, tar and vapor. For purifying, it is passed through coolers, tar is removed by condensation, whereas soot and ash are removed by centrifugal separation.
- Clean producer gas provides the process heat to operate stoves (for cooking), boilers, driers, ovens and furnaces. The major application is in area of electric power generation either through dual-fuel IC engines (where diesel oil is replaced to an extent of 60%-80%), or through 100% gas-fired spark ignition engines.
- Fixed bed gasifiers can attain efficiency up to 75% for conversion of solid biomass to gaseous fuel. However, the performance depends on fuel size and moisture content, volatiles and ash content.

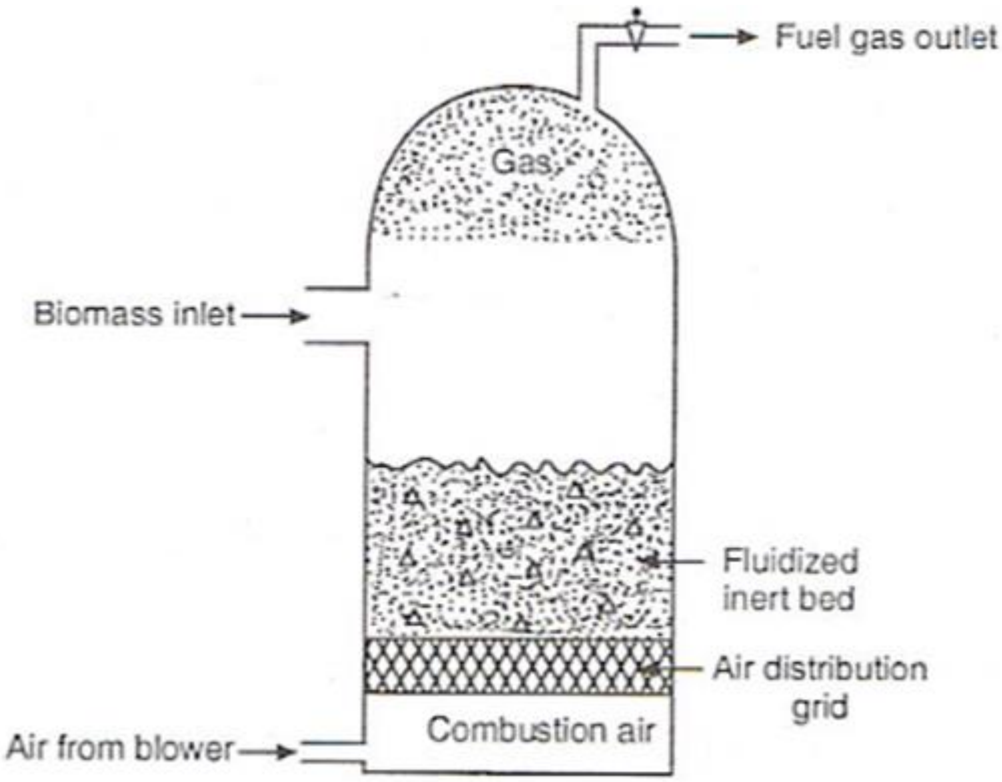
6.5 Gasification of Biomass – Fixed bed gasifier, process

Wood Chips in Biomass Gasifier

- 200 tons of wood chips daily
- Forest thinning; wood pallets
- Converted to gas at ~1010^{o}C
- Combined cycle gas turbine
- 8MW power output



6.5 Gasification of Biomass – Fluidized Bed Gasifier



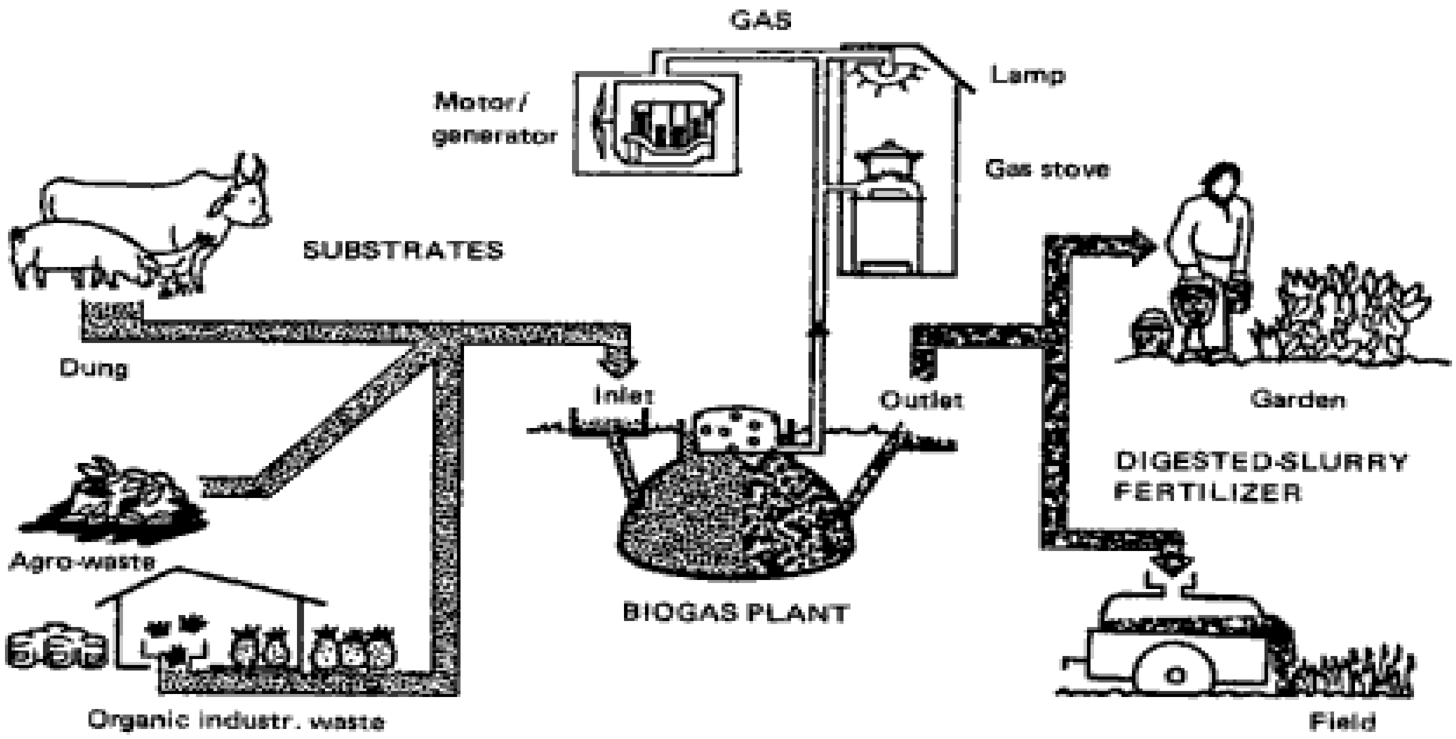
Fluidized bed gasifier.

6.5 Gasification of Biomass – Fluidized Bed Gasifier, process

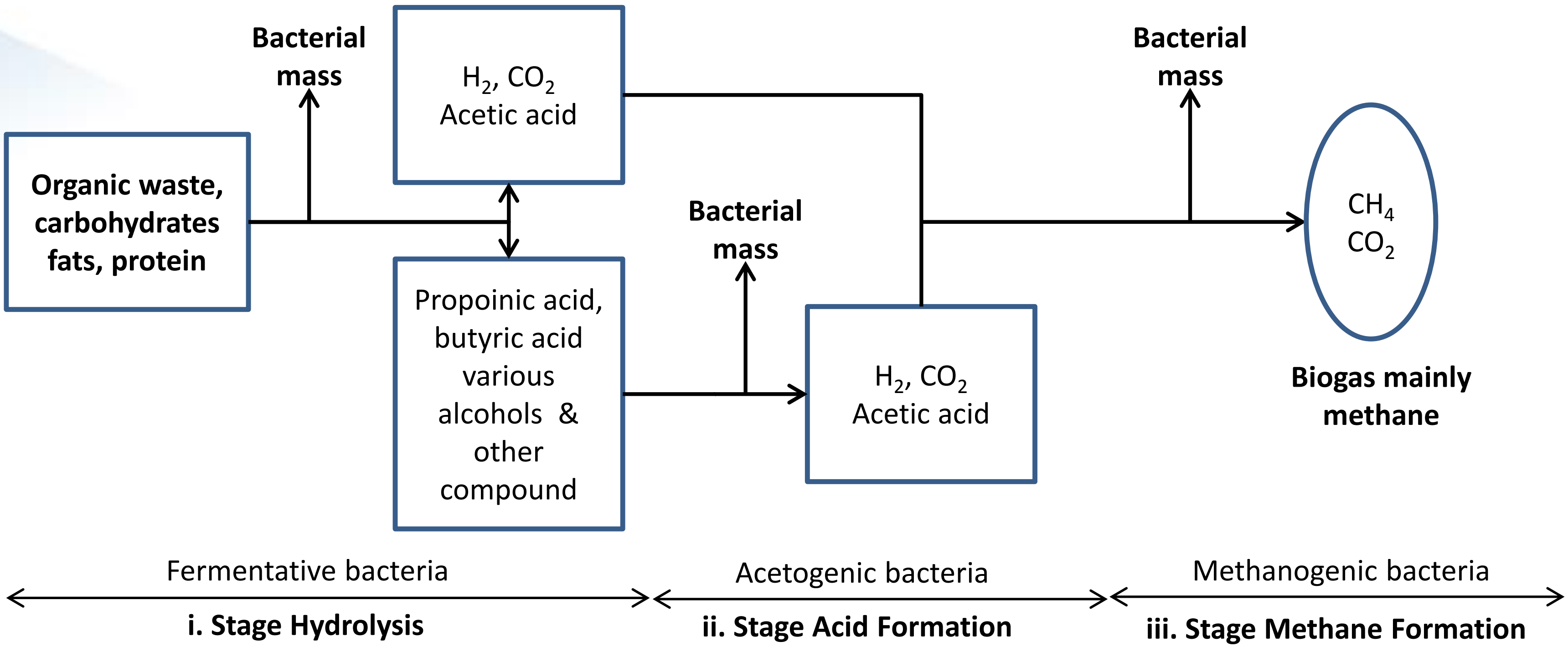
- Fluidized Bed Combustion (FBC) is a better option to use than the problematic biomass of farm residues like rice husk, bagasse, industrial waste such as saw dust and pulping effluents, sewage sludge etc.
- Hot bed of inert solid particles of sand or crushed refractory support on a fine mesh or grid. The bed material is fluidized by an upward current of air, bubbling through the bed and the particles attain a state of high turbulence, and the bed exhibits fluid like properties.
- Uniform temperature 850-1050^{o}C is maintained. The fluidized bed in turbulence provides a higher conversion efficiency at low operating temperatures to gasify low-grade fuels.
- Bed material is pre-heated to ignition temperature of the fuel, biomass is then injected causing rapid oxidation and gasification. Fuel gas so produced contains impurities, dust, char particles and tar. It needs conditioning and cleaning for utilization as an engine fuel.

6.6 Biogas from Biomass Anaerobic Digestion – Cycle

Biogas plant converts cattle dung and other organic matter into inflammable renewable biogas, safe fuel for cooking and lighting. The left-over digested slurry is used as enriched manure in agriculture lands.



6.6 Biogas from Biomass Anaerobic Digestion – Process



Anaerobic digestion process

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6.6 Biogas from Biomass Anaerobic Digestion – Process

Biogas is produced from wet biomass through a biological conversion process that involves bacterial breakdown of organic matter by micro-organisms to produce CH_4, CO_2 and H_20. The process is known as 'anaerobic digestion' which proceeds in three steps, **i) Hydrolysis ii) Acid formation iii) Methane formation**

i) **Hydrolysis:** Organic waste of animal and plants contains carbohydrates in the form of cellulose, hemicellulose and lignin. A group of anaerobic micro-organisms (celluolytic bacteria/hydrobytic bacteria) breaks down complex organic material into simple and soluble organic components, primarily acetates. The rate of hydrolysis depends on bacterial concentration, quality of substrate, pH (between 6 and 7) and temperature (30°C-40°C) of digester contents.

6.6 Biogas from Biomass Anaerobic Digestion – Process

ii) **Acid formation:** Decomposed simple organic material is acted upon by acetogenic bacteria and converted into simple acetic acid. Acid-producing bacteria, involved in the second step, convert the intermediates of fermenting bacteria into acetic acid (CH_3COOH), hydrogen (H_2) and carbon dioxide (CO_2). They reduce the compounds with a low molecular weight into alcohols, organic acids, amino acids, carbon dioxide, hydrogen sulfide and traces of methane.

iii) **Methane formation:** the bacteria decompose compounds with a low molecular weight. Acetic acid so formed becomes the substrate strictly for anaerobic methanogenic bacteria, which ferment acetic acid to methane and CO_2. Gas production is stable for pH between 6.6 and 7.6. Biogas consists of CH_4, CO_2 and traces of other gases. such as H_2, CO, N_2, O_2 and H_2S. Gas mixture is saturated with water vapor. The methane content of biogas is about 60% which provides a high calorific value to find use in cooking, lighting and power generation.

6.6 Biogas from Biomass Anaerobic Digestion – 8 Affecting Factors

i. **Solid-to-water ratio:** Cattle dung contains about 18% solid matter and the remaining 82% is water. Anaerobic fermentation proceeds at a faster rate if the slurry contains about 9% solid matter. Digester feed is prepared by mixing water in the ratio 1:1 by weight to reduce the solid content. To increase the solid matter, crop residues and weed plants may be mixed with the feed stock.

ii. **Volumetric loading rate:** It is expressed as the quantity of organic waste fed into the digester per day per unit volume. In general, the municipal sewage treatment plants operate at a loading rate of 1.0 to 1.5 $kg/m^3/day$. Overloading and under-loading reduce the biogas production with a fixed retention time. For a desired retention period of 30 days, a quantity equal to 1/30th of digester volume needs to be fed daily.

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6.6 Biogas from Biomass Anaerobic Digestion – 8 Affecting Factors

iii. **Temperature** affects bacterial activity; methane formation is optimum in the temperature range 35°-3S°C. Biogas production decreases below 20°C and stops at 8°C. In cold regions a solar canopy is built over the biogas plants to maintain the desired temperature.

In hot regions, another micro-organism called 'thermophilic' is utilized for anaerobic fermentation in the temperature range 55°C-60°C. Gas production rises with the increase in average ambient air temperature. As the temperature increases, the total retention period decreases and vice-versa. However, the total gas production remains practically the same.

iv. **Seeding:** Cattle dung contains both acid forming bacteria and methane forming bacteria. Acid forming bacteria multiply fast, while the methane forming bacteria grow slowly. To start and accelerate fermentation, seeding of methane forming bacteria is required. A small quantity of digested slurry rich in methane-forming bacteria is added to freshly charged digester.

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6.6 Biogas from Biomass Anaerobic Digestion – 8 Affecting Factors

v. **pH value** indicates the concentration of hydrogen ions. Micro-organisms are sensitive to pH of the digested slurry. For optimum biogas production, pH can be varied between 6.5-7.5. At pH of 6.2, acid conditions prevail which restrain the growth of methanogenic bacteria. Control on pH should be exercised by adding alkali when it drops below 6.6.

vi. **C:N Ratio:** Methanogenic bacteria needs carbon and nitrogen for its survival. Carbon is required for energy while nitrogen for building cell protein. The consumption of carbon is 30 to 35 times faster than that of nitrogen. A favorable ratio of C:N can be taken as 30:1. Any deviation from this ratio lowers the biogas production. A proper balance of C:N ratio is maintained either by adding saw dust having a high C:N ratio or by poultry waste having a low C:N ratio.

6.6 Biogas from Biomass Anaerobic Digestion – 8 Affecting Factors

vii. **Retention Time** is the period for which the biomass slurry is retained inside the digester. It refers to the volume of digester divided by the volume of slurry added per day. Thus, a 120 liter digester which is fed at 5 liters per day would have a retention time of 24 days. It is optimized to achieve 80% complete digestion considering ambient temperature.

viii. **Stirring** the contents of the digester is necessary to mix the bacteria rich fluid in the slurry. It provides better contact between micro-organism and the substrate and uniformly distributes the volatile solids in the slurry. Gas production improves by 15% over the full cycle.

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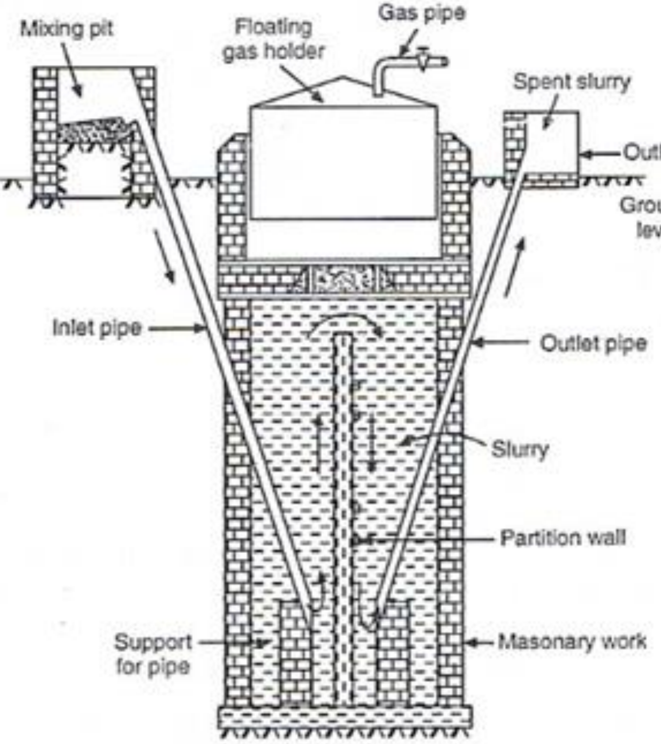
6.6 Biogas from Biomass Anaerobic Digestion – Plants, batch type

- Floating drum (constant pressure) type
- Fixed dome (constant volume) type

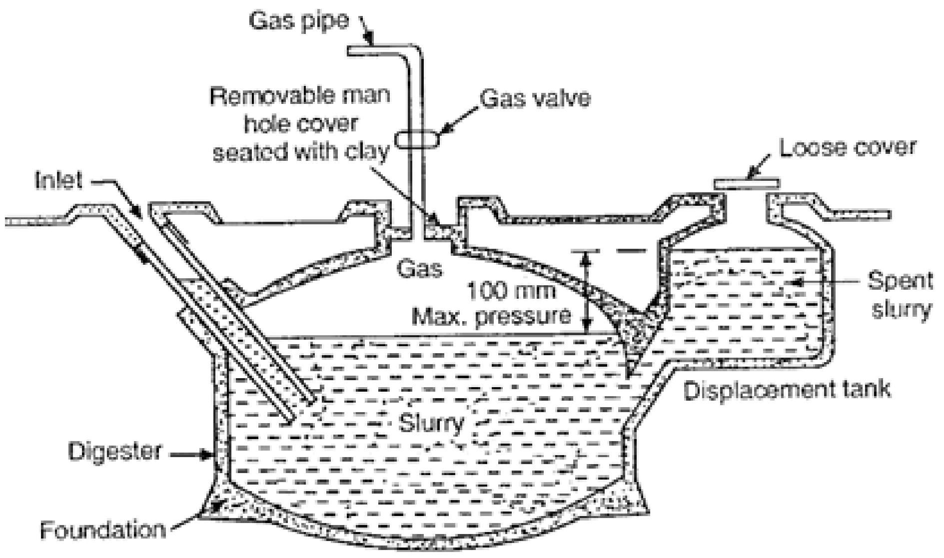
Floating Drum Biogas Plant is a popular model developed by Khadi Village Industries Commission (KVIC) was standardized in 1961. It comprises an underground cylindrical masonry digester having an inlet pipe for feeding animal dung slurry and an outlet pipe for sludge. There is a steel dome for gas collection' which floats over the slurry. It moves up and down depending upon accumulation and discharge of gas guided by the dome guide shaft.



A partition wall is provided in the digester to improve circulation, necessary for fermentation. The floating gas holder builds gas pressure of about 10 cm of water column, sufficient to supply gas up to 100 m. Gas pressure also forces out the spent slurry through a sludge pipe.

6.6 Biogas from Biomass Anaerobic Digestion – Plants, batch type

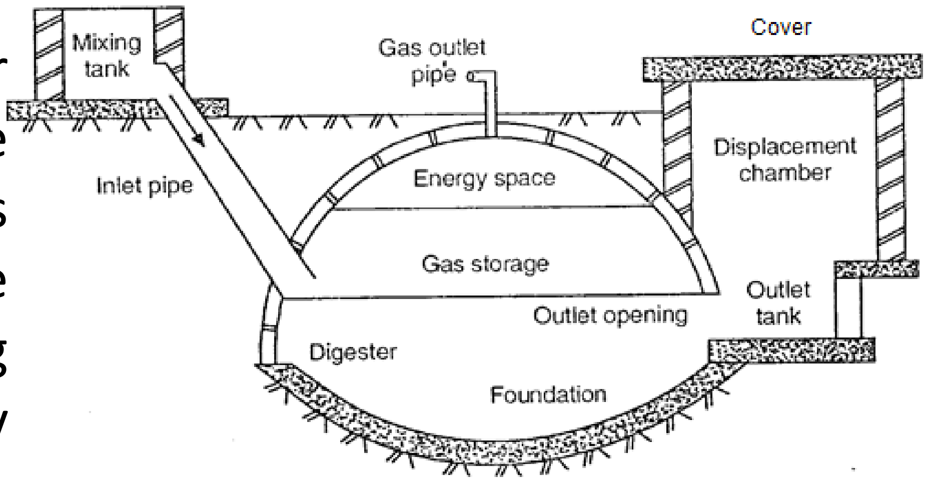
Fixed Dome Biogas Plant (Janta) is an economical design where the digester is combined with a dome-shaped gas holder. It is known as Janata model; the composite unit is made of brick and cement masonry having no moving parts, thus ensuring no wear and tear and longer working life. When gas is produced, the



pressure in the dome changes from 0 to 100 cm of water column. It regulates gas distribution and outflow of spent slurry.

6.6 Biogas from Biomass Anaerobic Digestion – Plants, batch type

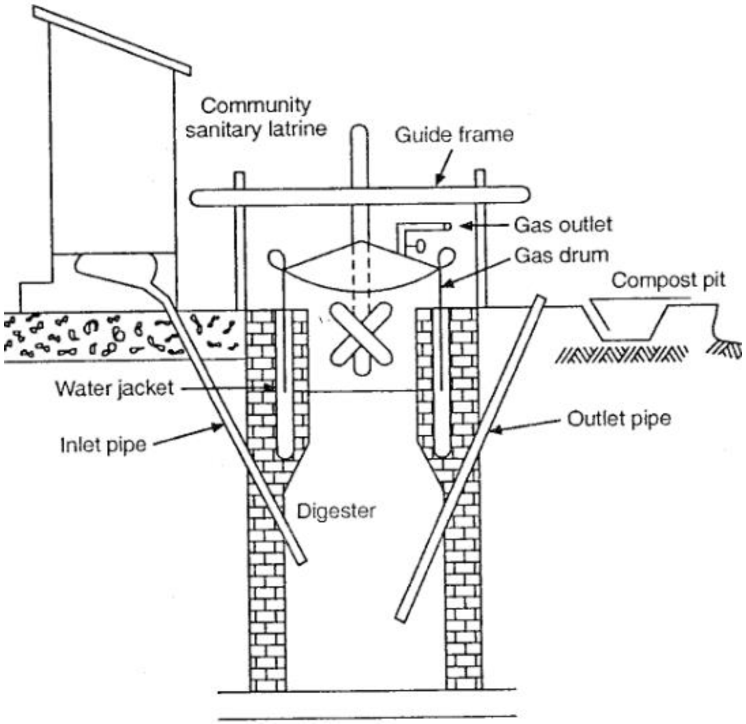
Deenbandhu Biogas Plant



developed by AFPRO (Action For Food Production) with the objective to extend the biogas technology to places where the availability of bricks is a limiting factor and bamboo is easily available. Its cost is reduced as the surface area is minimized by joining segments of two different diameter spheres at their bases. It requires less space being mainly underground and 30% economical compared to the Janta biogas plant. After intensive trial and testing it has been approved by MNRE for family size installation.

6.6 Biogas from Biomass Anaerobic Digestion – Plants, batch type

Community Night-soil Based Biogas Plants have been developed to facilitate sanitary treatment of human waste at community and institutional level. This installation constitutes a floating metal drum with a water jacket. It is linked with community toilets and serves a population of about 1000 persons to provide fuel for cooking, operate dual-fuel engines for water supply and generate electric power.



6.6 Biogas from Biomass Anaerobic Digestion

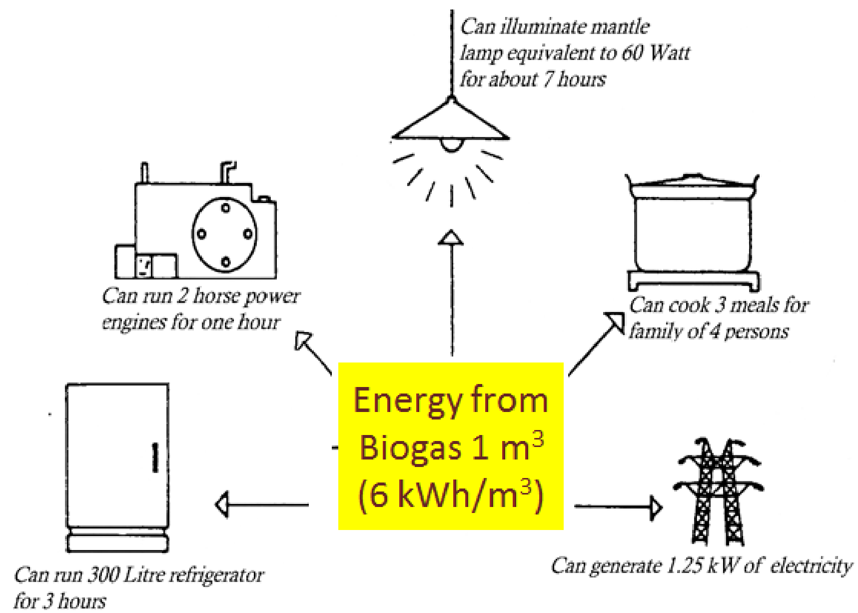
Properties

- Methane (CH_4): 40-70 vol.%
- Carbon dioxide (CO_2): 30-60 vol.%
- Other gases: 1-5 vol.% including
  - Hydrogen (H_2): 0-1 vol.%
  - Hydrogen sulfide (H_2S): 0-3 vol.%
- Calorific value about 6 kWh/m^3

Applications

Biogas is a lean gas that can be used like other fuel gas for household and industrial purposes, especially for

- Gas cookers/stoves
- Biogas lamps
- Radiant heaters
- Incubators
- Refrigerators
- Engines



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6.6 Biogas from Biomass Anaerobic Digestion – Conversion yield

Raw material	Production rate	Gas yield m^3 per kg dry matter	Retention time (days) at 35 °C,
Cow dung	10-15 kg/day/head	0.34	50
Poultry manure	0.06 kg/day/head	0.46 – 0.58	20
Sheep manure	0.75 kg/day/head	0.37 – 0.61	-
Night soil	0.75/kg/day/head	0.38	30
Rice husk	1-1.3 tons/ha/year	5.67	33
Algae	40 tons/ha/year	0.32	-
Water hyacinth	60 tons/ha/year	0.42	46

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6.6 Biogas from Biomass Anaerobic Digestion – Equivalence

Biogas Production

- 1 kg cattle dung 40 liters biogas
- 1 kg buffalo dung 30 liter biogas
- 1 kg pig dung 60 liter biogas
- 1 kg chicken droppings 70 liter biogas
- Cattle, buffalo and chicken: 15 liters biogas/day/ kg live weight
- Pigs, humans: 30 liters biogas per day/kg weight

Energy Equivalence of 1 m^3 of Biogas

- Wood (approx. 4.5 kWh/kg) 1.3 kg
- Diesel, Kerosene (approx. 12 kWh/kg) 0.5 kg
- Cow dung (approx. 5 kWh/kg dry matter) 1.2 kg
- Plant residues (approx. 4.5 kWh/kg dry matter) 1.3 kg
- Hard coal (approx. 8.5 kWh/kg) 0.7 kg
- Propane (approx. 25 kWh/m^3) 0.24 m^3

6.6 Biogas from Biomass Anaerobic Digestion – Benefits

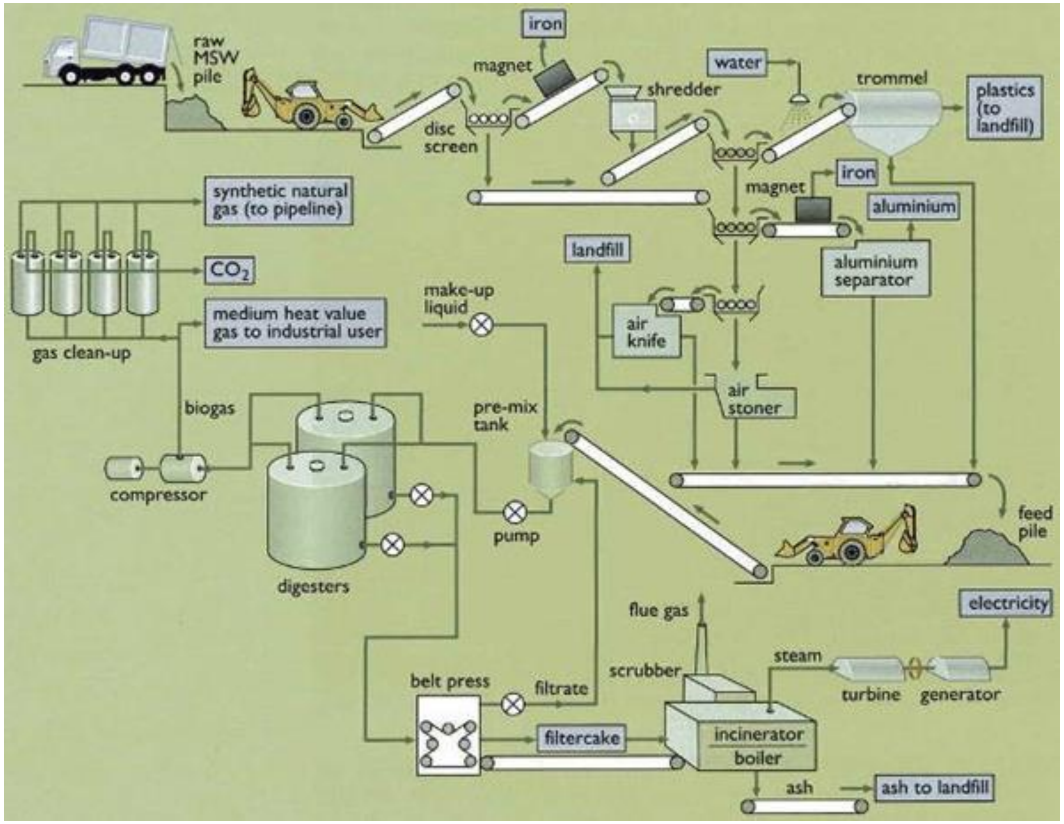
Advantages

- Biomass is a renewable resource and is readily available
- Use of biomass as fuel reduces the dependence on fossil fuels
- Adds secondary value to agricultural crop
- Growing biomass crops produce oxygen and consume carbon dioxide

Disadvantages

- Energy comes mainly from plants which must be harvested
- Land used to grow biomass materials is needed for other uses
- Biomass crops can deplete soil of nutrients
- Burning plants releases carbon dioxide
- Bi products of biomass contain less energy per gallon than gasoline
- Research needed to make more cost efficient

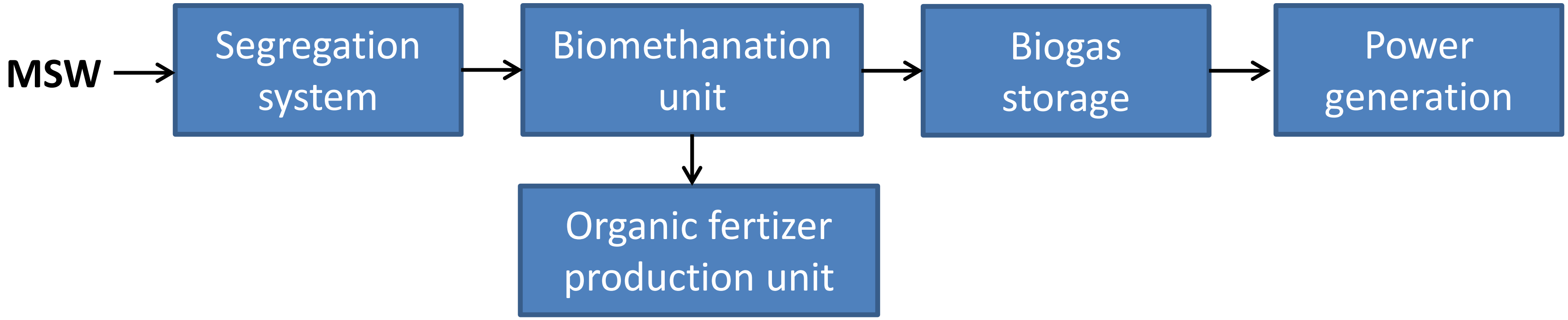
6.7 Energy Recovery From Urban Waste



Integrated waste management system includes sorting, anaerobic digestion and fuel for power generation

6.7 Energy Recovery From Urban Waste

Urban waste represents a large source of substrate for energy production. It contains dry waste of household mixed with kitchen scrap. A segregation system in which inorganics (metal, glass, grit) and plastic material are sorted out, keeping items which are largely cellulosic with fats and proteins, i.e. are digestible. The collected MSW is converted into dry volatile solids which produce biogas and the spent slurry in the digester is used as organic fertilizer. The biogas so produced is fed into biogas engines to generate electricity.



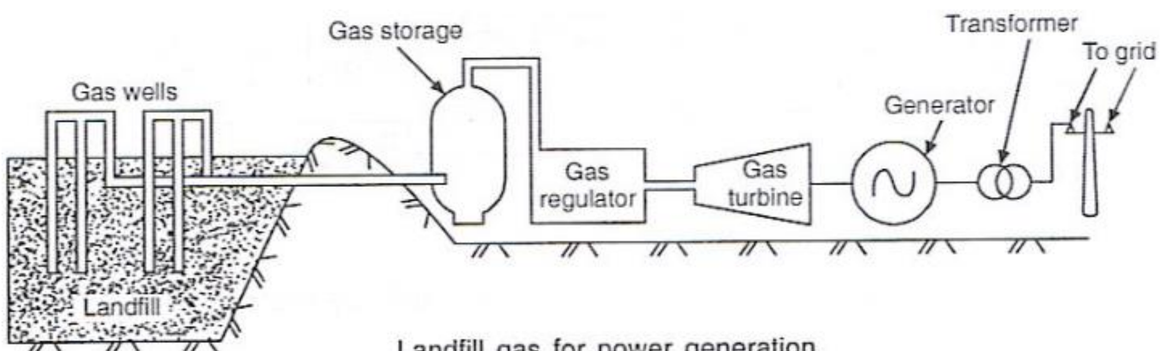
6.7 Energy Recovery From Urban Waste

Rapid urbanization and industrialization have resulted in the creation of enormous quantities of wastes in urban and industrial areas. Study of waste to energy can be divided into:

- **Municipal Solid Waste (MSW)** 7 million tonnes of municipal solid waste is disposed of in landfill in Peninsular Malaysia per year (2005).
- **Municipal Liquid Waste Sewage** in cities is a source of biomass energy and in Malaysia about 3000 million cubic meters of liquid waste needs proper disposal every year.
- **Urban Industrial Waste** Industries produce a large number of residues as by-products that can be used as biomass energy sources. Food industry includes pealing and scraps from fruit and vegetables. Wine making produces distillery waste water (spent wash). Paper and pulp making effluent is 'black liquor' which is a source for bio-oil. Starch and glucose industry wastes are maize husk, tapioca fiber and stems. Rice mills provide large volumes of rice husk. Sugar mills waste is a source of huge quantity of bagasse.

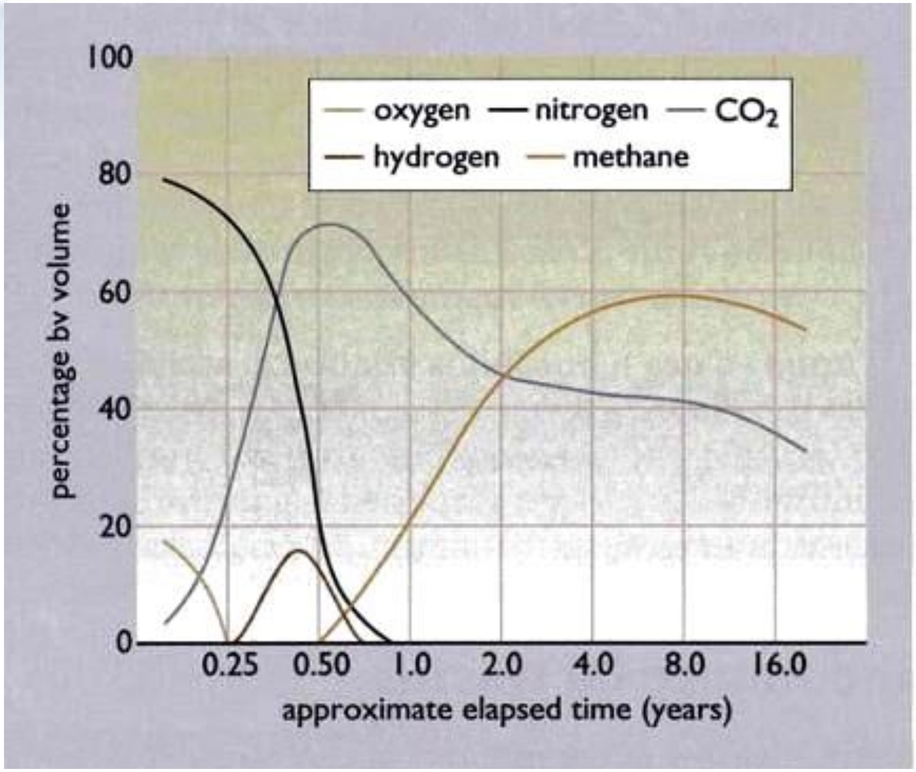
6.7 Energy Recovery From Urban Waste – Sanitary landfill

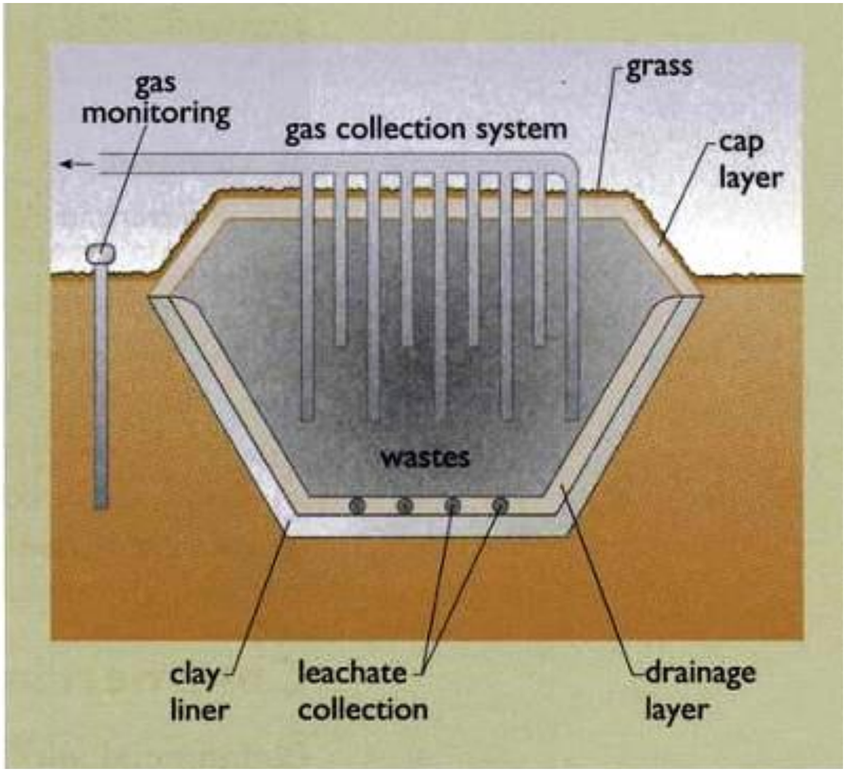
Recycling of city garbage and MSW poses a serious problem due to its enormous quantity. Its sanitary disposal through landfill is a successful method elsewhere. A large pit at the outskirt is prepared and a pipe system for gas collection is laid down before the waste is filled. For anaerobic digestion, MSW is buried, eventually the gas produced does not escape into the atmosphere. After 2-3 months, depending on the climate, landfill gas can be extracted by inserting perforated pipes into the landfill. The gas flows through pipes under normal pressure. The gas has calorific value of 4500 kcal/m^3, can be used for direct heating, cooking and generate power. The world largest landfill gas plants in California producing 46 MWe of electricity.



Landfill gas for power generation.

6.7 Energy Recovery From Urban Waste – Sanitary landfill





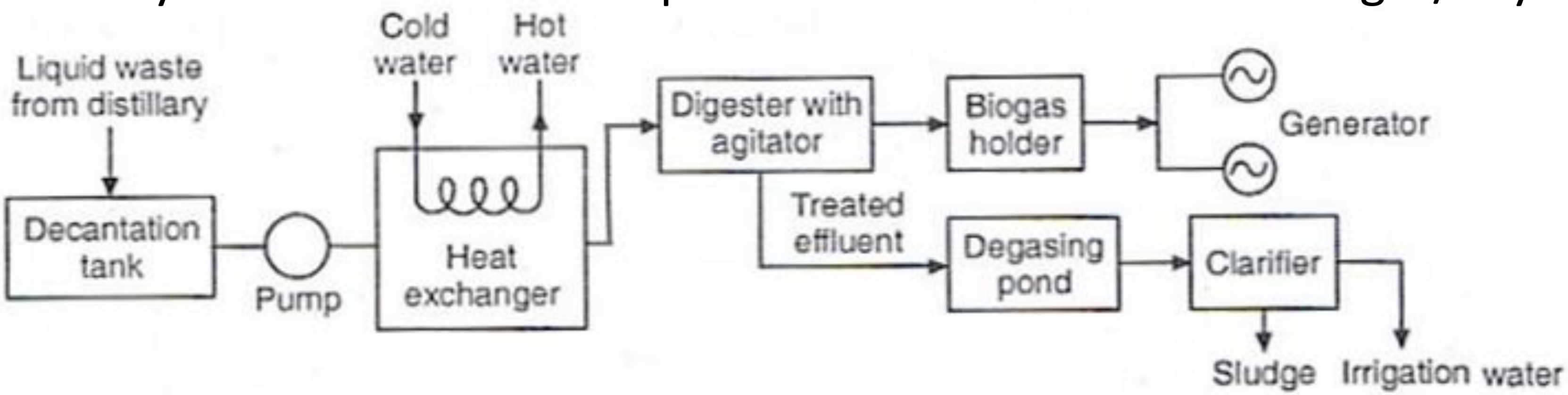
6.7 Energy Recovery From Urban Waste – Liquid Waste

Sewage is a source of biomass energy similar to other animal wastes. Energy can be extracted from sewage, using anaerobic digestion to produce biogas for electricity generation.

Pulp and Paper Mill Black Liquor Waste in the pulp and paper industry consumes a large amount of energy and water in its various unit operations. The waste discharged water contains compounds from wood and raw material, useful for recovery of energy.

6.7 Energy Recovery From Urban Waste – Liquid Waste

Distillery liquid wastes carry rich raw material for producing biogas. Liquid effluent from a distillery is collected in a tank where the suspended solids settle down. Decanted effluent which contains fermented molasses is pumped into a digester through a heat exchanger. Effluent is cooled to maintain the digester temperature at 36-38°C, allowed to be digested anaerobically for 12-15 days, during which biogas is produced and accumulated in a gas holder and stored under pressure. A distillery waste is sufficient to produce about 21000 m^3 of biogas/day.



6.7 Energy Recovery From Urban Waste – Cogeneration

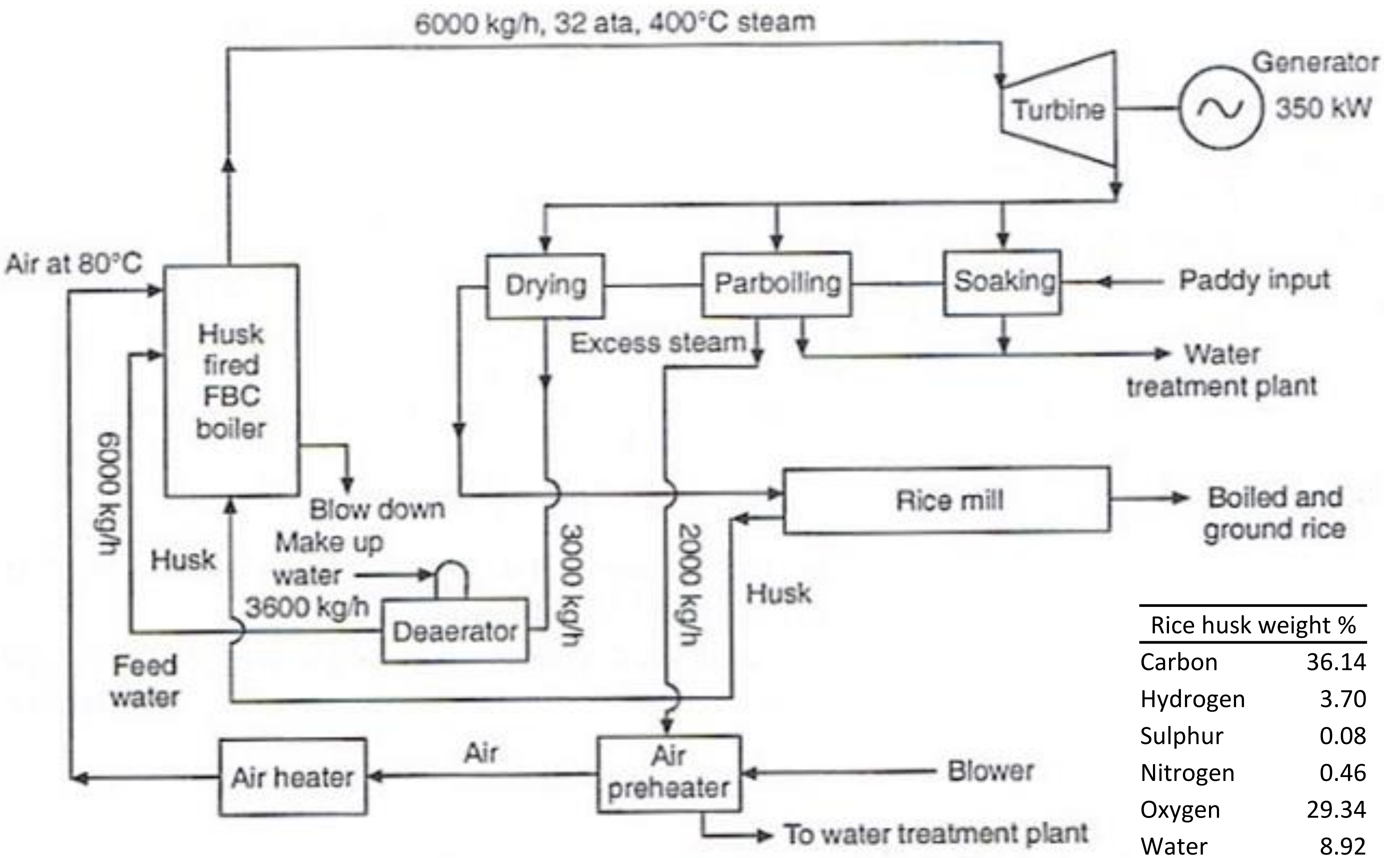
Cogeneration is the sequential generation of two different forms of useful energy from a single primary energy source, typically mechanical energy and thermal energy. Mechanical energy is mainly to drive an alternator for electrical generation. Thermal energy can be used for direct process applications or for production of steam.

- Sugar industry uses bagasse-based cogeneration for achieving self-sufficiency in steam and electricity. Cogeneration cleans up the environment, generates power for in-house consumption and earns additional revenue from the sale of surplus electricity.
- The main equipment required for bagasse-based cogeneration projects comprises high temperature/pressure bagasse-fired boilers, a steam turbine and a grid-interfacing system.
- Steam generation temperature/pressure if increased from 400^0C/32 bar to 485°C/66 bar, more than 80 kWh of additional electricity is generated from each tonne of cane crushed.

6.7 Energy Recovery From Urban Waste – Cogeneration, rice mill

- Rice production from padi has undergone changes from traditional soaking and drying to modern method of parboiling at higher temperature. It results in increased productivity of husk and quality rice. Husk produced is effectively utilized for steam production, which is used for both process and power generation.
- The calorific value of rice husk varies from 2637 to 3355 kcal/kg depending on variety. Rice husk is difficult to handle because of its silica-cellulose structure. Hence, the 'Fluidized Bed Combustion' (FBC) boiler is used to ensure complete combustion as firing is balanced between buoyancy and gravitational force. Steam from the boiler is fed to the back pressure turbine coupled with an electric generator.

6.7 Energy Recovery From Urban Waste – Cogeneration, rice mill



Cogeneration plant in a rice mill (50 tonnes capacity).

Rice husk weight %	
Carbon	36.14
Hydrogen	3.70
Sulphur	0.08
Nitrogen	0.46
Oxygen	29.34
Water	8.92
Ash	21.36

6.7 Energy Recovery From Urban Waste – Cogeneration, rice mill

Steam pressure after expanding in turbine is utilized for three processes

- Soaking
- Parboiling and
- Drying. Pressurized deaerator supplies water to the boiler. Make-up water is added into deaerator besides the hot water received from turbine exhaust after the drying process. Excess steam from parboiling process is fed into an air preheater and the hot air is further heated to maintain 80°C before feeding into the boiler.

Thus, a 50 tonne/batch capacity rice mill generates 350 kW from rice husk which is normally dumped and wasted. Cogeneration has a potential of 10,000 MW (India) from rice mills, distilleries, paper mills, petrochemicals and fertilizer plants.

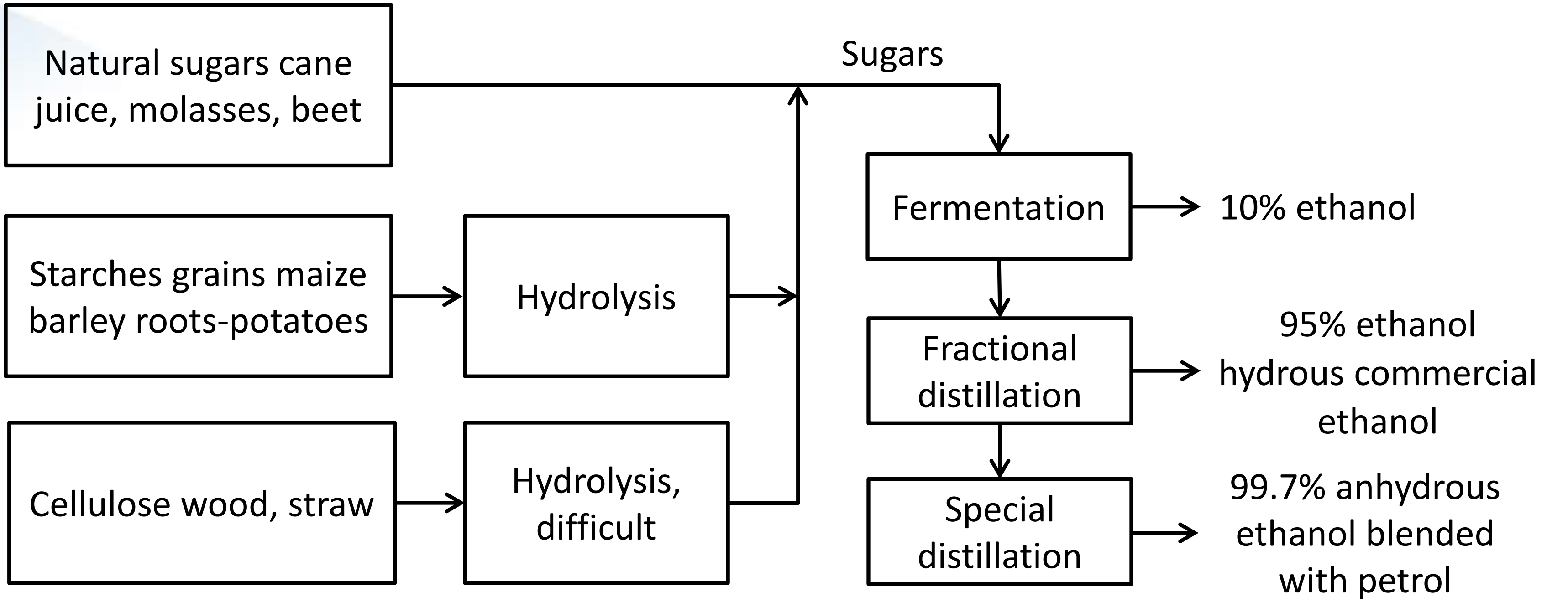
6.8 Ethanol from Biomass

Ethanol is ethyl alcohol (C_2H_sOH), a colorless flammable liquid. It is a renewable energy source which can substitute petroleum products. Ethanol can be produced from a variety of biomass materials, containing sugar, starch and cellulose. The best-known feedstock under three categories are:

i. **Sugars:** sugarcane, sugar beet, sweet sorghum, grapes, molasses
ii. **Starches:** maize, wheat, barley, potatoes, cassava, rice
iii. **Cellulose:** wood, straw, stems of grasses, bamboo, sugarcane bagasse.

6.8 Ethanol from Biomass

Ethanol from three biomass resources



NB: Molasses is a residue of sugar factory from which balance 40-47% sugar cannot be obtained conventionally. But it can be fermented with a yeast *(saccharomyces cerevisiac)* to produce alcohol.

6.8 Ethanol from Biomass

Ethanol from three biomass resources, process

i. **Sugar** rich crops, especially the sugarcane which contains the valuable raw material for crystal sugar, and by-products from sugar mills are molasses that contain 50 to 55% sugar content. It is monosaccharide form of sugar which refers to the glucose ($C_6H_{12}0_6$) and fructose ($C_6H_{l2}0_6$) content in cane. Sweet fruits like ripe grape, mangoes, etc. contain glucose in natural form. Juice containing sugar can easily be fermented into ethanol by adding yeast. Yeasts are microorganisms called *Saccharomyees Cerevisiae* which produce enzymes, that convert sugar to ethanol.

$$C_6H_{12}O_6 \xrightarrow{\text{Yeast}} 2C_2H_5OH + 2CO_2$$

Molasses also contain fermentable sugar comprising glucose, sucrose and fructose which are converted into alcohol.

6.8 Ethanol from Biomass

Ethanol from three biomass resources, process

ii. **Starch** crops constitute grains which are rich in carbohydrates. Starch $(C_6H_{10}0_5)_n$ has a complicated structure having many glucose molecules linked together in a long chain called disaccharide forms of sugar. It requires starch chain to be converted into sugar prior to fermentation. Yeast culture cannot convert starch into fermentable sugars. Conversion can be done either by hydrolysis of starch with dilute H_2S0_4 or through enzymatic method. Starch is converted into maltose and glucose prior to initiating ethanol production.

$$2(C_6H_{10}O_5)_n + nH_2O \xrightarrow{\text{Hydrolysis}} nC_{12}H_{22}O_{11}$$

(Starch) (Maltose)

$$C_{12}H_{22}O_{11} + H_2O \longrightarrow 2C_6H_{12}O_6$$

$$C_6H_{12}O_6 \xrightarrow{\text{Fermentation}} 2C_2H_5OH + 2CO_2$$

6.8 Ethanol from Biomass

Ethanol from three biomass resources, process

iii. **Cellulose** contained in wood, grasses and crop residue contain a long chain of sugars and lignin available in plants which hinders hydrolysis to sugars. This complex material is called 'polysaccharides' and not as easy as that of a starch to simple sugars.

The conversion of cellulosic material is carried out by special hydrolysis with dilute H_2S0_4 at high temperature I80°-200°C, which causes the product sugar to decompose into glucose and finally ethanol by adjusting acid concentration, operating temperature and reaction time.

$$(C_6H_{10}O_5)_n + nH_2O \longrightarrow nC_6H_{12}O_6$$

(Cellulose) (Glucose)

$$C_6H_{12}O_6 \xrightarrow{\text{Fermentation}} 2C_2H_5OH + 2CO_2$$

(Cellulose) (Ethanol)

6.8 Ethanol from Biomass

Ethanol from three biomass resources, process

Ethanol production (liter)	Per Tonne	Annual Per Ha
Sugar beet	90-100	3800-4800
Sugarcane	60-80	3500-7000
Sweet sorghum	80-90	2500-3500
Potato	100-120	2200-3300
Maize	360-400	1500-3000
Cassava	175-190	2200-2300
Wheat	370-420	800-2000
Barley	310-350	700-1300
Soft wood (hydraulic agent dilute acid)	190-220	1800-3100
Hard wood (dilute acid)	160-180	1500-2500
Straw (dilute acid)	140-160	200-500

6.8 Ethanol from Biomass – Brazil's PRO-ALCOHOL Program

1. More than 90% new cars use ethanol produced from sugar residues.
2. The world's largest commercial biomass system.
3. Established 1975, when price of oil was high and sugar was low
4. In first 25 years avoid fossil fuel imports and saved $40 billion directly reduced interest on foreign debt.
5. Production reached 15 billion liters per year at times.
6. Most vehicles currently run 011 gasohol with 26% ethanol content
7. Estimates in 1999, the program was reducing annual greenhouse gas emissions by almost 13 tonnes of carbon.
8. Economics of ethanol production are very uncertain.
9. Viability depends critically on world prices of sugar and crude oil, both of which have varied widely and often rapidly last 30 years.

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6.9 Biodiesel

- Biodiesel is a liquid fuel produced from non-edible oil seeds such as Jatropha which can be grown on wasteland.
- Oil extracted from the seeds has high viscosity (20 times that of diesel) which causes serious lubrication, oil contamination and injector choking problems.
- The problems are solved through trans-esterification, a process where the raw vegetables oils are treated with alcohol (methanol or ethanol with a catalyst) to form methyl or ethyl esters. The monoesters produced by trans-esterifying vegetable oil are called 'biodiesel' with low fuel viscosity, high octane and heating value.
- Endurance tests show that biodiesel can be adopted as an alternative fuel for existing diesel engines without modifications.
- In EU and USA, edible vegetable oils like sunflower, groundnut, soya bean and cotton seed, etc. are used to produce biodiesel while Malaysia is endowed palm oil.

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6.9 Biodiesel

- Biodiesel is the name of diesel fuel made from vegetable oil or animal fats. The concept dates back to 1885, when Dr. Rudoff Diesel developed the first diesel engine to run on vegetable oil. In recent past the use of bio oil as an alternative renewable fuel to compete with petroleum was proposed during 1980.
- The advantages of biodiesel as engine fuel are:
  i. biodegradable and produces 80% less CO_2 and 100% less $S0_2$
  ii. renewable,
  iii. higher octane number,
  iv. can be used as neat fuel (100% biodiesel) or mixed in any ratio with petro-diesel, and
  v. has a higher flash point making it safe to transport.

6.9 Biodiesel – From Jatropa

- Jatropa curcas drought resistant perennial shrub with 4-5 m height is ideally suited to green up the wastelands in arid areas.
- Commercial seed production commences from the 6th year onwards with yield of 6000 kg/ha under rain-fed conditions and 12000 kg/ha in irrigated areas.
- The average oil production is 0.25 kg oil/kg seed. The o1 cake is used as organic fertilizer.
- Research have confirmed the use of Jatropa curcas seed oil as promising substitutes for diesel but presently is uneconomical.
- Oil is extracted from Jatropa seeds in an oil press. It is treated with methanol (CH_30H) to produce three methyl ester molecules and one glycerol molecule. Alkalis like NaOH or KOH are used to catalyze the reaction rapidly from which glycerol is separated and methyl ester is obtained as biodiesel.

6.9 Biodiesel – From Jatropa

Characteristics of four biodiesels

Name	Flash point	Density 20/40^{O}C	Viscosity	Octane Number	Heating value
Diesel	32	0.82-0.86	2.0-7.5	42	34.5-36.0
Biodiesel (Jatropa)	161	0.878	4.54	65	33.7
Biodiesel (Sunflower)	183	0.880	4.60	49	33.5
Biodiesel Soyabean	178	0.885	4.50	45	33.5
Biodiesel Peanut	176	0.883	4.90	54	33.6

6.9 Biodiesel – Environmental Issues

6.9 Biodiesel – Environmental Issues

Biomass technologies are environment friendly since it is not burning fossil fuels which contribute significantly to the environmental problems namely greenhouse gases, air pollution, and water and soil contamination hence, improve the environment quality .

i. Air Quality Biomass alternatives can reduce the emission of nitrogen oxides, sulfur dioxides, and other air pollutants associated with fossil fuel use.

ii. Global Climate Change Increased emissions of greenhouse gases from use of fossil fuels, especially carbon dioxide, has created an enhanced greenhouse effect known as global climate change or global warming. Biomass technologies produce very low or no amount of carbon dioxide emissions.

iii. Soil Conservation Soil conservation issues associated with biomass production include soil erosion control, nutrient retention, carbon sequestration, and stabilization of riverbanks.

iv. Water Conservation Biomass technology life cycles may have impacts on watershed stability, groundwater quality, surface water runoff and quality, and local water use for crop irrigation and/or conversion facility needs.

v. Biodiversity and Habitat Change Biodiversity is the genetic and species diversity of living things in a defined area or region. Altered land use to support increased biomass production may result in changes in habitat and levels of biodiversity.

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6.10 Biomass in Malaysia – Bukit Tagar Sanitary Landfill

- BUKIT Tagar sanitary landfill contractor and operator KUB-Berjaya Enviro Sdn Bhd has just signed a 30-year concession to continue running the RM250mil facility could meet Kuala Lumpur and Selangor's municipal waste disposal needs for the next 65 years.
- Population increase by 2% every year, able to last for 50 years with landfill's total capacity 120mil tonnes.
- More programs and activities in reducing waste, including recycling efforts, to mitigate the waste produced by the increased population.
- Receives 2,500 tonnes of municipal solid waste daily from Kuala Lumpur and Selayang, able to last up to 130 years.
- An award-winning landfill that achieves zero discharge.
- All the by-products of waste decomposition including harmful methane gas and toxic leachate, are carefully collected for energy production or treatment.

6.10 Biomass in Malaysia – Bukit Tagar Sanitary Landfill

- Landfill produce 4MW of electricity and the half of the collected gas burned through flare stacks.
- One of the largest and most advanced engineered sanitary landfills in South-East Asia, partially supported by the Government via funding of some RM160mil.
- In operation here for the last 9 years.
- Among cheapest sanitary landfills in the world at RM49 per tonne to dump waste compare to locations in Germany RM1,000 - RM1,400, Australia RM214, China RM60 - RM75.
- Three other sanitary landfills in Malacca, Perlis and Perak..
- Also experimenting with a flexible solar panel, abundance of land and doubling the landfill as a solar farm.

6.10 Biomass in Malaysia – Biomass from oil palm industry

- Fifty percent of biomass in Malaysia comes from the oil palm industry, while the rest comes from wood and other agricultural waste like rice straw and husk. In the past most of these waste material has been either used for heating or simply burnt and the ash recycled into the system. Since open burning is no longer desirable, two possible approaches towards the utilization of these wastes are their direct use as fuel and conversion to alcohol which is further used as fuel.
- The palm oil industry utilizes a fair amount of this waste for its own energy requirements. There is a power generation project with a capacity of 10 MW being implemented in Perlis utilizing rice husk and straws as fuel.

Problem 6.1: Biogas digester

A biogas digester is to be designed to support 10 families of 5 members assuming a person on an average requires 7 kWh/day.

Determine:-

i. the volume of the digester,

ii. the number of cows required for feeding the digester with dung.

Given data:

Mass of solids in the dung is 4.5 kg/day/cow,

Biogas yield 0.34m^3/kg,

Burner efficiency 0.6,

Heat of combustion of biogas 20MJ/m^3.

Energy equivalent 0.278 kWh= 1 MJ

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Solution 6.1: Biogas digester

Total requirement/day = 10 x 5 x 7 = 350 kWh

Converting kWh into MJ = 350/0.278 = 1259 MJ

i) Total volume of biogas digester required, V_b

$0.6 \times 20\ MJ/m^3 \times V_b = 1259$

$V_b = 105\ m^3/day$

Total mass of solids required , *y* per day

$0.34\ m^3/kg \times y\ kg/day = 105\ m^3/day$

$y = 105/0.34 = 308.8\ kg/day$

ii) Number of cows required for obtaining the solid waste

4.5 kg/day x Number of cows = 308.8

Number of cows = 308.8/4.5 = 68.6 ≈ **69 cows**

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