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# Biomass Energy Conversion

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## 1. Introduction

The use of biomass as a source of energy varies in different countries and depends in part on the country's level of development. In many developing countries, biomass provides most of the basic energy needs, mostly as fuelwood, animal wastes or crop residues while in developed countries only a fraction of their energy requirement comes from agriculture and agro-industrial wastes. In the United States for example, biomass conversion amounts to about 3.25% of the energy supply (EIA, 2002 and Haq, 2002) while in Bhutan, the share of biomass energy in total energy use accounts for about 87% (Victor, and Victor, 2002).

Biomass resources could play a significant role in meeting the future energy requirements. However, the approach in their utilization should be carefully analyzed in view of diverse cultural, socio-economic and technological factors in a given locality. Agricultural and agro-industrial wastes can provide an inexpensive source of energy and effective low sulphur fuel. It could be processed into other fuels thereby reducing environmental hazards (e.g. biomass from sewage). Also, there is relative ease with which it could be gathered and generated. However, the conversion of light energy into biomass by plants is relatively of small percentage and there is relatively low concentration of biomass per unit area of land and water. The additional land for biomass production is getting scarce, and the high moisture content of fresh biomass makes collection and transport expensive. Thus, biomass energy conversion could be relatively inefficient. Moreover, extensive utilization of these resources may compete with the demand for these as food. These are some of the issues concerning the extensive utilization of biomass resources.

In view of the depleting forest and agricultural resources for energy use, attention should be focused on new and emerging technologies for their efficient conversion. There are a number of sources of energy for both rural or agricultural and urban or industrial residues. There is a need to diversify the traditional resources for energy to meet the demands. These include, among others: (1) planting high energy value crops, fast growing trees, sugar and starchy crops, aquatic plants, oil and hydrocarbon crops, and (2) getting energy from municipal sewage and solid wastes. Some common properties of biomass resources will be reviewed to gain perspective of biomass as a source of energy compared with traditional fossil fuel sources.

The primary advantage in the use of biomass as an energy resource is that it is a renewable feedstock and does not contribute to global warming.

## 2. Biomass properties and characterization

The important biomass properties include the following: (a) heating value, (b) proximate analysis and (c) ultimate analysis. Any biomass conversion process begins with knowing its energy content in units of MJ/kg and compared with traditional resources like coal. Further, biomass resources may be describe based on its proximate analysis whereby its moisture content (MC) is reported, followed by the volatile combustible matter (VCM) contents, fixed carbon (FC) and ash. Finally, the ultimate analysis is important to illustrate the biomass composition in relation to the top five elements it contains as follows: (a) carbon (C), (b) hydrogen (H) (c) oxygen (O), (d) nitrogen (N) and (e) sulphur (S) content. Other characterization would include describing its compositional contents such as lignin, cellulose and hemi-celluloses , carbohydrates and fat contents.

When biomass is converted thermally in the presence of excess amounts of air, (i.e. combustion) the total energy released in the form of heat is termed its heating value or calorific value. The heating value of biomass is reported in units of kJ/kg. Gasoline used as fuel for running internal combustion engines has a reported heating value of about 47 MJ/kg and diesel has heating value of about 45 MJ/kg. Biomass on the other hand may have heating values ranging from 15 - 25 MJ/kg.

### 2.1 Heating value and ultimate analysis of biomass

Heating value of biomass is usually measured using a bomb calorimeter. Table 1 shows the ultimate analyses and heating value of some fossil fuels and common biomass. In the absence of equipment for measuring heating values of biomass, two most common equations are used. These are the Dulong equation (Gupta and Manhas, 2008) and the Boie equation (Annamalai, et al., 1987) shown in equations (1) and (2).

Material	Elements (% dry weight)						Heating Values MJ/kg
	C	H	N	S	O	Ash	
Pittsburgh seam coal	75.5	5.0	1.2	3.1	4.9	10.3	31.7
Utah coal	77.9	6.0	1.5	0.6	9.9	4.1	32.9
Wyoming Elkol coal	71.5	5.3	1.2	0.9	16.9	4.2	29.5
Lignite	64.0	4.2	0.9	1.3	19.2	10.4	24.9
Charcoal	80.3	3.1	0.2	0.0	13.0	3.4	57.4
Douglas fir	52.3	6.3	0.1	0.0	40.5	0.8	21.3
Pine bark	52.3	5.8	0.2	0.0	38.8	2.9	20.4
Redwood	53.5	5.9	0.1	0.0	40.3	0.2	21.0
Rice hulls	38.5	5.7	0.5	0.0	39.8	15.5	15.4
Rice straw	39.2	5.1	0.6	0.1	35.8	19.2	15.2
Sawdust	49.7	6.2	0.7	0.2	42.5	0.7	20.0
Paper	43.4	5.8	0.3	0.2	44.3	6.0	17.6
Feedlot manure (fresh)	45.4	5.4	1.0	0.3	32.0	15.9	17.4
Municipal solid waste	47.6	6.0	1.2	0.3	32.9	12.0	19.9
Corn cobs	46.2	7.6	1.2	0.3	42.3	2.4	26.3
Sorghum stalks	40.0	5.2	1.4	0.2	40.7	12.5	15.4
Cotton gin trash (CGT)	42.0	5.4	1.4	0.0	36.7	14.5	15.5

Table 1. Ultimate analysis data and heating values for selected solid and biomass fuels (from LePori and Soltes, 1985, with permission).

The Dulong equation is given by the following equation (1),

$$\text{HV (kJ/kg)} = 33,823 \cdot C + 144,250 \cdot (\text{H}-\text{O}/8) + 9,419 \cdot S \quad (1)$$

where C, H, O, N and S are the elemental mass fractions in the material.

Example. From the ultimate analysis data shown in Table 1, estimate the heating value in MJ/kg of douglas fir.

Solution.

1. Substituting the mass fractions of the elements into the equation, we have

$$\text{HV (kJ/kg)} = 33,823 \cdot (0.523) + 144,250 \cdot (0.063 - ((0.405)/8)) + 9,419 \cdot (0)$$

2. Thus, the heating value is calculated as

$$\text{HV (kJ/kg)} = 17,689 + 1,785 + 0 = 19,474 \text{ kJ/kg (19.5 MJ/kg).}$$

Note that the heating value from the table is given as 21.3 MJ/kg, an 8.45% difference. The Dulong equation is valid when the oxygen content of the biomass is less than 10%. In this example, the oxygen content of douglas fir is 40.5% and way above 10% , hence a large difference.

The Boie equation is given by the following equation (2),

$$\text{HV (kJ/kg)} = 35,160 \cdot C + 116,225 \cdot H - 11,090 \cdot O + 6,280 \cdot N + 10,465 \cdot S \quad (2)$$

where C, H, O, N and S are the elemental mass fractions in the material.

## 2.2 Proximate analysis of biomass

The proximate analysis is a good indicator of biomass quality for further conversion and processing. Proximate analysis is important for thermal conversion processes since the process require relatively dry biomass (normally less than 10% moisture). If gaseous combustible fuel from biomass is to be produced, the feedstock with the highest volatile matter content is ideal to use. For slagging and fouling issues, the feedstock with the lowest ash content is an excellent choice. The fixed carbon is used to relate the heating value of the product and co-products. Table 2 shows some proximate analysis data for some biomass resources.

Material	Proximate Analysis (% weight, wet basis)				Proximate Analysis (% weight, dry basis)		
	MC	VCM	FC	Ash	VCM	FC	Ash
Corn cob (Stout, 1985)	15.0	76.60	7.00	1.40	90.12	8.23	1.65
Stover (Stout, 1985)	35.0	54.60	7.15	3.25	84.00	11.00	5.00
CGT	9.01	64.78	14.36	11.85	71.20	15.78	13.02
Switchgrass	10.31	73.24	13.01	3.44	81.67	14.51	3.82
Sorghum	22.11	55.62	11.25	11.02	71.40	14.45	14.15
Woodchips	21.05	67.46	10.07	1.42	85.44	12.76	1.80

Table 2. Proximate analysis data for selected biomass.

## 3. Biomass conversion processes

The development of conversion technologies for the utilization of biomass resources for energy is growing at a fast pace. Most developing countries find it hard to catch up because

the level of technology is beyond their manpower as well as their manufacturing and technological capability. Added to this is the unavailability of local materials and parts for the fabrication of these conversion units. Figure 1 shows the different methods for converting biomass into convenient fuel. Biomass conversion into heat energy is still the most efficient process but not all of energy requirement is in the form of heat. Biomass resources need to be converted into chemical, electrical or mechanical energy in order to have widespread use. These take the form of solid fuel like charcoal, liquid fuel like ethanol or gaseous fuel like methane. These fuels can be used in a wide range of energy conversion devices to satisfy the diverse energy needs. In general, conversion technologies for biomass utilization may either be based on bio-chemical or thermo-chemical conversion processes. Each process will be described separately.

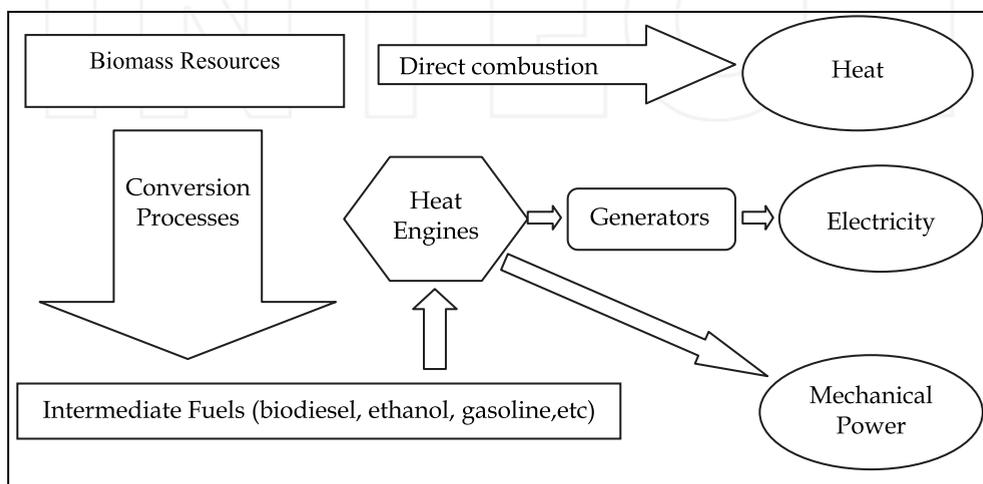


Fig. 1. Methods of using biomass for energy.

### 3.1 Bio-chemical conversion processes

The two most important biochemical conversion processes are the anaerobic digestion and fermentation processes.

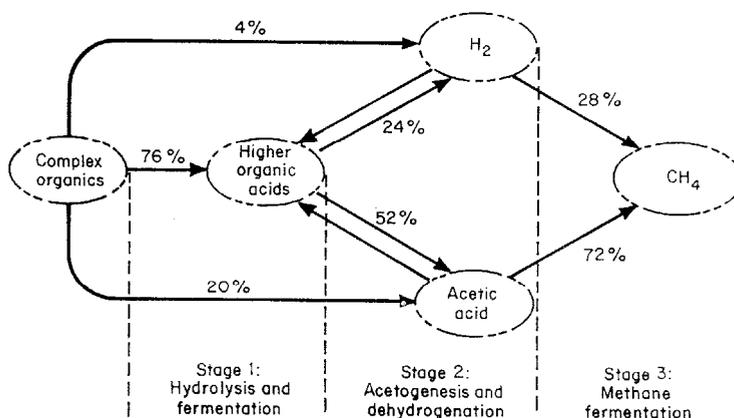
#### 3.1.1 Anaerobic digestion

Anaerobic digestion is the treatment of biomass with naturally occurring microorganisms in the absence of air (oxygen) to produce a combustible gaseous fuel comprising primarily of methane ( $\text{CH}_4$ ) and carbon dioxide ( $\text{CO}_2$ ) and traces of other gases such as nitrogen ( $\text{N}_2$ ) and hydrogen sulphide ( $\text{H}_2\text{S}$ ). The gaseous mixtures is commonly termed "biogas". Virtually all nitrogen (N), phosphorus (P) and potassium (K) remain in the digested biomass.

The entire process takes place in three basic steps as shown in Figure 2. The first step is the conversion of complex organic solids into soluble compounds by enzymatic hydrolysis. The soluble organic material formed is then converted into mainly short-chain acids and alcohols during the acidogenesis step. In the methanogenesis step, the products of the second step are converted into gases by different species of strictly anaerobic bacteria. The percentage of methane in the final mixture has been reported to vary between 50 to 80%. A

typical mixture consists of 65% methane and 35% CO<sub>2</sub> with traces of other gases. The methane producing bacteria (called methanogenic bacteria) generally require a pH range for growth of 6.4 to 7.2. The acid producing bacteria can withstand low pH. In doing their work, the acid producing bacteria lower the pH and accumulate acids and salts of organic acids. If the methane-forming organisms do not rapidly convert these products, the conditions become adverse to methane formers. This is why the first type of reactors developed for conversion of biomass wastes into methane have long retention times seeking equilibrium between acid and methane formers.

Municipal wastes and livestock manures are the most suitable materials for anaerobic digestion. In the US, numerous landfill facilities now recover methane and use it for power generation. Aquatic biomass such as water hyacinth or micro-algae can be digested and may become valuable sources of energy in the future. Anaerobic digestion of organic wastes may constitute an effective device for pollution control with simultaneous energy generation and nutrient conservation. A major advantage of anaerobic digestion is that it utilizes biomass with high water contents of as high as 99%. Another advantage is the availability of conversion systems in smaller units. Also the residue has fertilizer value and can be used in crop production. The primary disadvantage of anaerobic digestion of diluted wastes is the large quantity of sludge that must be disposed of after the digestion process including the wastewater and the cost of biogas storage. In cold climates, a significant fraction of the gas produced may be used to maintain the reactor operating temperature. Otherwise, microorganisms that thrive on lower or moderate temperatures should be used.



(Source: American Chemical Society)

Fig. 2. Steps in anaerobic digestion process with energy flow represented as % chemical oxygen demand (COD).

### 3.1.1.1 The first generation biogas reactors

Three main types of biogas facilities have been successfully developed in Asia for widespread biogas production in households and industrial use. These are the "Chinese Digester" of fixed dome type, the "Indian Gobar Gas Plant" of floating gas holder type and the rectangular commercial size biogas digesters developed in Taiwan. These are what we may call the first generation biogas reactors. Shown in Figure 3 is the common Chinese digester design. These

designs have eliminated the use of a floating gas holder and incorporated local materials for construction (brick or concrete). Biogas is pressurized in the dome and can be easily used for cooking and lighting. Figure 4 shows the “Indian Gobar Gas Plant” with floating gas holder.

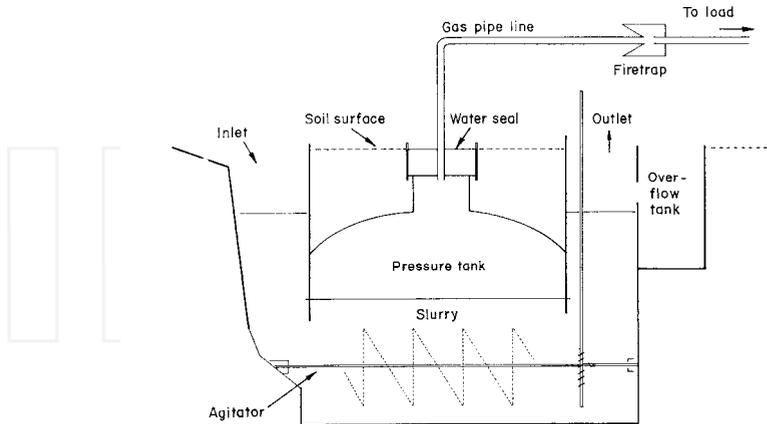


Fig. 3. The “Chinese Digester” of the dome type.

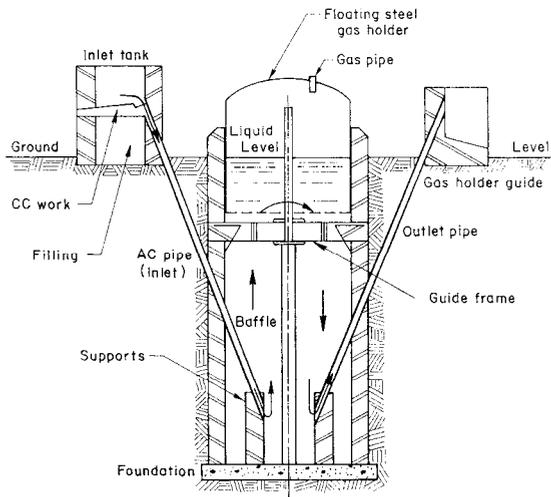


Fig. 4. The “Indian Gobar Gas Plant” schematic showing cross-sectional design.

The Indian design uses concrete inlet and outlet tanks and reactor. The steel cover acts as the floating gasholder. These digesters have no pumps, motors, mixing devices or other moving parts and digestion takes place at ambient temperature. As fresh material is added each day, digested slurry is displaced through an outlet pipe. The digesters contain a baffle in the center which ensures proper utilization of the entire digester volume and prevents short circuiting of fresh biomass material to the outlet pipe.

Figure 5 is an example of a rectangular biogas digester used in commercial swine facilities in Taiwan. Similar reactors have been built and used in the Philippines for commercial swine facilities (Maramba, 1978). The gas holder is designed and constructed separately.

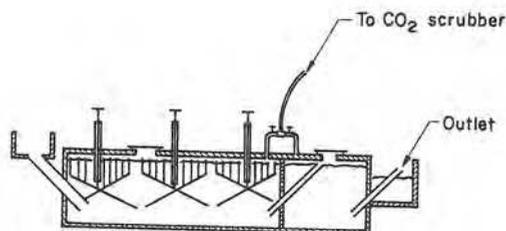


Fig. 5. The Taiwan rectangular digester design with a separate gas holder.

While the above designs have been operated successfully, the reactors are still considered World War II technologies. The main disadvantage is the long retention times of between 30 to 60 days. Thus, for large scale units, they require larger reactor volumes which make the initial cost and area requirements quite high. Their main advantage is the fact that these units have less maintenance and operational costs and they are less prone to breakdowns due to variations in the quantity and quality of feed. They are resistant to shock loadings and minimal process parameters are monitored for efficient operation. The only operating procedure made is the daily mixing of the slurry.

### 3.1.1.2 The second generation biogas digesters

There are now new technologies which we may call the second generation biogas digesters. These high rate bio-reactors were originally designed for low strength liquid wastes but the progress has been remarkable and most units can now be used for even the high strength wastes with high quantities of suspended solids like those of livestock manure.

Callander, et al., (1983), have made an extensive review of the development of the high rate digester technology. The improvements of such digesters can be largely attributed to better understanding of the microbiology of the methane production process. The most popular high rate anaerobic digesters originated from many conventional wastewater treatment plants that utilizes the anaerobic contact process (Figure 6) followed by the anaerobic clarigester. Perhaps the design that has caused widespread attention is the development of the upflow anaerobic sludge blanket (UASB) developed in Netherlands (Lettinga, et al., 1980). Many commercial high rate digesters are now based on this design. Other reactors include the anaerobic filters (Young, et. al., 1969), the expanded bed fixed film reactor, and the stationary fixed film reactor.

As researchers began to understand the microbiology of the processes, they began to realize the varied nature and characteristics of the microorganisms used in the conversion. Thus recent designs call for the separation of two types of microorganisms in the reactors. Some new reactors are designed whereby acid forming bacteria are separated from the methane producing bacteria. With this design, the acid formers are now independent from the methane formers and therefore each group of microorganisms can do its job without harming the population of the other types of microorganisms.

The retention times have been reduced for most of the high rate biogas digesters and thus reducing the size of the digesters. However, there are corresponding need for a modest

laboratory for microbial analysis, system pH control and monitoring of other parameters such as buffering capacity, solids retention times, alkalinity and the like.

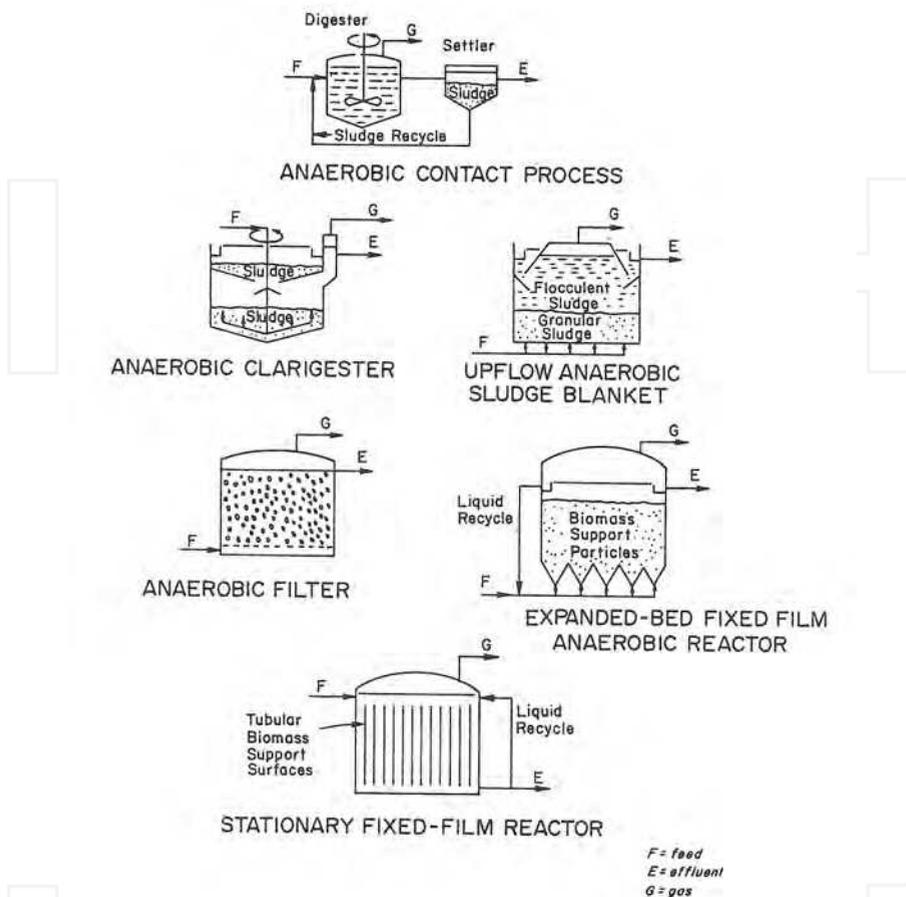


Fig. 6. Some examples of second generation biogas digesters.

### 3.1.2 Ethanol fermentation

Ethyl alcohol can be produced from a variety of sugar containing materials by fermentation with yeasts. Strains of *Saccharomyces cerevisiae* are usually selected to carry on the fermentation that converts glucose ( $C_6H_{12}O_6$ ) into ethyl alcohol ( $C_2H_5OH$ ) and carbon dioxide ( $CO_2$ ). In the batch process the substrate is diluted to a sugar content of about 20% by weight, acidified to pH 4-5, 8-10%, the liquid is distilled, fractionated and rectified. One gallon of alcohol (3.79 liters, 21,257 kcal) is obtained from 2.5 gallons of cane molasses or the equivalent of 5.85 kg of sugar (21,842 kcal). So there is almost no energy loss in the fermentation process.

When a starchy material, such a corn, grain sorghum or barley, is used as substrate, the starch must be converted into fermentable sugars before yeast fermentation. The

decomposition of large organic molecules requires the catalytic action of certain enzymes also produced by microorganisms. The most popular microbe is the *Aspegillus niger*.

Crops mentioned as potential substrate for the production of alcohol include sugarcane, sorghum, cassava, and sugar beets. The two main by-products of then fermentation are  $\text{CO}_2$  and the spent materials, which will contain the non-fermentable fraction of the substrate, the non-fermented sugars and the yeast cells. The two most important reasons for the high costs for ethanol production are: the batch nature of the process and the end-product (ethanol) inhibition of the yeast.

Continuous fermentation has been found successful on a laboratory scale. One way of avoiding end product inhibition is operation under vacuum so that ethanol is removed as it is formed. More researches are underway. Figure 7 shows a schematic diagram for the production of high percent ethanol from cassava (NRC, 1983).

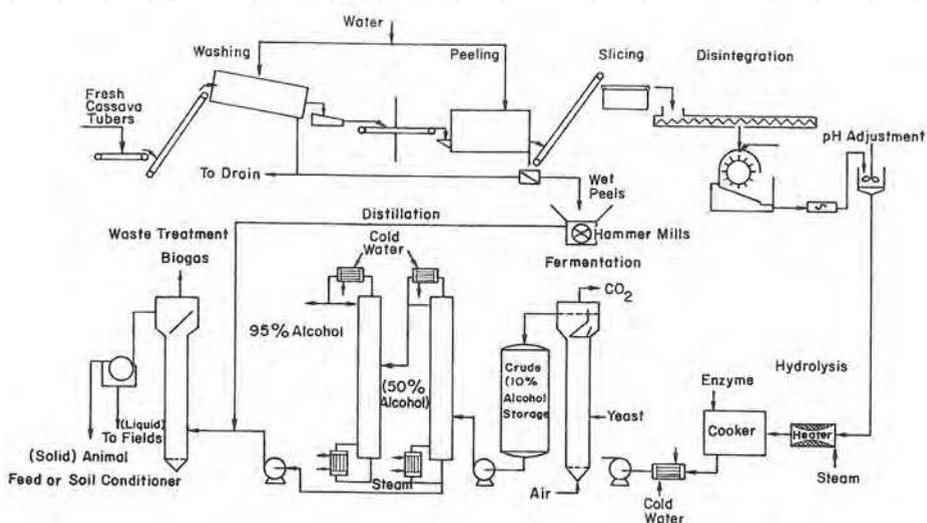


Fig. 7. Schematic of ethanol production from cassava.

If the feedstock is high in cellulosic components, these must be hydrolyzed also by a different sets of enzymes to break down the long chain cellulose structure into shorter chain compounds. In our laboratory facilities, we made use of enzymes produced by *Trichoderma reesi*. Commercially, genetically modified *T. reesi* may be sourced from Genencor International (Palo Alto, California, USA).

### 3.2 Thermo-chemical conversion processes

Biomass wastes can be easily converted into other forms of energy at high temperatures, They break down to form smaller and less complex molecules both liquid and gaseous including some solid products. Combustion represents a complete oxidation to carbon dioxide ( $\text{CO}_2$ ) and water ( $\text{H}_2\text{O}$ ). By controlling the process using a combination of temperature, pressures and various catalysts, and through limiting the oxygen supply, partial breakdown can be achieved to yield a variety of useful fuels. The main thermo-chemical conversion approaches are as follows: pyrolysis/charcoal production, gasification

and combustion. The advantages of thermo-chemical conversion processes include the following:

- a. Rapid completion of reactions
- b. Large volume reduction of biomass
- c. Range of liquid, solid and gaseous products are produced
- d. Some processes do not require additional heat to complete the process

### 3.2.1 Pyrolysis

Pyrolysis or destructive distillation is an irreversible chemical change caused by the action of heat in the absence of oxygen. Pyrolysis of biomass leads to gases, liquids and solid residues. The important components of pyrolysis gas in most cases are hydrogen, carbon monoxide, carbon dioxide, methane and lesser quantities of other hydrocarbons ( $C_2H_4$ ,  $C_2H_6$ , etc.). The liquid consists of methanol, acetic acid, acetone, water and tar. The solid residue consists of carbon and ash. Thus pyrolysis can be used to convert biomass into valuable chemicals and industrial feedstock.

In a typical pyrolysis process the feed material goes through the following operations: (a) primary shredding (b) drying the shredded material (c) removal of organics (d) further shredding to fine size (e) pyrolysis (f) cooling of the products to condense the liquids and (g) storage of the products.

Different types of pyrolytic reactors include vertical shaft reactors, horizontal beds. Among these, the simplest and generally cheapest is the vertical shaft type. Fluidized bed reactors are relatively a recent development. Figure 8 shows a rotary kiln pyrolysis reactor. The unit is cylindrical, slightly inclined and rotates slowly which causes the biomass to move through the kiln to the discharge end.

Numerous technologies have now been developed for the production of bio-oil and char using the pyrolysis process, Many of the reactors developed are improvements on the traditional reactors used in rural areas of developing countries that include simple pit kilns or drum type reactors. The energy efficiency of charcoal production using these methods is only the order of 17-29% while theoretically, efficiencies as high as 40% could be achieved.

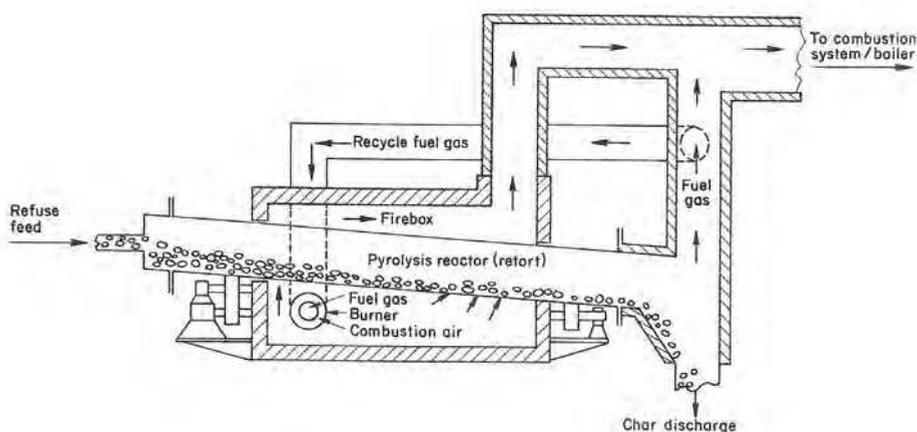


Fig. 8. Schematic of the rotary kiln pyrolysis reactor.

### 3.2.2 Gasification

Gasification is the thermo-chemical process of converting biomass waste into a low medium energy gas utilizing sub-stoichiometric amounts of oxidant (Coovattanachai, 1991). The simplest form of gasification is air gasification in which biomass is subjected to partial combustion with a limited supply of air. Air gasifiers are simple, cheap and reliable. Their chief drawback is that the gas produced is diluted with nitrogen and hence has low calorific value. The gas produced is uneconomical to distribute; it must be used on-site for process heat. In oxygen gasification, pure oxygen is used so that the gas produced is of high energy content. The chief disadvantage of oxygen gasification is that it requires an oxygen plant and thus increases the total cost of gasification. The schematic diagram of the processes occurring in a gasifier is shown in Figure 9 including the temperature profile at each important step in the process.

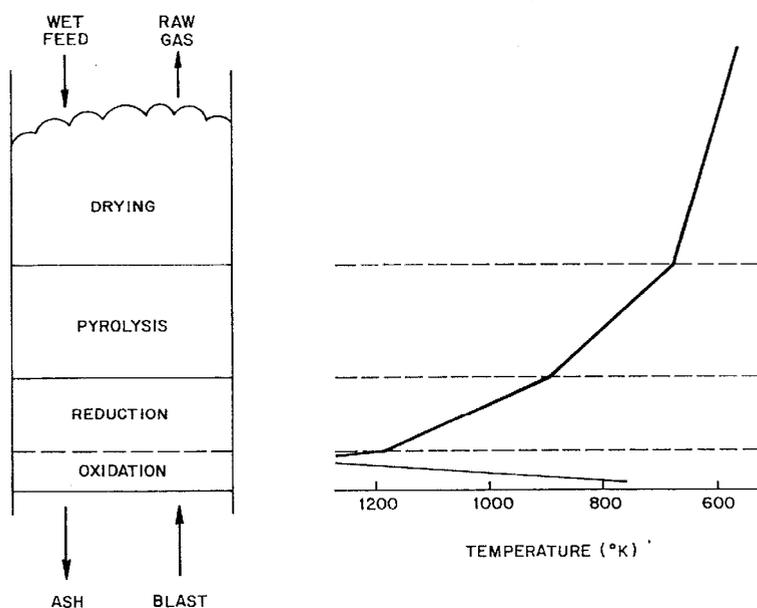


Fig. 9. Schematic diagram of processes occurring in a gasifier and the temperature profile.

The simplest air gasifier is the updraft gasifier shown in Figure 10. Air is introduced at the bottom of the bed of biomass near the hearth zone. The gas produced is usually at a low temperature. The sensible heat of the gas is used to dry and preheat the biomass before it reaches the reduction zone. Products from the distillation and drying zones consist mainly of water vapor, tar and oil vapors and are not passed through the hot bed. They therefore leave the reactor uncracked and will later condense at temperatures between 125°C – 400°C.

Because the tar vapors leaving an updraft gas producer seriously interfere with the operation of internal combustion engines, the downdraft gasifiers (Barret, et. al., 1985) are more extensively used. The air is introduced into a downward flowing bed of solid fuel and the gas outlet is at the bottom as shown in Figure 11. The tarry oils and vapors given off in

the distillation zone are cracked and reduced to non-condensable gaseous products while passing through the oxidation (hearth) zone. Downdraft gasifiers have a reduced cross-sectional area above which the air is introduced. The throat ensures a homogeneous layer of hot carbon through which the distillation gases must pass.

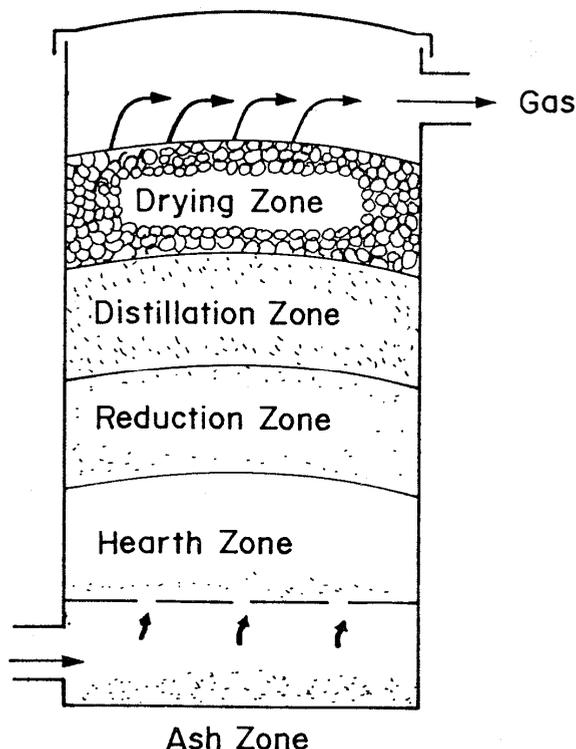


Fig. 10. Schematic diagram of an updraft gasifier.

The crossdraft gasifier is also a fixed bed gasifier where the feed material could be moved by gravity while the flow of air is at an angle against the feed flow. The usual flow of air is perpendicular to the flow of biomass. They have almost the same performance as the updraft and downdraft gasifiers.

A fluidized bed gasifier (LePori and Soltes, 1985) consists of a fluidized bed of inert particles in which biomass is fed. The gas stream generally carries with it the char particles out of the bed. These particles are separated from the gas by means of cyclones. Fluidized beds can gasify much higher amounts of biomass area per unit of time compared to the other types of gasifiers. The precise composition of the gas from the gasifiers depends on the type of biomass used, the temperature and rate of reaction. Typically, if wood is used as the feed, the gas composition is shown in Table 3. The heat content is about  $5500 \text{ kJ/m}^3$ . The synthesis gas quality for the Texas A&M University fluidized bed gasifier is shown in Table 4 (LePori, 1985). A schematic of a fluidized bed gasifier is shown in Figure 12.

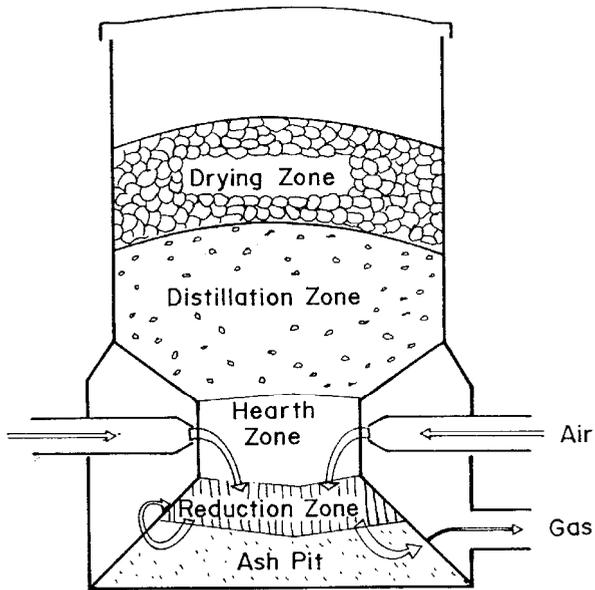


Fig. 11. Schematic diagram of a downdraft gasifier.

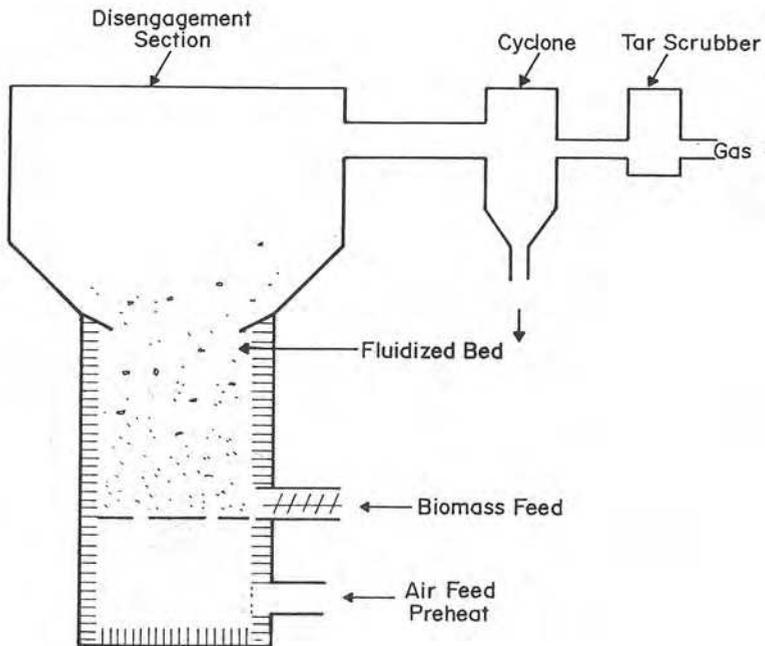


Fig. 12. Schematic diagram of a fluidized bed gasifier.

Type of Gas	Percent Composition
1. Carbon dioxide (CO <sub>2</sub> )	10%
2. Carbon monoxide (CO)	20-22%
3. Hydrogen (H <sub>2</sub> )	12-15%
4. Methane (CH <sub>4</sub> )	2-3%
5. Nitrogen (N <sub>2</sub> )	50-53%

Table 3. Typical gas composition of a fluidized bed gasifier using wood as feedstock.

Type of Gas	Percent Composition
1. Carbon dioxide (CO <sub>2</sub> )	18.25%
2. Carbon monoxide (CO)	13.44%
3. Hydrogen (H <sub>2</sub> )	14.68%
4. Methane (CH <sub>4</sub> )	3.21%
5. Nitrogen (N <sub>2</sub> )	47.31%
6. Ethylene (C <sub>2</sub> H <sub>4</sub> )	1.83%
7. Ethane (C <sub>2</sub> H <sub>6</sub> )	0.36%

Table 4. Typical gas composition of the TAMU fluidized bed gasifier.

### 3.2.3 Biomass combustion

One of the most common methods of biomass conversion is by direct combustion or burning. The simplest units include numerous cookstoves already developed in rural areas of developing countries. Much improved and continuous flow designs include the Spreader-Stoker system (similar to that shown in Figure 13) used in many refuse derived fuels (RDF) facility for converting solid wastes, and the fluidized bed combustion units (similar to that shown in Figure 12). The number component parts of this system is listed below:

1. Refuse charging hopper
2. Refuse charging throat
3. Charging ram
4. Grates
5. Roller bearings
6. Hydraulic power cylinders and control valves
7. Vertical drop-off
8. Overfire air jets
9. Combustion air
10. Automatic sifting removal system

In a spreader-stoker system, the fuel is introduced into the firebox above a grate. Smaller particles will tend to burn in suspension and larger pieces will fall onto the grate. Most units, if properly designed, can handle biomass with moisture content as high as 50-55%. Moisture contained in the fuel is driven off partially when the fuel is in suspension and partially on the grate. The feed system should provide an even thin layer of fuel on the grate.

In a fluidized bed combustor (FBC), the fuel particle burns in a fluidized bed of inert particles utilizing oxygen from the air. Advantages of fluidized bed combustion include: (1) high heat transfer rate, (2) increased combustion intensity compared to conventional combustors and, (3)

absence of fouling and deposits on heat transfer surfaces. The schematic diagram of a fluidized bed combustor is similar to that of a fluidized bed gasifier. The only difference is the use of excess air for combustion processes and starved air for gasification processes.

So far FBC has been used mostly for coals. A number of wastes, e.g. wastes from coal mining and municipal wastes, are also sometimes incinerated in fluidized beds. It has been suggested that certain quick-maturing varieties of wood could be combusted in fluidized beds for generation of steam. There is indeed a global search for suitable varieties of wood for this purpose and FBC is likely to play an important role in supplying energy requirements in certain countries in the future.

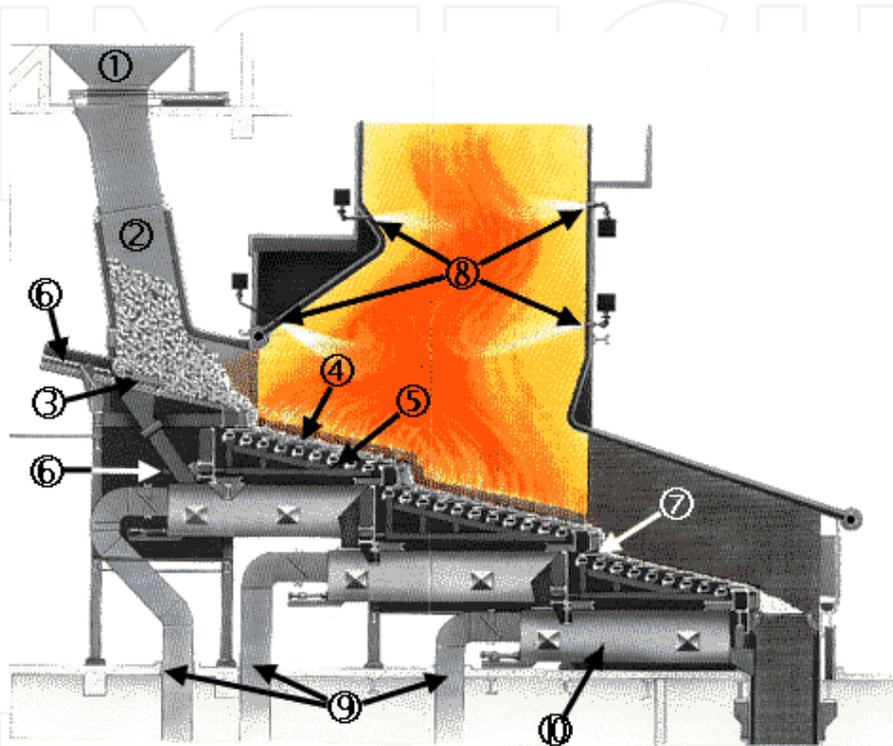


Fig. 13. Schematic diagram of a reciprocating grate combustor (Courtesy of Detroit Reciprogate Stocker).

Granular biomass fuels, e.g. paddy husk and chips of wood up to 2cm x 2cm x 2cm in size have been successfully combusted in fluidized beds of sand particles. Conventional combustion of paddy husk is slow and inefficient. Nearly complete combustion and high combustion intensities of paddy husk can be achieved in a fluidized bed combustor. The same combustor can also be used for burning wood. Combustion intensities up to about 500 Kg/hr-m<sup>2</sup> have been achieved in fluidized bed combustors using biomass fuels.

A number of thermo-chemical conversion processes exist for converting biomass into liquid fuels. These can be crudely divided into direct liquefaction and indirect liquefaction (in which the biomass is gasified as a preliminary step) processes. While all these techniques are relatively sophisticated and will generally be suitable for large scale conversion facilities,

they do represent an important energy option for the future because the heavy premium that liquid fuels carry.

The steam produced from heat of combustion of biomass may power a steam turbine to produce electricity. However, because of the high ash contents of most biomass resources, direct combustion of these biomass resources is not practical and efficient due to slagging and fouling problems. Because of these problems, some biomass with high ash are often mixed with low ash biomass such as coal, also termed co-firing.

### 3.2.4 Biomass co-firing

*Co-firing* refers to mixing biomass and fossil fuels in conventional power plants. Significant reductions in sulfur dioxide ( $\text{SO}_2$  – an air pollutant released when coal is burned) emissions are achieved using co-firing systems in power plants that use coal as input fuel. Small-scale studies at Texas A&M University show that co-firing of manure with coal may also reduce nitrogen oxides ( $\text{NO}_x$ - contribute to air pollution) emissions from coal (Carlin, 2009). Manure contains ammonia ( $\text{NH}_3$ ). Upon co-firing manure and coal,  $\text{NH}_3$  is released from manure and combines with  $\text{NO}_x$  to produce harmless N and water.

Biomass co-firing has the potential to cut emissions from coal powered plants without significantly increasing the cost of infrastructure investments (Neville, 2011). Research shows that when implemented at relatively low biomass-to-coal ratios, energy consumption, solid waste generation and emissions are all reduced. However, mixing biomass and coal (especially manure) does create some challenges that must be address.

There are three types of co-firing systems adopted around the world as follows:

- a. Direct co-firing
- b. Indirect co-firing, and
- c. Separate biomass co-firing.

Direct co-firing is the simplest of the three and the most common option especially if the biomass have very similar characteristics with coal. In this process, more than one type of fuel is injected into the furnace at the same time. Indirect co-firing involves converting the biomass into gaseous form before firing. The last type has a separate boiler for the co-fired fuel.

It was reported that the carbon life cycle and energy balance when co-firing 15% biomass with coal is carbon neutral or better (Eisenstat, et al., 2009). In this research, carbon emissions are reduced by 18%.

## 4. Conclusion

From the above discussions we observe a rapid development of technologies for the conversion of biomass into heat energy and fuels. Countries should take advantage of these rapidly developing technologies. However, as more conversion technologies are developed, the biomass resource base may be the next constraint. Thus, methods to diversify the biomass resource base have to be made in conjunction with the use of emerging technologies for conversion. The sources of biomass have to be broadened from the traditional crop residues, livestock manure and fuel wood to culturing energy crops such as aquatic biomass (e.g. algae) while recovering the energy from municipal solid wastes and sewage.

Attempt has to be made to make use of more efficient equipment and technologies for energy utilization. In anaerobic digestion for example, many countries are still utilizing age old first generation anaerobic reactors while high rate biogas reactors are already gaining

popularity. In the implementation of new and emerging technologies, lessons learned from past experiences must be taken into consideration. Many of these technologies require highly qualified and skilful manpower, more advanced monitoring techniques and equipment and materials that many developing countries may not have. The government of each country should have an active role to support the developing of such technologies including massive information campaign and training and improvement of local expertise in the use of advanced materials and process equipment for biomass conversion into energy and fuels.

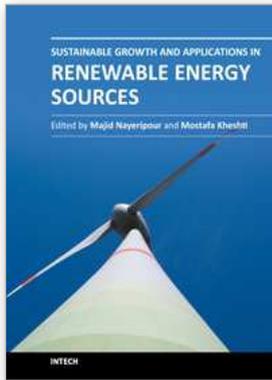
Finally, to reverse the trend in the depletion of agriculture and forestry resources, massive reforestation program must be made together with developing technologies for harvesting, pre-processing and storage of biomass. This should be implemented together with infrastructure development for efficient transport of biomass to where it is needed or develop technologies that will be brought to where biomass resources are abundant.

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## **Sustainable Growth and Applications in Renewable Energy Sources**

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Worldwide attention to environmental issues combined with the energy crisis force us to reduce greenhouse emissions and increase the usage of renewable energy sources as a solution to providing an efficient environment. This book addresses the current issues of sustainable growth and applications in renewable energy sources. The fifteen chapters of the book have been divided into two sections to organize the information accessible to readers. The book provides a variety of material, for instance on policies aiming at the promotion of sustainable development and implementation aspects of RES.

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