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THE ENERGY ASPECTS OF BIOMASS

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ABSTRACT

The concept of biomass as a storage of solar energy has been elaborated. The role of energy in the formation, propagation and utilization of biomass has been discussed with special reference to wood energy. Fuel values of different biomass can be predicted from their basic chemical constitution. The gross, net and usable heat contents of wood with respect to moisture content has been defined. Energetics of biomass conversion processes such as drying, classification, pyrolysis, gasification, liquefaction and combustion are discussed. It is proposed that field estimation of biomass energy should be carried out with some precautions to avoid the over or under estimation.

1. INTRODUCTION:

Although using the biomass as energy source had been the age-old practice, it had drawn little attention of scientists and technologists until recently when imminent energy crisis was felt strongly all over the world. However, biomass fuels are more difficult to study than their counterparts are. The complexity of the subject is due to its highly interdisciplinary nature. The agronomists, biologists, environmentalists and biomass conversion technologists all have to work together with the aim of solving the energy crisis through the biomass route. Fortunately, there is one term common to all; and that is "energy". It is therefore appropriate to have a closer look into the involvement of energy in biomass formation, propagation and utilization.

Energy can be defined as the measure of the ability to do work. The ability can be decided not only by the extent but by the quality also. In common language, the quality of energy is decided by[1] (a) fuels ability to do work, (b) maximum temperature a fuel can create and (c) flexibility with which it can be used. Scientifically, the quality is measured by the thermodynamic term "entropy" the degree of disorder. Lower the entropy higher is the quality of energy. The priority order of the quality is given as:

Mechanical energy = Electrical energy > Chemical energy > Heat energy

Mechanical energy is completely ordered and heat energy is disordered. Energy conversion increases the entropy and degrades the fuel quality. Conversion of high quality to high quality energy is highly efficient process. Heat energy can also be high quality energy if it is dissipated at very high temperature. Biomass energy comes in the category of chemical energy. Production of biomass is in fact the conversion of solar energy into chemical energy through photosynthetic route.

2. SOLAR ENERGY AND BIOMASS:

Sunlight is a form of heat energy whose quality is extremely high because of Sun's high temperature (5760 ^{0}C). We receive only 2.4×10^{-6} % of the total Sun's radiation. Out of the total radiation incident above our atmosphere, 35% is reflected, 17.5% absorbed by the atmosphere and cloud and only 47.5% enters our biosphere level. On an average 3×10^{24} Joules/year solar energy reaches our earth. Total aquatic and terrestrial biomass production is estimated to be 3×10^{21} Joules/year. Thus, only 0.1% of the incident solar energy is stored photosynthetically. Of the remaining incident energy 30% is reflected, 49% is lost as heat of water vaporization to drive the hydrological cycle and 21% as low-grade heat, which due to differential absorption causes the wind currents. Thus, solar energy maintains ecological balance on earth besides producing biomass by the route of photosynthesis.

2.1 THE PHOTOSYNTHETIC PROCESS

Photosynthesis in a green plant is the process in which sunlight is captured by pigment molecules and, through a sequence of primary and secondary reaction initiated by the excited chlorophyll reaction centers; it is transformed into stored chemical energy[2].

The overall reaction is summarized as the transfer of hydrogen atoms from water to carbon dioxide to form carbohydrate with liberation of oxygen.

$$n\,CO_2 + n\,H_2O \xrightarrow[\text{Chlorophyll}]{\text{Sunlight}} n\,O_2 + (CH_2O)_n$$

The low energy content molecules CO_2 and H_2O form an energy rich molecule carbohydrate with the help of solar energy. The carbohydrate finally promotes the metabolic and structural functions during the growth of plant. Apparently, photosynthesis is the root cause of biomass production.

The photosynthetic process occurs in three main steps with different time domains[2,3].

(1) 10^{-14} - 10^{-12} seconds

Initial light absorption by photosynthetic antenna pigments and transfer of energy to reaction centre pigments.

(2) 10^{-9} seconds

Photo-oxidation of reaction centre pigments.

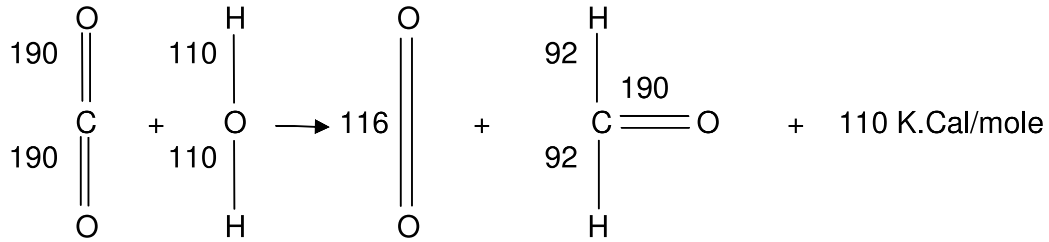
(3) 1 second

Chemical transfer of photo excited electrons via enzymes which finally results in the reduction of carbon-dioxide by water. The pigment molecule is also regenerated in its ground state within this period.

2.2 ENERGETICS OF PHOTOSYNTHESIS

Energy in biomass is stored in the form of bond energy. Energy liberated when two atoms become attached to each other is called bond energy. Higher the bond energy greater is the energy released during the formation of bond. In general, energy is stored in a process when weaker bonds are formed at the expense of strong bonds. Energy storage in photosynthesis occurs by formation of 0-0 bonds (-58 K.Cal./mole) and by destruction of O-H bonds (-110 K.Cal./mole) and C-O bonds (-95 K.Cal./mole) as shown below (an endothermic reaction).

$$CO_2 + H_2 \rightarrow O_2 + CH_2O \quad + 110 \text{ K.Cal/mole}$$



Let us now have a look at the energetics of three different photosynthetic steps.

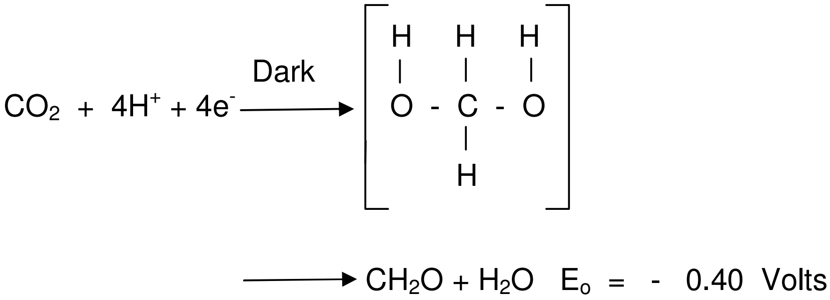
(I) In the first step, the light absorption can be maximized by fulfilling the following two conditions:

a) Largest possible area should be exposed to sunlight.
b) The absorbent should absorb light over wide frequency range of visible light.

In green plants, photosynthesis is confined to the membranous organelles called Chloroplasts. The number of chloroplasts varies from 1 to 1000 per eucaryotic cell depending on the plant type. Nature fulfills both the above-mentioned conditions by subdividing the chloroplasts into photosynthetic units each containing about 300 pigment molecules and a single reaction centre. These pigment molecules (carotenoids, phycoerythrin, phycocyanin and various chlorophylls) absorb light in wide frequency range of white light (Fig.1). A pigment molecule after absorbing light, reaches highly energized and unstable state. It gives out the excitation energy to the host system by coming back to its ground state. The structure of each photosynthetic unit is like antenna system i.e. energy funnel. The typical spatial arrangement of these units (Fig.2) increases the effective surface area. The absorbed solar energy is efficiently migrated to the reaction centre at the other end of antenna system to carry out further photo-oxidation.

(II) The second step i.e. photo-oxidation means ejection of electrons from water molecules to produce H^+ ions needed for CO_2 reduction. Thus, a photosynthetic reaction can be considered as an electrochemical oxidation-reduction reaction:

$$2H_2O \xrightarrow{\text{light}} O_2 + 4H^+ + 4e^- \qquad E_o = + 0.81 \text{ Volts}$$



$$CO_2 + 4H^+ + 4e^- \xrightarrow{\text{Dark}} \left[\begin{array}{ccccc} H & & H & & H \\ | & & | & & | \\ O & - & C & - & O \\ & & | & & \\ & & H & & \end{array} \right] \longrightarrow CH_2O + H_2O \qquad E_o = - 0.40 \text{ Volts}$$

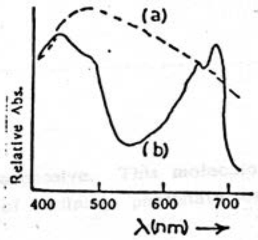


Fig. 1. Solar Spectrum (a), Chloroplast action spectrum (b)[1].

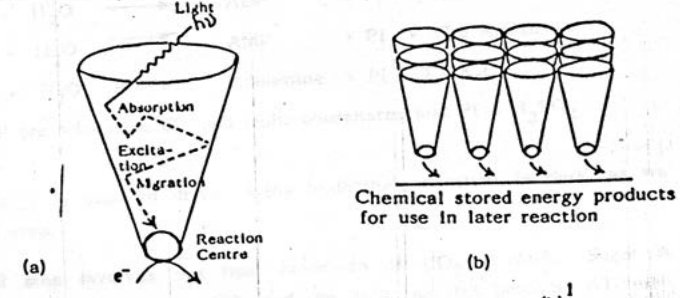
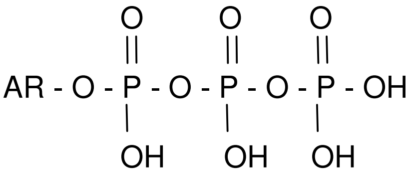


Fig. 2. Photo-antenna systems (a) and their spatial arrangements (b)[1]

Where E_o is the standard electrochemical potential of the given reaction at normal hydrogen electrode (NHE) scale. This photo-oxidation reaction is carried out by the involvement of various different intermediate enzymatic reaction sequences. During this reaction, the biological energy packet ATP (Adenosine Tri Phosphate) and strong reduction NADPH (Nicotinamide Dinucleotide Phosphates) are also obtained as byproduct besides the main product H^+. The universal energy packet ATP is in fact the ester of phosphoric acid.



$$\begin{array}{ccccccccccc} & & & & O & & O & & O & & \\ & & & & || & & || & & || & & \\ AR & - & O & - & P & - O - & P & - O - & P & - & OH \\ & & & & | & & | & & | & & \\ & & & & OH & & OH & & OH & & \end{array}$$

Where AR = Organic base called adenosine. This molecule liberates energy upon hydrolysis whereas the hydrolysis of ordinary phosphate esters is slightly endothermic.

$ATP + H_2O \rightarrow ADP + P_i + 7.3$ K.Cal.

$ADP + H_2O \rightarrow AMP + P_i + 7.3$ K.Cal.

$AMP + H_2O \rightarrow \text{Adenosine} + P_i + 3.4$ K.Cal.

Where ADP, AMP are adenosine di- and mono-phosphates and P_i = H_3PO_4= Phosphoric acid.

The liberated energy is used to drive many biological reactions in dark, as we shall see in third step.

(III) The third step involves the final reduction of CO_2 in dark. Sugar is finally synthesized from atmospheric CO_2 and the light reaction products ATP and NADPH in the following stoichiometry.

$$6\,CO_2 + 18\,ATP + 12\,NADPH + 12H^+ \rightarrow C_6H_{12}O_6 + 18ADP + 12NADP + 18P_i$$

where NADPH, NADP are reduced and oxidized nicotinamide dinucleotide phosphates.

Thus, the potential required to drive overall reaction is 1.21 volts. Free energy change of the photosynthetic reaction is 110 K.Cal. as obtained by the formula $\Delta G = nFE$, where n = number of electrons involved in the reaction, F = Faraday constant (96500 Coulombs) and E = potential required to drive the reaction. On electronic energy scale, volts can be treated as electron volts (eV). Thus the incident light should have energy at least 1.21 eV to carry out the whole photosynthetic reaction. It is interesting to observe that even the lowest energy light (Wavelength = 700 nm) has the energy of 1.76 eV as obtained by the formula $E_{eV} = 1235 / \boldsymbol{\lambda}$ (nm). This energy is sufficient to carry out the photo-oxidation even after considering some inherent loss processes.

2.3 FURTHER SYNTHESES

Photosynthetically produced glucose molecules further polymerize in different fashions to form starch and cellulose molecules. The former is responsible for metabolic reaction while the latter forms the structure of plants. The cellulose in wood, cotton, and common plant material with higher percentage of starch comes in the category of food (can be easily digested). Wood has higher percentage of cellulose than that in food materials.

The energy packet ATP formed during the basic photosynthetic process is also responsible for the protein synthesis in plants by the following route.

First Stage: Nitrogen Fixation

Atmospheric nitrogen is converted to ammonia with the help of nitrogenase enzyme complex.

$$N_2 + 6H^+ + 6e^- + 20\ ATP + 12H_2 \xrightarrow{\text{Nitrogenase}} 2NH_3 + 20\ ADP + 20\ P_i$$

Second Stage: Amino acid Formation

High concentration of ammonia is toxic for plants. Therefore, ammonia formed in the first stage is immediately converted to amino acids.

$$NH_3 \xrightarrow{\text{ATP}} \text{Amino acids.}$$

About 20 types of amino acids are formed.

Third Stage: Protein Formation

All the amino acids formed in the second stage link together to form protein.

$$\text{Amino acids} \xrightarrow{\text{ATP}} \text{Protein}$$

3. ENERGY CONTENT OF BIOMASS

Energy content of biomass is the energy stored in per unit mass of its body, which is released, on combustion. Plants are made of the elements C, H, O, and N. The ultimate composition after combustion is CO_2, H_2 and to some extent NO_x. Unlike photosynthetic storage of solar energy (section 2.2) here energy is released by the formation of stronger bonds O-H (-110 K.Cal./mole). A representative elemental composition of wood is shown in table[4].

TABLE - I

Elements		% of dry weight
Hydrogen (H)	-	6.3 - 6.4
Carbon (C)	-	50.8 - 52.9
Oxygen (O)	-	39.7 - 11.8
Nitrogen (N)	-	0.1 - 0.4
Sulphur (S)	-	Nil - Nil
Ash	-	0.9 - 1.0

On an average wood contains 77% volatile matter, 22% fixed carbon and 1% ash. Assuming that fixed carbon is burned on the furnace grate and that the volatile matters are burned as flame, it is clear that over 60% of the total calorific value resides in volatiles[4].

3.1 THE CRITERION FOR FUEL

An approximate relation between elemental composition of fuel and combustibility can be formulated[5]. For this purpose, an average reduction level R is defined as:

$$R = \frac{N_C + 9.5\ N_H - 0.5\ N_O}{N_C}$$

where N_C N_H and N_O are the number of carbon, hydrogen and oxygen in the molecule (Nitrogen is considered to be negligible). R is the number of oxygen molecules needed to burn a compound to CO_2 and H_2O, divided by number of carbon atoms present in the molecule. The basis of this formula is that each C-atom requires one molecule of O_2 to be converted to CO_2, each H-atom requires 0.25 molecules of O_2 to be converted to H_2O and each O-atom present in the molecule diminishes by one half the number of out side O_2 needed for combustion.

For completely oxidized carbon CO_2, R = O and for completely reduced carbon CH_4, R = 2. All other values of R vary between these two extreme values. It is interesting that for carbohydrate (CH_2O), R = 1. Thus the process of photosynthesis lifts reduction level of carbon from R = O to R = 1. As a result, about one-half of the maximum possible combustion energy per atom of carbon is stored.

A general formula for wood material can be given as $C_{NC}\ H_{NH}\ O_{NO}$. As a general rule, heat of combustion of this molecule is about 110 K. Cal/mole per carbon per unit R. Thus, we can get a rough estimate of heat of combustion of the given wood quality. In fact, the actual heat of combustion has been found to be within ± 1.5% of the calculated one. Also, it is clear that the plants with less oxygen content will be more useful as fuel.

In alcoholic fermentation of glucose (R=1), some of it is reduced to ethanol C_2H_5OH (R=1.5) and another part is oxidized to CO_2 (R=O). The net effect is the release of only 2.1 K.Cal./Mole while the same molecule of glucose releases (110x1x6 K.Cal.) = 660 K.Cal./mole when oxidized by oxygen to CO_2 and H_2O during respiration. It is worth noting here that photosynthesis lifts the reduction level of carbon from 0 to 1 and respiration brings it back to zero.

3.2 MEASUREMENT OF CALORIFIC VALUE

The calorific value of a biomass can be measured in Bomb Calorimeter where the matter is burnt in a sealed chamber in an atmosphere of pure oxygen gas. The routine procedure is described elsewhere [6,7]. We shall discuss the method here in context with wood.

a) The high moisture content of most wood materials require that the sample must be oven dried at 80 -110 ^{o}C.

b) Plants have different parts such as wood, bark, leaves, etc. Each of them will have separate calorific value. The user should select a method for preparing sample that will not destroy or remove any of the combustible constituents. Alternatively, the calorific value of each part should be mentioned separately.

c) It is necessary to make several preliminary tests to determine the approximate maximum allowable moisture content at which sample can be ignited in Bomb without difficulty.

e) Due to variation in composition, it is difficult to get reproducible results. Therefore, one should mention the average value, the number of tests and percentage variation.

Other general precautions for bomb calorimeter used are as follows:

a) The Calorimeter cannot withstand a sample, which liberates more than 41.8 KJ. In general, the use of sample, more than 1.10 gm should be avoided.

b) The bomb should not be overcharged with oxygen.

c) The operator should stand away from the calorimeter at least after 15 seconds of firing the sample inside.

The calorific values of some biomass materials are given in table [8,9].

TABLE - 2

Biomass		Calorific Value MJ/Kg.
Farm Product		
Cow dung	-	15.0
Cow dung Cake	-	12.6
Groundnut Shell	-	18.1
Mustard Stalk	-	18.8
Wheat Straw	-	17.3
Saw Dust	-	19.7
Rice Husk	-	14.5
Wood		
Acacia auriculiformis	-	20.06 - 20.48
A. branchystachya	-	17.97 - 18.39
A. Cyclops	-	16.72 - 17.55
Callindra Calothyrsus	-	18.81 - 19.85
Gliricidia sepium	-	19.64 - 20.48
Gmelina arborea	-	20.06
Sesbania bispinosa	-	17.55 - 18.39
Prosopis juliflora	-	17.97 - 18.39

3.3 DIFFERENT ENERGY VALUES

Energy values of wood can be expressed in three ways [4] (a) Gross calorific values, (b) Net calorific value and (c) usable heat content. In all the cases, moisture content of material plays an important role in combustion. In combustion practice, wood moisture content is measured on a wet-weight basis i.e. percentage of total original weight. However, for forest products, dry weight basis is being used (amount of moisture is given as percentage of dry matter only). The inter conversion of both the methods are given below:

$$\% \text{ M.C (wet basis)} = \frac{\% \text{ M.C. (dry basis)}}{100 + \% \text{ M.C. (dry basis)}} \times 100$$

$$\% \text{ M.C (wet basis)} = \frac{\% \text{ M.C. (wet basis)}}{100 - \% \text{ M.C. (wet basis)}} \times 100$$

3.3.1 GROSS CALORIFIC VALUE

The gross calorific value is a measure of total energy embodied in the unit weight of fuel. It is known as “higher heating value” also. Experimentally, it is determined by bomb calorimeter method. In the standard procedures, wood samples are usually oven dried before calorimetric analysis. Thus, value thus obtained is called gross anhydrous calorific value. If the wood contains some moisture also, the gross calorific value at moisture content is given by

$$C_g = C_{ga} \, (1\text{-}m)$$

where C_{ga} = anhydrous gross C.V.
C_g = gross C.V.

Thus for moisture content of 30%
C_{ga} = 18.6 MJ/Kg.
C_g = 13.02 MJ/Kg.

3.3.2 NET CALORIFIC VALUE

Even during the combustion of dry matter, water is formed by the reaction of fuel's hydrogen content with oxygen. In the measurement of C_{ga} the heat released by the condensation of internal water is also added up in the total value. In fact, for practical purpose, no such condensation heat release is gained. Rather some useful heat is wasted in evaporating this water content. The net calorific value of "lower heating value" takes care of this fact.

Since hydrogen produces 9 times its own weight of water when burned, the amount of water formed by the combustion of 1 Kg of oven dry wood is

$$W = 9 \times M_H \text{ Kg}$$

Where M_H = % hydrogen in wood

Thus, the net calorific value can be given as:

$$C_n = C_{ga} - 9 \times \Delta H \times M_H$$

Where H = Latent heat of vaporization of steam 2.44 KJ/Kg.

If the moisture content is in (wet weight basis), the revised formula would be

$$C_n = C_{ga} \, (1\text{-}m) - \Delta H \, m + 9 \, M_H \, (1\text{-}m)$$

For the wood of moisture content 30% and hydrogen 6% the formula can be generalized as

C_n = 17.28 - 19.72 m MJ/Kg

3.3.3 USABLE HEAT CONTENT

Earlier mentioned heat content values are the standard reference values and useful from academic point of view. But in practice, it would be more useful to obtain the actual energy available in the furnace after facing many loss processes. The main losses are:

1. Further heating the moisture vapor (L_1)
2. Heating the gases CO_2, N_2 (L_2)
3. Heating the excess air (L_3)
4. Other conventional losses such as radiation, conduction, convection and humidity of air (L_4)

The total loss $L = L_1 + L_2 + L_3 + L_4$

Each of terms can be separately given as:

$L_1 = S_{H2O} [m + 9 M_H (1 - m] (T_f - T_i)$

$L_2 = S_{N2} + CO_2 [(1 - m) (W_{CO2} + W_{N2})] (T_f - T_i)$

$L_3 = S_{Air} [(1 - m) (W_S \times R_E)] (T_f - T_i)$

$L_4 = Cg \times 0.04$.

where S_{H2O}, $S_{N2} + CO_2$, S_{Air} are the specific heats of H_2O, S_{N2+CO2} in flue gas and air in the range of temperatures T_f and T_i.

T_i = Temperature of air and fuel entering the furnace.

T_f = Temperature of flue gases

W_{CO2}, W_{M2} = weights (Kg) of CO_2 and N_2 in flue gas after burning 1Kg. of wood with stoichiometric air (6.21 Kg.).

W_S = Stoichiometric weight of air required for complete combustion of 1 kg of wood (6.21 Kg).

R_E = Excess air expressed as a decimal of stoichiometric air requirement (e.g. 0.5, 0.8 times).

m = moisture content (wet weight basis).

The value of L_4 is the assumed one, based on general observation.

The final usable heat content or "recoverable heat content" of wood fuel is given as: Usable heat Content $C_U = C_n - L_1 + L_2 + L_3 + L_4$

3.4 THE COMPROMISE ENERGY UNIT

The very basic statement of second law of thermodynamics "Energy can neither be created nor destroyed, it can only be converted from one form to another" itself indicates that all forms of energy must have something common among themselves. As a concept, all of them can be defined as measure of the ability to do work. As we know that biomass energy can be directly converted into heat, electricity, oil, light and mechanical energy. Through modern energy plantation techniques, each of the above mentioned energy forms could be converted into biomass more or less directly. Rather muscle power is also added to it. Thus energy is the unifying concept for food, fuel and other stored or moving energy forms. Unfortunately, severe lack of unity occurs in using the units of energy such as:

Heat energy	Btu, Calories
Electrical energy	Kilowatt-hours
Mechanical energy	Horsepower-hours, foot pound
Electromagnetic energy	ergs
Food energy	Calories
Coal energy	Metric tonnes equivalents
Oil energy	Barrel oil equivalents
Food Crop energy	Bushels
Atomic energy	TNT equivalents

Fortunately, this complication has been avoided by using a compromise unit (International system of units) i.e. Joules. 1 Joule = 0.239 Calories = 0.000949 Btu

This unit is now universally used whether one speaks of oil, gasoline, electricity, food, water, reservoir, wood, cow dung or muscle energy. The conversion factors are given below:

TABLE - 3

To convert from	To	Multiply by
British thermal unit (Btu)	kilojoules	1.054
Calories (Cal)	Joules	4.19
Ergs (Eg)	Joules	1×10^{-7}
Kilowatt hours (KWh)	megajoules	3.6
Megajoules (MJ)	kilojoules	1000
Gigajoules (GJ)	megajoules	1000
Terajoules (TJ)	gigajoules	1000
Watts (W)	joules/sec	1
Liter petrol	megajoules	35
Kilogram oil	megajoules	43.2
Barrel oil equivalent	gigajoules	6.1
Tonne Coal equivalent	gigajoules	29.3
Tonne Coal equivalent	barrel oil equivalent	4.8

4. ENERGETICS OF BIOMASS CONVERSIONS

Wood is used as energy source for heating, mechanical work or for electricity generation. It can be either used as "firewood" i.e. used for direct combustion or as fuel-wood i.e. converted into secondary fuels such as producer gas, alcohol etc. A detail survey of different conversion processes is given elsewhere [9]. Emphasis will be given here only on the energetics of different processes in brief.

4.1 DRYING

The process of physical removal of water from wood is called drying. Drying the biomass is important because it improves its colorific value. The energy required for drying will vary largely for different system. Generally, 9% of energy value of wood is lost in reduction the moisture content from 30% to 9%

4.2 DENSIFICATION

Using the loose biomass e.g. bark, sawdust, chips, leaves and shaving is very inconvenient. That is why they are converted into a uniformly sized fuel by densification process i.e. compressing the material particle by mechanical means. Due to uniformity of size, the densified materials can be used in more efficient way. However, densification is an energy consuming process and necessitates the use of electrical energy input for size reduction, transportation, agglomeration and for moisture removal (74.16 - 540 MJ/tonne of fuel).

4.3 PYROLYSIS

Pyrolysis involves thermal decomposition of wood either in absence of air or in limited air. This process is used either for carbonization i.e. charcoal production or for gasification i.e. combustible gas production. The energetic effectiveness of the conversion process can be assessed by the following terms.

$$\text{Yield (Y)} = \frac{\text{Mass of product fuel}}{\text{Mass of input fuel}}$$

$$\text{Conversion efficiency } (\eta_c) = \frac{\text{Energy content of product fuel}}{\text{Energy content of input fuel}}$$

$$\text{Calorific value ratio (R)} = \frac{\text{Calorific value of product fuel}}{\text{Calorific value of product fuel}}$$

They are correlated by the following formula

$$\eta_c = Y \times R$$

4.3.1 CARBONIZATION

The aim of carbonization is to obtain a solid fuel with a predominant fraction of fixed carbon and distill volatiles by pyrolysis of wood in absence of air. Thus, it is a total utilization process in which following three products are formed:

a) Charcoal (C.V. 27-33 MJ/Kg)

b) Condensable volatiles known as pyrolytic oil (mainly pyroligneous acid) with calorific value 27 - 31.5 MJ/Liter.

c) Non-Condensable gases such as CO, N_2, H_2 CH_4, CO_2 (C.V. 8.36 MJ/Nm^3).

The overall conversion efficiency of charcoal production process is 10 - 30% depending upon the methods and quality of wood.

4.3.2 GASIFICATION

The aim of the gasification process is to generate a gaseous fuel, the volatiles are vaporized and combusted and fixed part is reduced to CO_2 and H_2. Small chips of wood are burned in closed fire chamber (gasifier) with limited air supply (only 0.2 to 0.4 of stoichiometric requirement of air). The resulting gas contains CO, H_2, tars, vaporized volatiles, CO_2, N_2, CH_4 with calorific value (4.18 - 6.27 MJ/Nm^3).

The efficiency of conversion of wood to cold unclean gas is 85-95%. The overall efficiency of wood energy to mechanical power conversion is 15%. The efficiency of conversion of wood energy to thermal energy is 45-50%.

4.4 LIQUEFACTION

The high energy density i.e. energy content per unit volume of liquid fuels obtained from wood, makes it the most attractive from practical point of view. Liquid fuel from wood can be used as a substitute for kerosene and gasoline. The comparative energy density is shown below:

TABLE - 4

Parameters	Liquid	Solid	Gas
Energy density ($Million\ KJ/m^3$)	16.4-37.62	5.01 - 10.92	0.0083
Energy Density Ratio	25	10	1

Liquefaction of wood can be done by following different ways.

4.4.1 HYDROLYSIS

Hydrolysis is the chemical addition of water to cellulose ($C_6H_{10}O_5$....) to convert it to glucose ($C_6H_{12}O_6$) which is finally converted to ethyl alcohol (C_2H_5OH). Ethyl alcohol is well known as a clean fuel. Hydrolysis is carried out either (a) by dissolving the cellulosic material in concentrated acid and then break it to glucose. Glucose is converted into ethyl alcohol after being fermented by yeast. Following are the data on hydrolysis of wood.

-Yield: 190 liters/tonne of oven dry wood
- Calorific value of ethanol: 23.6 MJ./liter
- Wood to alcohol conversion: 14-23% efficiency.

4.4.3 LIQUEFACTION OF SYNTHESIS GAS

The mixture of gas containing only H_2 and CO is called synthesis gas. Wood is first converted to synthesis gas. Thereafter, the hydrocarbons and oxygenated aliphatic compounds are obtained by catalytic hydrogenation of CO according to following reactions:

(Fischer-Tropsch Method)

$CO + 2\ H_2$ ------ $CH_3\ OH$
$9\ CO + 19\ H_2$ ----- $C_9H_2O + 9\ H_2O$

Yield - 190 liters/tonne of dry wood
Calorific value (average) = 34.6 MJ/Liter.

4.5 COMBUSTION

The combustion of wood is the direct burning of wood in air. When wood is exposed to heat at 250^0C, the total combustion occurs in three stages.

a) Drying - (Moisture removal)
b) Pyrolysis - (burning of volatiles)
c) Glowing - (fixed carbon burning)

The efficiency of wood burner depends upon burner design, wood quality and size of burner. Wood burner efficiency is obtained generally by measuring the heat utilized in boiling the given quantity of water by the known weight of wood. The ratio of heat required to boil the given quantity of water and wood consumption (in joules) for the same period, gives the efficiency of system. In general, the efficiency of wood stoves vary between 4% to 25%.

5. FIELD ESTIMATION OF BIOMASS ENERGY

Just as wheat grower is interested in grain yield, a biomass energy technologist would be interested in "energy yield". The concept of energy plantation itself aims at harvesting energy. For this purpose, one needs to find out the yield of biomass in the given area. The yield can be determined either after harvesting or in the uncut plantation itself[10-14]. The calorific values of different tree species vary between 16.72 - 20.48 MJ/Kg (Table-2). Therefore, one has to take precautions while estimating the energy value of whole field of energy plantation.

a) Above mentioned calorific values are reported typically for stems of the wood. However, an energy plant contains also bark, leaves, branches and root. Each of the parts has different calorific value. The biomass yield should be estimated separately for each part in the whole field. Total energy yield should be taken up as the addition of energy values of different parts.

b) If energy plantation contains only one type of trees, the calculation is easier. However, when different species are mixed up in a single plot, an estimation of biomass yield separately for different species is necessary. Otherwise, there are chances of overestimation or underestimation of energy yield. For a non-uniform and completely mixed up energy plantation the general compromise calorific value is taken to be 16.72 MJ/Kg.

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