Technologies For Biomass Utilization

PART 1

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Technologies for Biomass Utilisation

PART 1

- Applications to be serviced
- Biomass, classification and properties
- What happens when biomass is heated
- Stoichiometry and Calorific value
- Power of a combustor
- Flame temperature

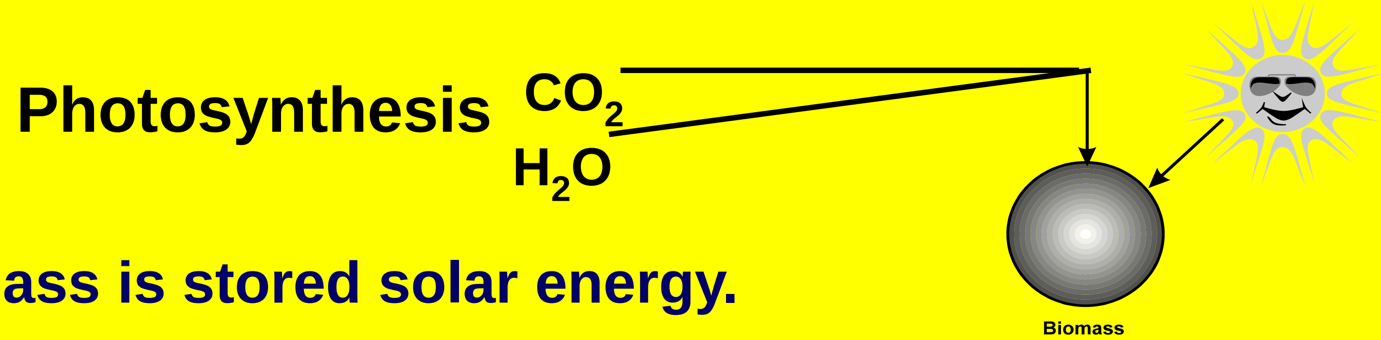
Applications

Thermal (Fossil fuel/Electricity Replacement)

- **Drying ⇒ 50 to 150 °C (with or without clean up)**
- **Hot water/cooking ⇒100 to 500 °C**
- **Heat treatment, process heat, etc (700 to 900 °C)**
- **Non ferrous melting ⇒ ~ 1200 °C**
- **Ceramic industry ⇒ ~ 1000, 1350 °C (glazing}**
- **Glass Industry ⇒ 1450 °C**

If we wish to replace all of fossil fuels, we need to see how to obtain as high a temperature as possible (it is not a matter of calories alone. It is also **°C** which matters)

Varieties of biomass / Waste



Biomass is stored solar energy.

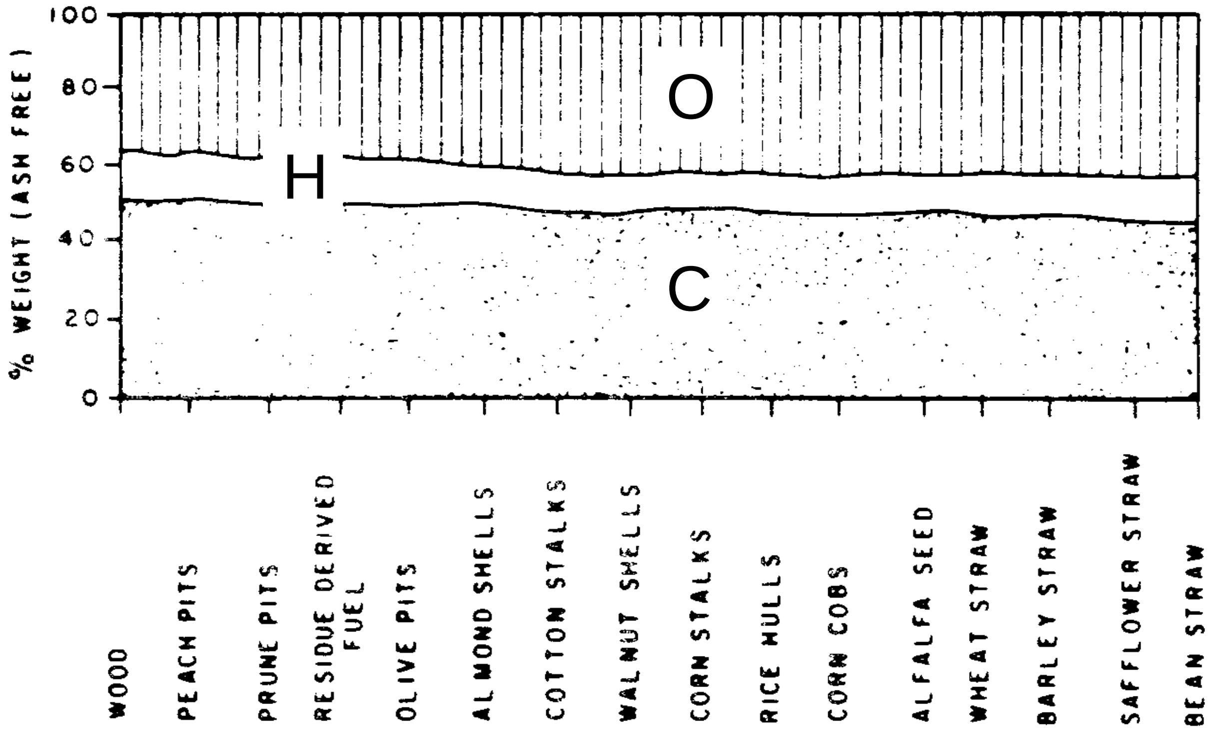
- **Biomass can be classified as woody and non-woody.**
- **Woody biomass is essentially the solid stalk of the main trunk and branches in trees/plants. It is a structural element in the living material. It is dense and has little ash.**
- **Even agricultural residues which may consist of whole plants or branches of plants can be woody, like cotton stalk and mulberry stalk. Weeds like Juliflora Prosopis, Lantana camera, usually found in tropical climates can also be treated as woody biomass.**

Biomass classification

Woody	Wastes and light weight crop residues
Branches of wood , Bamboo	Rice husk, Rice straw
Some agricultural wastes	Sawdust , Bagasse
corncobs, coconut shells	Sugarcane trash, peanut shells
Cotton stock, Mulberry sticks	Coir pith, bagase pith
Lantana Camara, Prosopis Julifora	Wheat straw, straws of cereals
Density > 250 - 600 kg/m^3	< 250 kg/m^3
Ash < 3%	~ 6 - 20 %

Ultimate analysis of several biomass

Ultimate Analysis of Wood and Coal (32).



Ultimate Analysis of Biomass Fuel Tested at the University of California, Davis.

Bulk Densities of Pulverised Fuels

Fuel (sun dry)	Ash (%)	Bulk Density (kg/m^3)
Saw dust (< 3 mm)	< 1.0	300 - 350
Rice husk	20	100 - 130
Rice husk pulverised (< 2 mm)	20	380 - 400
Sugar cane trash (chaff cut)	6	50 - 60
Sugar cane trash (pulverised, < 4 mm)	6	70 - 90
Ground nut shell	3.5	120 -140
Ground nut shell (pulverised, < 2 mm)	3.5	330 - 360

Composition of Biomass, $CH_n O_m N_p$

Even though woody and non-woody classification is important, it is useful to recognise that the composition is nearly same over a number of species.

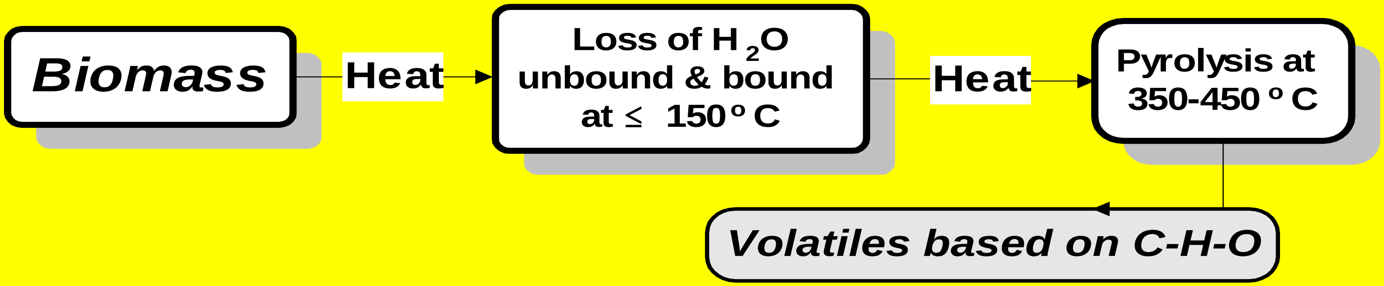
Material	n	m	p
Rice husk	1.78	0.56	0.007
Saw dust	1.65	0.69	-
Paper	1.60	0.65	0.005
Rice straw	1.56	0.50	0.008
Douglas fir, Beech, poplar	1.45	0.60	0.002
Pine bark, Red wood	1.33	0.60	0.002

Structurally, biomass is composed of about 50% cellulose, 25% hemicellulose and 25% lignin. Cellulose and hemi-cellulose break down easier than lignin, thermally as well as bacterially.

When biomass is heated, it begins to loose moisture, unbound first and bound later.

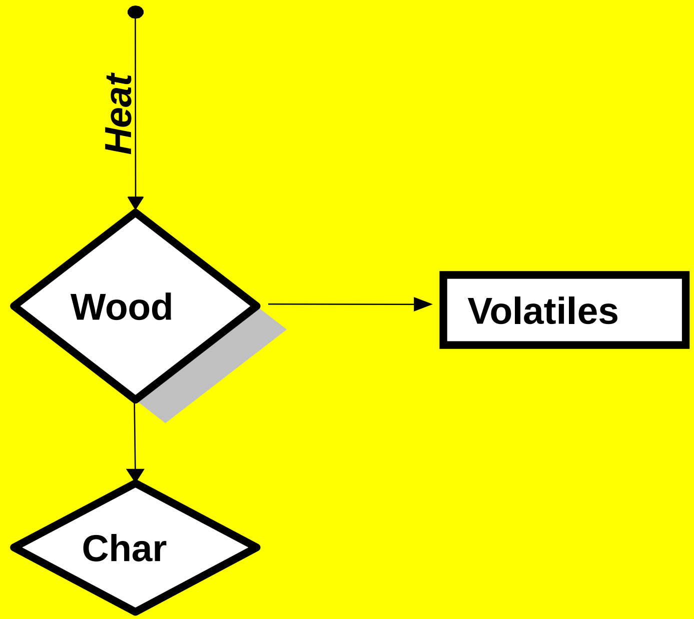
Biomass as Volatiles + Carbon + Ash:

What happens when biomass is heated?



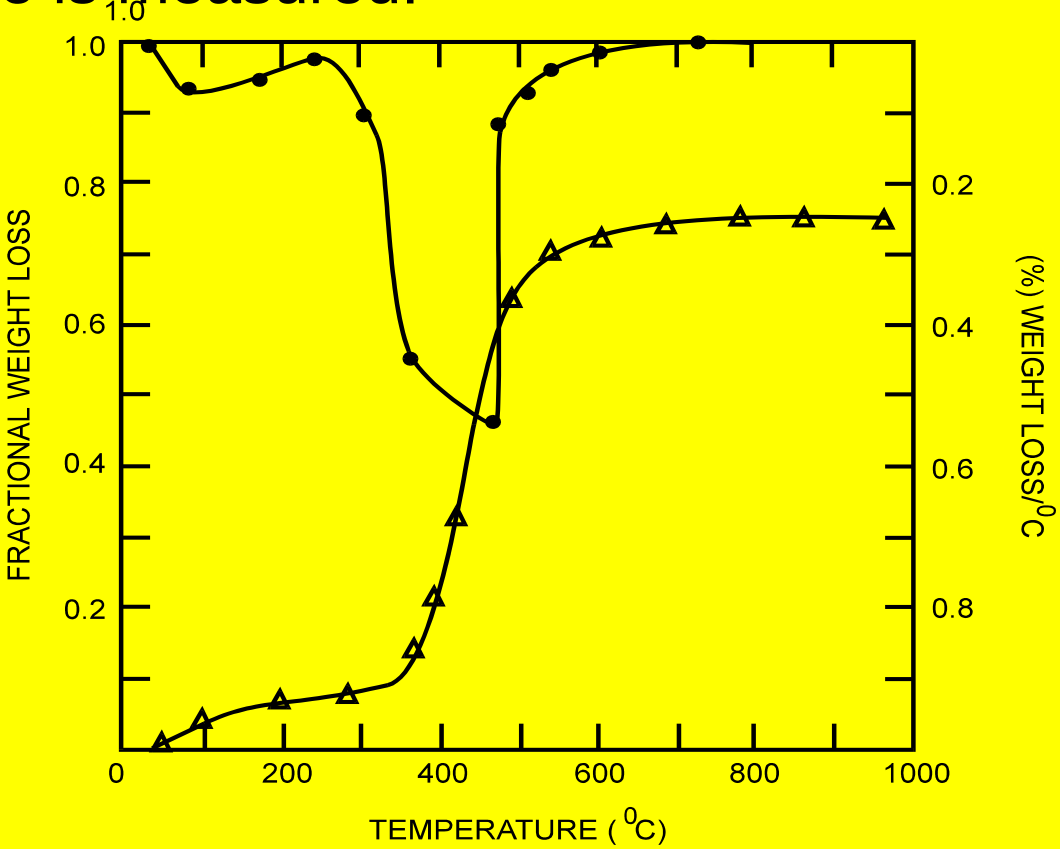
Most Hydrogen will be lost during this process. What will be left behind is called char, consisting of mostly carbon, but some hydrogen and oxygen are also left behind. Typical composition of char could be $CH_{0.1}o_{0.06}N_{0.002}$.

These can be represented as follows



Thermo-gravimetric Analysis (TGA)

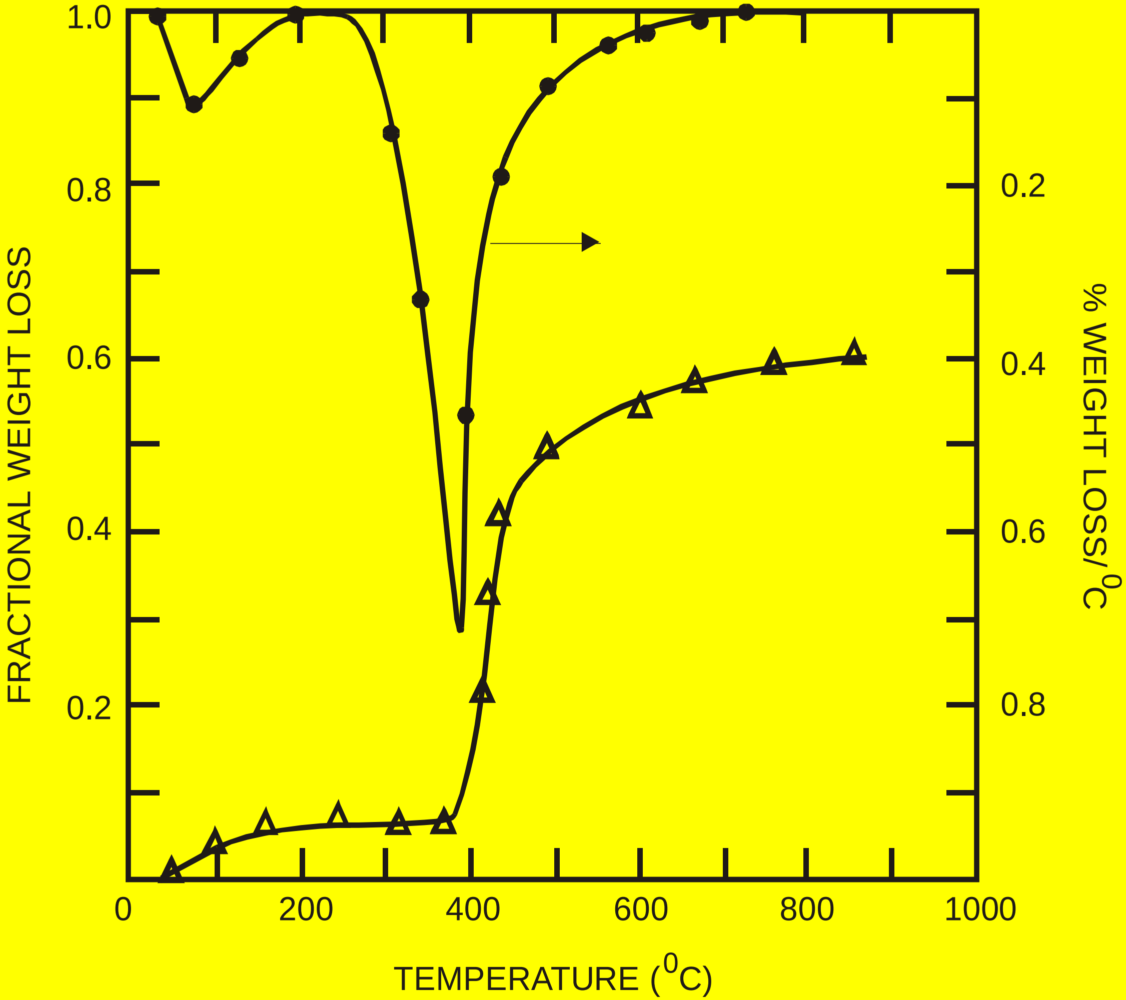
To understand what happens to the weight of a sample of wood when it is heated, one conducts an experiment called TGA. A sample is placed in a fine quartz balance and heated at a specific heating rate. The weight of sample with temperature is measured.



THERMOGRAM OF BAGASSE

Source: Thermochemical charactoisation for biomass residues, Grover P D, IIT Delhi, "94

Themogravimetric Analysis - contd



THERMOGRAM OF RICE HUSK

Source: Thermochemical charactoisation for biomass residues, Grover P D, IIT Delhi, "94

Volatiles, fixed carbon and ash content

Biomass	Volatiles, %	Fixed Carbon, %	Ash, %
Bagasse	75	17	3
Rice husk	60	20	20
Corncob	80	16	4
Wood	75	24	1

A Comparison of these with coal is as follows:

Component	Agro Residues	Wood	Coal
Volatile	60 - 75	75 - 80	20 - 30
Fixed Carbon	20 - 30	17 - 24	50 - 70
Ash	3 - 20	< 1	5 - 40

Notice that Coal has much smaller fraction of volatiles

Calorific Value

The Calorific Value of all biomass is obtained from Bomb calorimeter experiments and is represented by

$$\text{Lower Cal value (MJ/kg)} = (18.0 - 20\, f_w)\,(1 - f_{ash}), \quad (\text{for } f_w < 50\ \%)$$

where f_w = moisture fraction in dry wood , f_{ash} = ash fraction of dry wood

Typically sun dry wood has 10 % moisture. The ash fraction is about 0.5 %. Thus the calorific value of sun dry wood is 15.8 MJ/kg.

The calorific value in relation to other fossil fuels is as below

Fuel	Cal Value, MJ/kg
Biomass (wood)	16 - 18
Coal (5 % Ash)	35 - 37
Coal (40 % Ash)	20 - 22
Diesel / gasoline	42 - 44

Thermal power of a gasifier/combustor

Notice that the calorific value of biomass is roughly same as coal with 40% ash. In many countries the coal available has this kind of calorific value (including India). This has implications on the use of renewable source of energy as fuel instead of coal in manners not realised by most users far away from the pithead of coal. Notice also that the Calorific value of fuel oil is about two and half times that of biomass.

$$\text{Power of a Combustor, kW} = \frac{\text{Fuel (kg/hr)} \times \text{Cal Value kJ/kg}}{3600}$$

This is approximately expressed (for most of the biomass) as

$$\text{Power, kW} = 4.5 \times \text{fuel flow rate, kg/hr}$$

A 10 kg/hr of biomass burning system delivers a thermal power of 45 kW

Note: 10^5 kcal per hour = 4.186 x 10^5 kJ /3600 s = 116.2 kJ/s = 116.2 kW
(this is shown here because kcal per hour is an old unit used by many)

Air-to-fuel ratio

The amount of air needed to completely burn the fuel to CO_2 and H_2O is known as stoichiometric ratio. The amount required for converting carbon to carbon dioxide, hydrogen to water constitute the amount of air required. If the fuel has some oxygen in its structure then the amount of air required is smaller.

For a typical hydrocarbon we have:

$$CH_n + \left(1+\frac{n}{4}\right)\left(O_2+\frac{79}{21}N_2\right) \rightarrow CO_2 + \frac{n}{2}H_2O + \left(1+\frac{n}{4}\right)\frac{79}{21}N_2$$

A hydrocarbon fuel leads to stoichiometric ratio (S)

$$S = \frac{32 + 3.76\left(1+\frac{n}{4}\right)}{12+n}$$

is **14.4** for n=1.8 and **17.1** for n=4

These are the typical values for diesel/gasoline and methane, [n = 4]

Air-to-Fuel ratio Contd…

If we take a typical biomass

$$CH_{1.4}O_{0.6}N_{0.002} + 1.05\left(O_2 + \frac{79}{21}N_2\right) \longrightarrow CO_2 + 0.7\,H_2O + 3.952\,N_2$$

We get S = 6.3,

In general,

$$CH_nO_mN_p + \left[O_2 + \frac{79}{21}N_2\right] \longrightarrow CO_2 + \frac{n}{2}H_2O + \left[1 + \frac{n}{4} - \frac{m}{2} - \frac{p}{2}\right]N_2$$

$$\frac{A}{F} = \frac{(32+3.76)\left[1 + \frac{n}{4} - \frac{m}{2}\right]}{12+n+16m}$$

Stoichiometry and equivalence ratio

Bio-fuel	n	m	Ash (%wt)	(A/F) at stoichiometry
Rice husk	1.78	0.56	20.0	5.60
Saw dust	1.65	0.69	0.80	5.90
Paper	1.60	0.65	6.00	5.75
Rice straw	1.56	0.50	20.0	5.80
Douglas fir	1.45	0.60	0.80	6.30
Beech, Poplar, Red wood	1.33	0.60	0.20	6.00
Pine bark	1.33	0.60	2.90	5.85

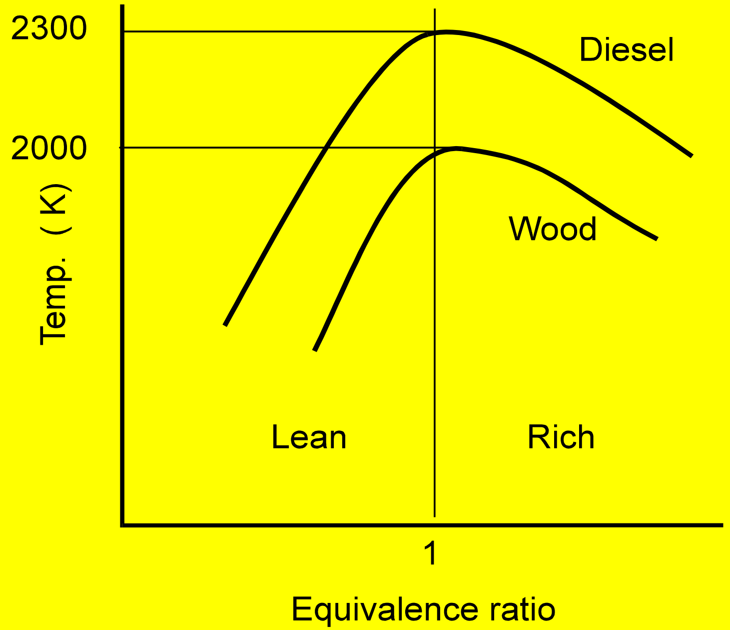
Depending on the mixture ratio (air-to-fuel), whether it is more or less than the stoichiometric value, one has lean or rich operating conditions.

These are described by a quantity called the equivalence ratio (f) which is the ratio of the air-to-fuel at stoichiometry to the actual value.

$$f = \left\{ (A/F)_{\text{Stoichiometry}} \Big/ (A/F) \right\}$$

$f < 1 \Rightarrow$ lean and $f > 1 \Rightarrow$ rich conditions

The flame temperature



Measured values of flame temperature for wood combustion in actual systems is generally around 1000^{0}C (1273 K) and rarely exceeds 1400^{0}C (1673 K). Note, however, that the theoretical value is close to 2000 K (1667 ^{0}C).

Is this why we call this theory and the other experiment?!

It is important that we understand this.