

Biomass Energy Conversion

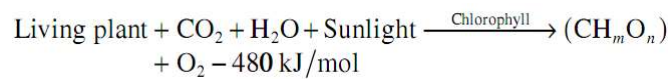
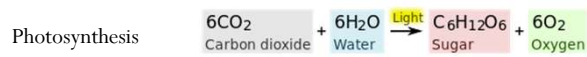
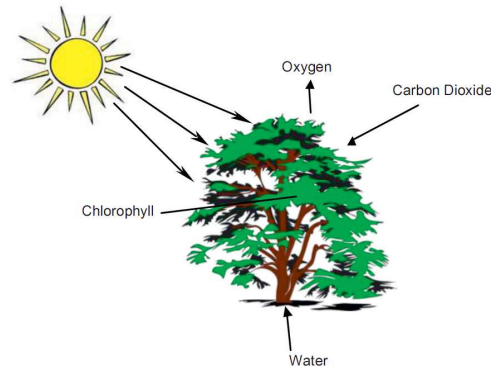
Biomass

- Biomass refers to any organic materials that are derived from plants or animals

Definition by United Nations Framework Convention on Climate Change

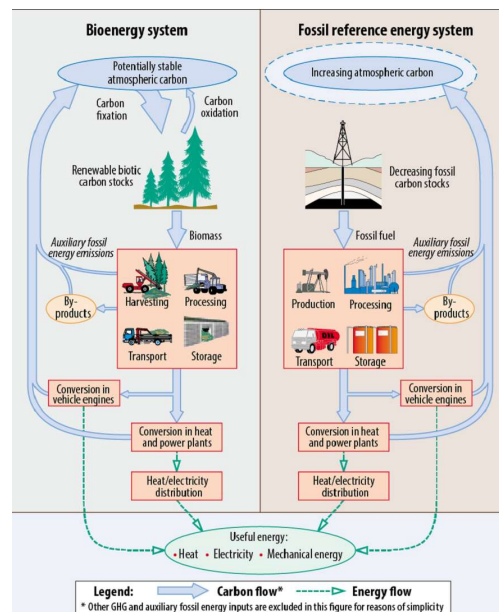
- **Non-fossilized** and **biodegradable** organic material originating from plants, animals and micro-organisms. This shall also include products, by-products, residues and waste from agriculture, forestry and related industries as well as the **non-fossilized** and **biodegradable** organic fractions of industrial and municipal wastes
 - ❖ Agricultural: food grain, bagasse (crushed sugarcane), corn stalks, straw, nut shells, and manure from cattle, poultry etc.
 - ❖ Forest: trees, wood waste, wood or bark, sawdust
 - ❖ Municipal: sewage sludge, food waste, waste paper
 - ❖ Biological: animal waste, aquatic species

Biomass Formation

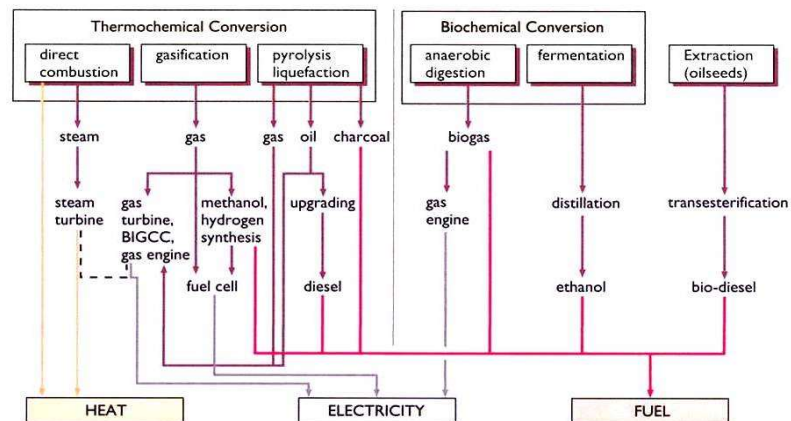


Biomass as an energy source

- Most of the biomass can be cultivated on a regular basis and replenished, bio-energy is considered a renewable energy source
- Bio-energy may be considered as a **carbon neutral system**
- It depends!



Biomass Energy Conversion



Biofuel

- Any fuel that is derived from biomass - recently living organisms or their metabolic by-products
- It is considered as a renewable, unlike natural sources such as petroleum, coal etc.



Fuel-Characteristics

- High calorific value
- Moderate ignition temperature
- Low moisture content
- Low non-combustible matter
- Harmless combustion products
- Low cost
- Easiness for transport
- Uniform size

Fuels Comparison

Fuel	HHV MJ/kg	kcal/g	BTU/lb
Hydrogen	141.9	33.9	61,000
Gasoline	47.0	11.3	20,000
Diesel	45.0	10.7	19,300
Ethanol	29.7	7.1	12,000
Propane	49.9	11.9	21,000
Butane	49.2	11.8	21,200
Wood	15.0	3.6	6,000
Coal (lignite)	15.0	4.4	8,000
Coal (anthracite)	36	7.8	14,000
Natural gas	54.0	13.0	23,000

Ultimate Analysis

	C (%)	H (%)	N (%)	S (%)	O (%)	Ash (%)	HHV (kJ/kg)
Maple	50.6	6.0	0.3	0	41.7	1.4	19,958
Douglas fir	52.3	6.3	9.1	0	40.5	0.8	21,051
Douglas fir (bark)	56.2	5.9	0	0	36.7	1.2	22,098
Redwood	53.5	5.9	0.1	0	40.3	0.2	21,028
Redwood waste	53.4	6.0	39.9	0.1	0.1	0.6	21,314
Sewage sludge	29.2	3.8	4.1	0.7	19.9	42.1	16,000
Straw-rice	39.2	5.1	0.6	0.1	35.8	19.2	15,213
Husk-rice	38.5	5.7	0.5	0	39.8	15.5	15,376
SW	47.2	6.5	0	0	45.4	1.0	20,502
Paper	43.4	5.8	0.3	0.2	44.3	6.0	17,613
MSW	47.6	6.0	1.2	0.3	32.9	12.0	19,879
Animal waste	42.7	5.5	2.4	0.3	31.3	17.8	17,167
Peat	54.5	5.1	1.65	0.45	33.09	5.2	21,230
Lignite	62.5	4.38	0.94	1.41	17.2	13.4	24,451
PRB coal	65.8	4.88	0.86	1.0	16.2	11.2	26,436
Anthracite	83.7	1.9	0.9	0.7	10.5	2.3	27,656
Petcoke	82	0.5	0.7	0.8	10.0	6.0	28,377

Combustion

- In combustion reactions, rapid oxidation of combustible elements of the fuel results in energy release as combustion products are formed.
- The three major combustible chemical elements in most common fuels are carbon, hydrogen, and sulphur.
- Sulphur is usually a relatively unimportant contributor to the energy released, but it can be a significant cause of pollution and corrosion problems.
- Combustion is complete when all the carbon present in the fuel is burned to carbon dioxide, all the hydrogen is burned to water, all the sulphur is burned to sulphur dioxide, and all other combustible elements are fully oxidized.
- When these conditions are not fulfilled, combustion is incomplete.

Air in Combustion

- Air is considered to be 21% oxygen and 79% nitrogen on a molar basis
- With this idealization the molar ratio of the nitrogen to the oxygen is $0.79/0.21 = 3.76$
- When air supplies the oxygen in a combustion reaction, therefore, every mole of oxygen is accompanied by 3.76 moles of nitrogen

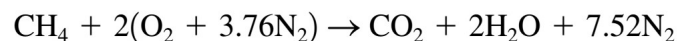
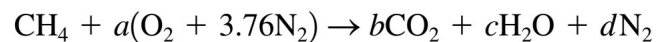
Theoretical Air

The minimum amount of air that supplies sufficient oxygen for the complete combustion of all the carbon, hydrogen, and sulphur present in the fuel is called the ***theoretical amount of air***.

The products would consist of carbon dioxide, water, sulphur dioxide, the nitrogen accompanying the oxygen in the air, and any nitrogen contained in the fuel

No free oxygen would appear in the products.

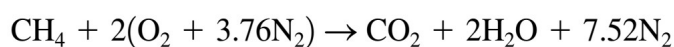
the theoretical amount of air for the complete combustion of methane:



Air Fuel Ratio

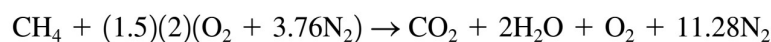
$$\frac{\text{mass of air}}{\text{mass of fuel}} = \frac{\text{moles of air} \times M_{\text{air}}}{\text{moles of fuel} \times M_{\text{fuel}}} \\ = \frac{\text{moles of air}}{\text{moles of fuel}} \left(\frac{M_{\text{air}}}{M_{\text{fuel}}} \right)$$

$$AF = \bar{AF} \left(\frac{M_{\text{air}}}{M_{\text{fuel}}} \right)$$

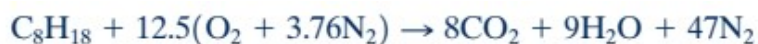
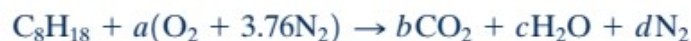


$$AF = \bar{AF} \left(\frac{M_{\text{air}}}{M_{\text{fuel}}} \right) = 9.52 \left(\frac{28.97}{16.04} \right) = 17.19$$

Complete combustion of methane with 150% theoretical air (50% excess air)

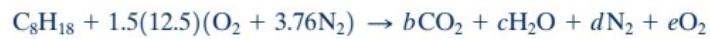


Determine the air–fuel ratio on both a molar and mass basis for the complete combustion of octane, C_8H_{18} , with (a) the theoretical amount of air, (b) 150% theoretical air (50% excess air).



$$\bar{AF} = \frac{12.5 + 12.5(3.76)}{1} = \frac{12.5(4.76)}{1} = 59.5 \frac{\text{kmol (air)}}{\text{kmol (fuel)}}$$

$$AF = \left[59.5 \frac{\text{kmol (air)}}{\text{kmol (fuel)}} \right] \left[\frac{28.97 \frac{\text{kg (air)}}{\text{kmol (air)}}}{114.22 \frac{\text{kg (fuel)}}{\text{kmol (fuel)}}} \right] = 15.1 \frac{\text{kg (air)}}{\text{kg (fuel)}}$$

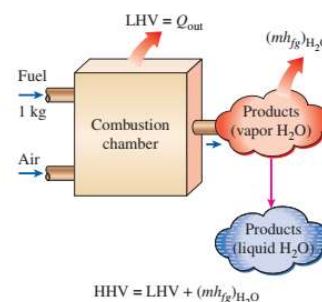


$$\overline{AF} = \frac{18.75(4.76)}{1} = 89.25 \frac{\text{kmol (air)}}{\text{kmol (fuel)}}$$

On a mass basis, the air–fuel ratio is 22.6 kg (air)/kg (fuel).

Calorific Value/Heating Value

- Amount of heat released when a fuel is burned completely in a steady-flow process and the products are returned to the state of the reactants. The heating value depends on the phase of the H_2O in the products.
- The heating value is called the higher heating value (HHV) when the H_2O in the products is in the liquid form
- It is called the lower heating value (LHV) when the H_2O in the products is in the vapor form



A certain biogas consists of 75 percent methane (CH_4) and 25 percent carbon dioxide (CO_2) by volume. If the higher heating value (HHV) of methane is 55,530 kJ/kg and the lower heating value (LHV) is 50,050 kJ/kg, what are the HHV and LHV of this biogas?

$$y_{\text{CH}_4} = 0.75$$

$$y_{\text{CO}_2} = 0.25$$

We consider 100 kmol of biogas mixture. In this mixture, there are 75 kmol of CH_4 and 25 kmol of CO_2 . The mass of CH_4 and CO_2 are

$$m_{\text{CH}_4} = N_{\text{CH}_4} M_{\text{CH}_4} = (75 \text{ kmol})(16 \text{ kg/kmol}) = 1200 \text{ kg}$$

$$m_{\text{CO}_2} = N_{\text{CO}_2} M_{\text{CO}_2} = (25 \text{ kmol})(44 \text{ kg/kmol}) = 1100 \text{ kg}$$

The total mass of the mixture is

$$m_{\text{total}} = m_{\text{CH}_4} + m_{\text{CO}_2} = 1200 + 1100 = 2300 \text{ kg}$$

The mass fraction of CH_4 is

$$\text{mf}_{\text{CH}_4} = \frac{m_{\text{CH}_4}}{m_{\text{total}}} = \frac{1200 \text{ kg}}{2300 \text{ kg}} = 0.5217$$

$$\text{HHV}_{\text{biogas}} = \text{mf}_{\text{CH}_4} \times \text{HHV}_{\text{CH}_4} = (0.5217)(55,530 \text{ kJ/kg}) = \mathbf{28,970 \text{ kJ/kg}}$$

$$\text{LHV}_{\text{biogas}} = \text{mf}_{\text{CH}_4} \times \text{LHV}_{\text{CH}_4} = (0.5217)(50,050 \text{ kJ/kg}) = \mathbf{26,110 \text{ kJ/kg}} \quad \blacktriangle$$

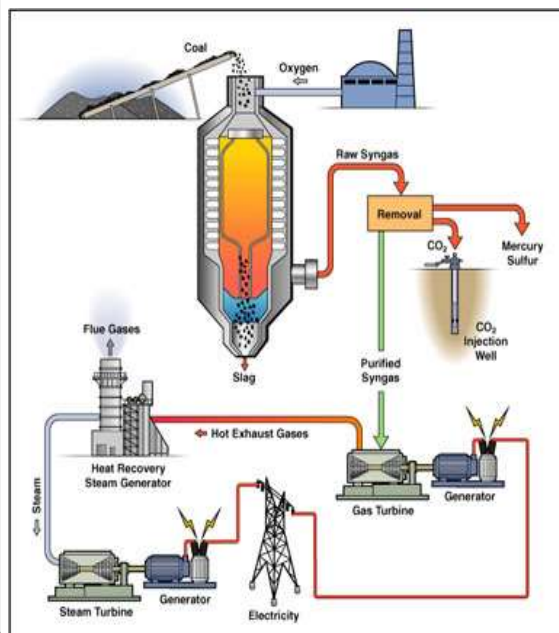
Motivation for Biomass Conversion

- Renewability

Fast-growing plants are being considered as fuel for new energy projects.

- Environmental Benefits

Emission	Pulverized-Coal Combustion	Gasification	Combined Natural-Gas Combustion
CO ₂ (kg/1000 MWh)	0.77	0.68	0.36
Water use (L/1000 MWh)	4.62	2.84	2.16
SO ₂ (kg/MWh)	0.68	0.045	0
NO _x (kg/MWh)	0.61	0.082	0.09
Total solids (kg/100 MWh)	0.98	0.34	~0



- Emission from an IGCC plant is 745 g/kWh compared to 770 g/kWh from a combustion-based subcritical pulverized coal (PC) plant
- In an IGCC plant, CO₂ is more concentrated in the flue gas, making it easier to sequester than it is in a conventional PC plant

- Most virgin or fresh biomass contains little to no Sulphur
- Biomass-derived feedstock such as municipal solid waste (MSW) or sewage sludge does contain sulphur, which requires limestone for the capture of it
- Interestingly, such derived feedstock also contains small amounts of calcium, which intrinsically aids sulphur capture
- A combustion system firing fossil fuels can oxidize the nitrogen in fuel and in air into NO (acid rain precursor) or into N_2O (greenhouse gas)
Both are difficult to remove
- In a gasification system, nitrogen appears as either N_2 or NH_3 , which is removed relatively easily in the syngas-cleaning stage
- Particulate in the syngas is also reduced significantly by multiple gas cleanup systems, including a primary cyclone, scrubbers, gas cooling, and acid gas-removal units

Comparison of Thermo-chemical Processes

Process	Temperature (°C)	Pressure (MPa)	Catalyst	Drying
Liquefaction	250–330	5–20	Essential	Not required
Pyrolysis	300–600	0.1–0.5	Not required	Necessary
Combustion	700–1400	≥ 0.1	Not required	Not essential, but may help
Gasification	500–1300	≥ 0.1	Not essential	Necessary
Torrefaction	200–300	0.1	Not required	Necessary

Biochemical Conversion

- Biomass molecules are broken down into smaller molecules by bacteria or enzymes
- This process is much slower than thermo-chemical conversion, but does not require much external energy
 - ❖ Digestion (anaerobic and aerobic)
 - ❖ Fermentation
 - ❖ Enzymatic or acid hydrolysis

The main products of **anaerobic digestion** are methane and carbon dioxide in addition to a solid residue

Bacteria access oxygen from the biomass itself instead of from ambient air.

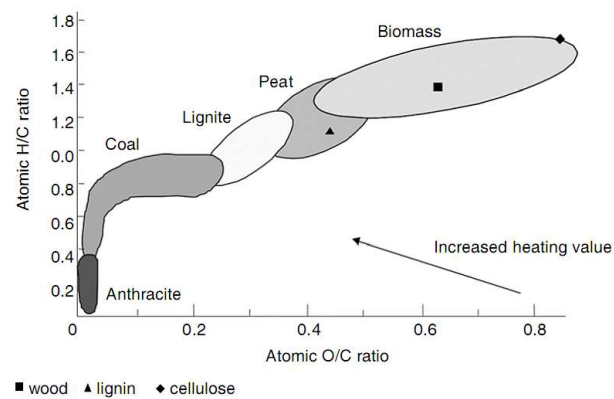
Aerobic digestion, or composting, is also a biochemical breakdown of biomass, except that it takes place in the presence of oxygen

It uses different types of microorganisms that access oxygen from the air, producing carbon dioxide, heat, and a solid digestate.

Fermentation

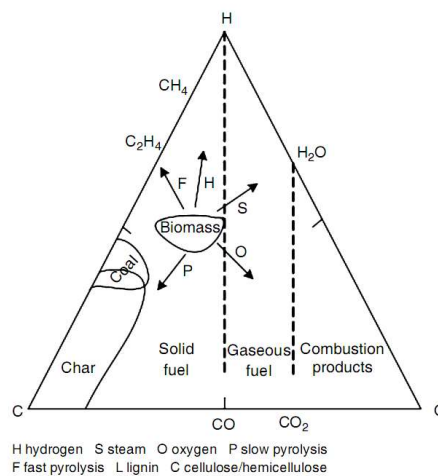
- Part of the biomass is converted into sugars using acid or enzymes
- The sugar is then converted into ethanol or other chemicals with the help of yeasts
- The lignin is not converted and is left either for combustion or for thermochemical conversion into chemicals. Unlike in anaerobic digestion, **the product of fermentation is liquid**
- Fermentation of starch and sugar-based feedstock (i.e., corn and sugarcane) into ethanol is fully commercial, but this is not the case with cellulosic biomass because of the expense and difficulty in breaking down (hydrolyzing) the materials into fermentable sugars
- Ligno-cellulosic feedstock, like wood, requires hydrolysis pretreatment (acid, enzymatic, or hydrothermal) to break down the cellulose and hemicellulose into simple sugars needed by the yeast and bacteria for the fermentation process.

Classification: Van-Krevelen Diagram



$$\left[\frac{H}{C}\right] = 1.4125 \left[\frac{O}{C}\right] + 0.5004$$

Ternary diagram



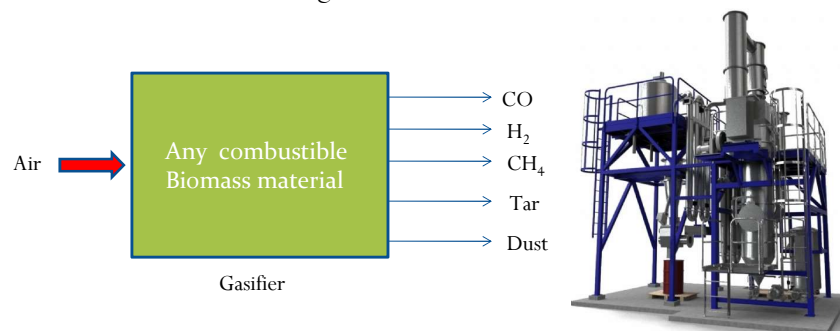
Gasification

- Conversion of any carbonaceous fuel to a gaseous product with a useable heating value
- Excludes combustion, because the product flue gas has no residual heating value!
- The dominant technology is partial oxidation, which produces from the fuel a synthesis gas (syngas) consisting of hydrogen and carbon monoxide in varying ratios
- The oxidant may be pure oxygen, air, and/or steam
- Syngas is also used as a feedstock in the production of chemicals like methanol

HISTORY

- The history of gasification dates back to the seventeenth century
- First patent for gasification- Robert Gardner (1788)
- Producer gas to drive IC engine - John Barber (1791)
- Gas generated from coal for lighting- Murdoc (1792)
- During World war II, over one million vehicles world wide were converted to producer gas (1939)
- After end of World War II, with plentiful and cheap gasoline and diesel availability gasification lost its importance (1945)
- The 1970's oil shocks brought a renewed interest in the technology (1973)
- Gasification came out as a natural choice for producing gas from renewable biomass due to global warming and depletion of fossil fuels (post 2000)

- The production of producer gas is called gasification
- It is the partial combustion of solid fuel (biomass) and takes place at temperatures of about 1000°C
- The reactor is called a gasifier



- Complete combustion of biomass : nitrogen, water vapor, carbon dioxide and surplus of oxygen
- In gasification, the products of combustion are combustible gases like Carbon monoxide (CO), Hydrogen (H₂) and traces of Methane and non-useful products like tar and dust
- The production of these gases is by **reaction of water vapor and carbon dioxide through a glowing layer of charcoal**
- Thus the key to gasifier design is to create conditions such that
 - a) biomass is reduced to charcoal
 - b) charcoal is converted at suitable temperature to produce CO and H₂

Why Gasification?

- For a given energy throughput, the amount of flue gas obtained from gasification is less than that obtained from a direct combustion system
- A gasified fuel can be used in a wider range of application than solid fuel
- Gas can be more easily carried and distributed than a solid fuel
- The concentration of CO₂ in the flue gas of a gasification-based plant is considerably higher than that of a combustion-based plant
- Gasification produces less NO_x per unit energy output than does a combustion system
- The total solid waste generated in an IGCC plant is lower than that generated in a comparable combustion system
- Convenient for generation of electricity in a small remote location or for distributed power generation
- The producer gas from a gasifier can be used as a feedstock for the production of fertilizer, methanol, and gasoline

Why Gasification?

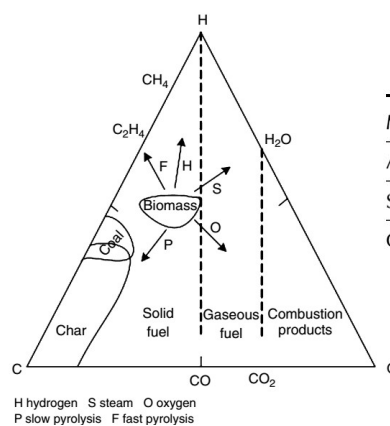
- $C + \frac{1}{2} O_2 \longrightarrow CO$ -111MJ/kmol
- $CO + \frac{1}{2} O_2 \longrightarrow CO_2$ -283 MJ/kmol
- $C + O_2 \longrightarrow CO_2$ -394 MJ/kmol
- ❖ 72% of the heating value of the carbon is conserved in the gas
- ❖ Fuel will contain hydrogen, and the percentage of the heat in the original fuel, which becomes available in the gas, is, in modern processes, generally between 75 and 88%

Steps

A typical biomass gasification process may include the following steps:

- Drying
- Thermal decomposition or pyrolysis (a thermal decomposition process that partially removes carbon from the feed but does not add hydrogen)
- Partial combustion of some gases, vapors, and char
- Gasification of decomposition products (**requires a gasifying medium like steam, air, or oxygen** to rearrange the molecular structure of the feedstock in order to convert the solid feedstock into gases, addition of hydrogen to the product)

Effect of gasifying media



Medium	Heating Value (MJ/Nm ³)
Air	4–7
Steam	10–18
Oxygen	12–28

• Chemistry of Gasification

- ❖ The chemistry of gasification is quite complex!
- ❖ It can be considered as consisting of a few major reactions which can progress to different extents depending on the gasification conditions (like temperature and pressure) and the feedstock used
- ❖ Combustion reactions take place in a gasification process, but, in comparison with conventional combustion which uses a stoichiometric excess of oxidant, gasification typically uses one-fifth to one-third of the theoretical oxidant
- ❖ The heat produced by the partial oxidation provides most of the energy required to drive the endothermic gasification reactions

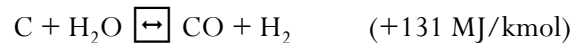
Major Reactions

- The combustion reactions:

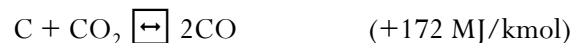


Other important gasification reactions include:

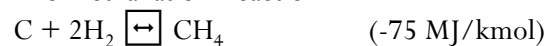
- The Water-Gas Reaction



- The Boudouard Reaction

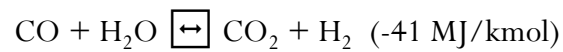


- The Methanation Reaction

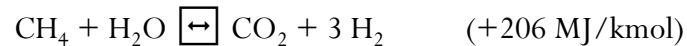


- The three heterogeneous reactions can be reduced to two homogeneous gas phase reactions of water-gas-shift and steam methane-reforming which collectively play a key role in determining the final equilibrium synthesis gas (syngas) composition

❖ “Water-Gas-Shift Reaction”



❖ “Steam-Methane-Reforming Reaction”



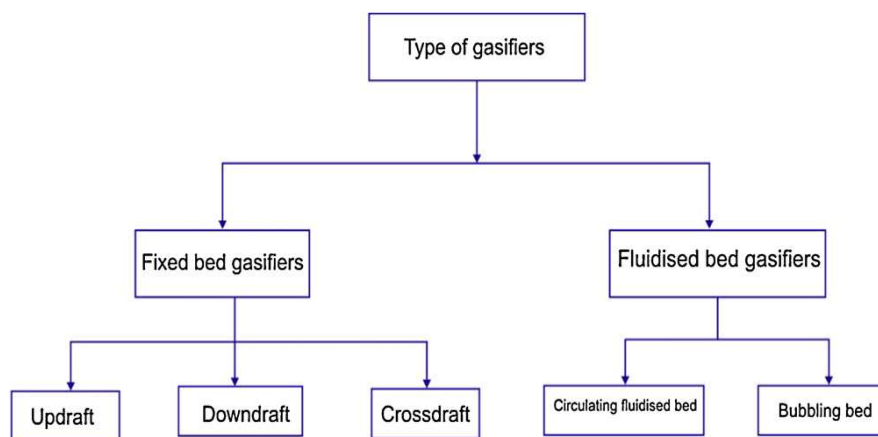
Process zones in a gasifier

- Four distinct processes take place in a gasifier as the fuel makes its way to gasification
- They are :
 - a) Drying of fuel
 - b) Pyrolysis – a process in which tar and other volatiles are driven off
 - c) Combustion
 - d) Reduction
- Though there is a considerable overlap of the processes, each can be assumed to occupy a separate zone where fundamentally different chemical and thermal reactions take place

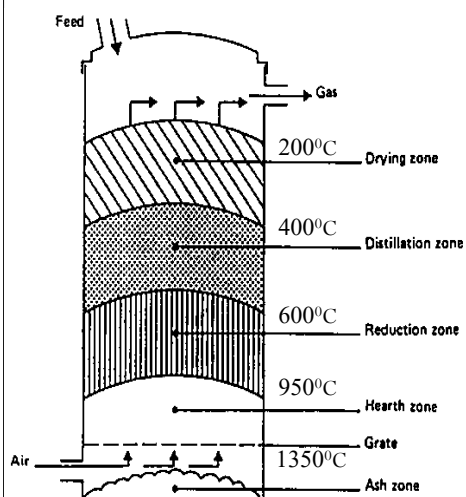
Pyrolysis

- Wood pyrolysis is an intricate process that is still not completely understood
- The products depend upon temperature, pressure, residence time and heat losses
- Upto the temperature of 200⁰C only water is driven off
- Between 200 to 280⁰C carbon dioxide, acetic acid and water are given off
- The real pyrolysis, which takes place between 280 to 500⁰C, produces large quantities of tar and gases containing carbon dioxide
- Besides light tars, some methyl alcohol is also formed
- Between 500 to 700⁰C the gas production is small and contains hydrogen

GASIFIER: CLASSIFICATION

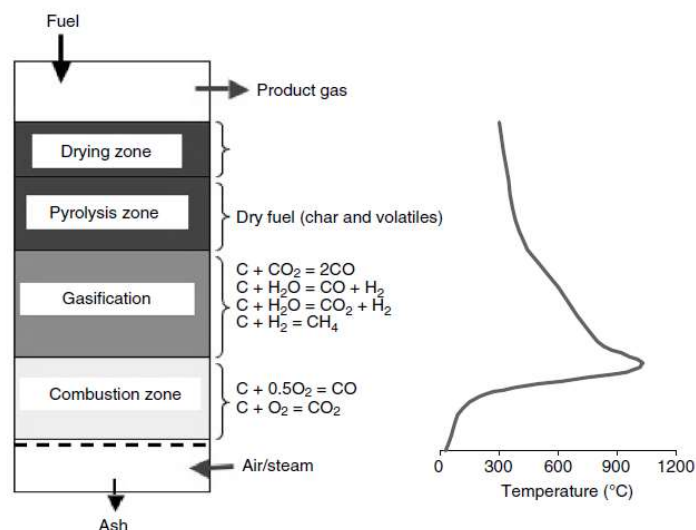


Updraft Gasifier



- The air intake is at the bottom and the gas leaves at the top
- Near the grate at the bottom the combustion reactions occur, which are followed by reduction reactions somewhat higher up in the gasifier
- In the upper part of the gasifier, heating and pyrolysis of the feedstock occur as a result of heat transfer by forced convection and radiation from the lower zones
- The tars and volatiles produced during this process will be carried in the gas stream
- Ash is removed from the bottom of the gasifier

Stages of Gasification

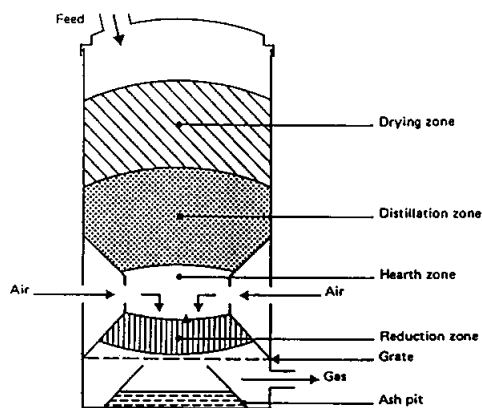


Source: Biomass Gasification and Pyrolysis Practical Design and Theory, Prabir Basu, Academic Press, UK 2010

Features of Updraft gasifiers

- Simplicity, high internal heat exchange leading to low gas exit temperatures and high equipment efficiency
- The possibility of operation with many types of feedstock (sawdust, cereal hulls, etc.)
- Problems associated with disposal of the tar containing condensates that result from the gas cleaning operations
- Poor reaction capability with heavy gas load

Down draft/co-current gasifiers



❖ Primary gasification air is introduced at /above the oxidation zone in the gasifier

❖ The producer gas is removed at the bottom of the apparatus, so that fuel and gas move in the same direction

Features of downdraft gasifiers

- Passage of tarry distillation products from the fuel through a glowing bed of charcoal assists gas formation
- Depending on the temperature of the hot zone and the residence time of the tarry vapours, a more or less complete breakdown of the tars is achieved
- The main advantage of downdraught gasifiers lies in the possibility of producing a tar-free gas suitable for engine applications
- Lower level of organic components in the condensate causes less environmental objections than updraught gasifiers
- Inability to operate on a number of unprocessed fuels (pelletized or briquetted feed is essential)
- lower efficiency resulting from the lack of internal heat exchange as well as the lower heating value of the gas

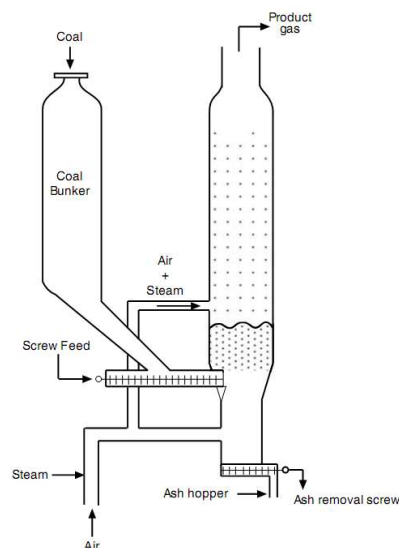
COMPARISON OF FIXED BED GASIFIERS

Characteristics	Updraft	Down draft
Moisture (%)	60 max	25 max
Gas exit temperature (°C)	200–400	700
Tar (g/Nm ³)	30–150	0.015–3.0
Gas LHV (MJ/Nm ³)	5–6	4.5–5.0
Hot-gas efficiency (%)	90–95	85–90

FLUIDIZED BED GASIFIERS (FB)

- Fluidization is defined as the operation through which fine solids are transformed into fluid like state through contact with a fluid.
- A fluidized bed is made of granular solids (bed materials) that are kept in a semi-suspended condition by the passage of the gasifying medium through them at the appropriate velocities.
- Unique features of FBG is its **excellent mixing** and **temperature uniformity**
- They are relatively insensitive to the fuel's quality
- Its tar production lies between that for updraft and downdraft gasifiers
- Principal types: 1. Bubbling (BFBG) 2. Circulating (CFBG)

High Temperature FBG



Features of Fluidized Bed Gasifiers

- Feedstock flexibility resulting from easy control of temperature, which can be kept below the melting or fusion point of the ash (rice husks), and their ability to deal with fluffy and fine grained materials (sawdust etc.) without the need of pre-processing
- High tar content of the product gas (up to 500 mg/m³ gas)
- Poor response to load changes
- Very small fluidized bed gasifiers are not foreseen and the application range must be tentatively set at above 500 kW (shaft power)

Bed Material

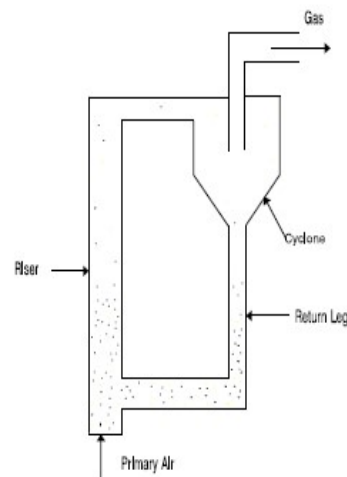
- The furnace of a fluidized bed gasifier contains a mass of granular solids,
- Size range of 0.1 to 0.3 mm or 0.25 to 1.0 mm depending on the type
 - ❖ Sand or gravel (for low-ash fuels, such as woodchips)
 - ❖ Fresh or spent limestone (for high-sulphur coal requiring control of emissions)
 - ❖ Ash from coal (for high- or medium-ash coal requiring no sulphur retention)

Biomass-fired systems may use special bed materials to avoid agglomeration in the bed

Combination of several types of bed materials may be used

CIRCULATING FLUIDIZED BED GASIFIER (CFB)

- Back mixing
- Particle entrainment
- It provides long gas residence time.
- Suitable for fuels with high volatiles.
- A CFB typically comprises a riser, a cyclone and a solid recycle device
- Fluidization velocity- 3.5–5.5m/s



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BUBBLING Vs CIRCULATING FLUIDIZED BED GASIFIER

- Both can be used for large scale application
- CFB has high velocity - good mixing and heat transfer
- CFB can have wide range of fuel particles
- CFB uses relatively fine particles ($< 400 \mu\text{m}$), provides large gas – solid contact surface areas.
- Large contact surface area and long residence time.

Biomass characterisation

➤ The most important properties related to the thermal conversion of biomass are as follows.

- Results of proximate analysis
- Results of ultimate analysis
- Heating value
- Hydrodynamic properties :
 1. Mean particle diameter
 2. Solid density
 3. Bulk density
 4. Voidage

Significance of proximate analysis

➤ High moisture content in the biomass leads to:

- Product gas with low heating value.
 - Incomplete cracking of the hydrocarbons released from the pyrolysis zone.
- If the ash content is greater than 5%, it will cause clinkering problems in the gasifier

- The reactivity of a solid fuel and its conversion to char inside the gasifier depend on its volatile matter content.
- Fixed carbon represents the solid carbon in the biomass that remains in the char in the pyrolysis process after devolatilization.
- Conversion of fixed carbon into gases determines the rate of gasification and its yield. **This conversion reaction, being the slowest, is used to determine the size of the gasifier.**

Ultimate analysis of biomass samples

- The composition of the biomass is expressed in terms of its basic elements except for its moisture and inorganic constituents.

$$C+H+O+N+S+ASH+M = 100\%$$

- C, H, O, N and S are the weight percentages of carbon, hydrogen, oxygen, nitrogen and sulfur, respectively in the biomass

Determination of HHV and stoichiometric ratio using correlations

- $HHV = 349.1C + 1178.3H + 100.5S - 103.4O - 15.1N - 21.1ASH$
- Amount of air required for complete combustion
 $= [0.1153C + 0.3434(H - O/8) + 0.0434S] \text{ kg/kg dry fuel}$

Determination Carbon and Hydrogen content using correlations

$$C = 0.635FC + 0.46VM - 0.095A \text{ Wt. \%}$$

$$H = 0.059FC + 0.060VM + 0.010A \text{ Wt. \%}$$

Heating Value

- The higher heating value of the biomass can be determined using a bomb calorimeter.
- It used for determining the efficiency of gasification process.
- The lower heating value (LHV) can be determined from HHV

$$HHV = LHV + (mh_{fg})_{H_2O} \quad (\text{kJ/kg fuel})$$

Results of Biomass Characterisation

Proximate analysis results

Feedstock	Fixed Carbon (wt. %)	Volatile Matter (wt. %)	Moisture (wt. %)	Ash (wt. %)
Coconut Shell	17	71	8	4
Saw dust	16	76	7	1
Rice husk	12	58	12	18
Coir pith	20	57	10	13
Rubber seed shell	24	51	11	14

• Ultimate Analysis Results

Biomass	N (wt. %)	C (wt. %)	S (wt. %)	H (wt. %)	O (wt. %)
Coconut shell powder	0.26	45.62	0.34	5.61	44.17
Rice husk	2.44	34.35	0.32	5.23	39.66
Saw dust	0.19	46.47	ND	5.82	46.52
Coir pith	0.60	44.08	ND	4.10	38.22
Rubber seed	2.13	41.11	0.27	6.60	35.89

- Chemical formula, Stoichiometric air-fuel ratio and elemental ratios of biomass

Biomass	Chemical formula	Stoichiometric air-fuel ratio	H/C	O/C
Coconut shell powder	$\text{CH}_{1.475}\text{O}_{0.726}$	5.30	0.123	0.97
Rice husk	$\text{CH}_{1.827}\text{O}_{0.866}$	4.068	0.152	1.15
Saw dust	$\text{CH}_{1.503}\text{O}_{0.751}$	5.36	0.125	1
Coir pith	$\text{CH}_{1.926}\text{O}_{0.697}$	4.85	0.093	0.867
Rubber seed	$\text{CH}_{1.926}\text{O}_{0.655}$	5.48	0.160	0.873

The feeds with a lower H/C ratio will produce a synthesis gas with a lower H_2 /CO ratio.

Heating Value of Biomass

Biomass	Higher heating value (MJ/kg)		Lower Heating Value (MJ/kg)
	Experimental	Theoretical	
Coconut shell powder	14.03	17.92	12.71
Rice husk	12.99	13.67	11.65
Saw dust	17.17	17.98	15.83
Coir pith	15.27	15.98	14.21

Fuel Characteristics

A gasifier fuel can be classified as good or bad according to the following parameters:

- 1) Energy content of the fuel
- 2) Bulk density
- 3) Moisture content
- 4) Dust content
- 5) Tar content
- 6) Ash and slagging characteristic

Composition of Producer Gas

Fuel	Gasification method	Volume Percentage					Calorific value MJ/m ³
		CO	H ₂	CH ₄	CO ₂	N ₂	
Charcoal	Downdraft	28-31	5-10	1-2	1-2	55-60	4.60-5.65
Wood with 12-20% moisture content	Downdraft	17-22	16-20	2-3	10-15	55-50	5.00-5.86
Wheat straw pellets	Downdraft	14-17	17-19	-	11-14	-	4.50
Coconut husks	Downdraft	16-20	17-19.5	-	10-15	-	5.80
Coconut shells	Downdraft	19-24	10-15	-	11-15	-	7.20
Pressed Sugarcane	Downdraft	15-18	15-18	-	12-14	-	5.30
Charcoal	Updraft	30	19.7	-	3.6	46	5.98
Corn cobs	Downdraft	18.6	16.5	6.4	-	-	6.29
Rice hulls pelleted	Downdraft	16.1	9.6	0.95	-	-	3.25
Cotton stalks cubed	Downdraft	15.7	11.7	3.4	-	-	4.32

- The maximum dilution of gas takes place because of presence of nitrogen
- Almost 50-60% of gas is composed of noncombustible nitrogen. Thus it may be beneficial to use oxygen instead of air for gasification
- However the cost and availability of oxygen may be a limiting factor in this regard
- Where the end product is methanol – a high energy quality item, then the cost and use of oxygen can be justified!

Tar in Gasification

- Tar is a major issue in both gasification and pyrolysis
- It is a thick, black, highly viscous liquid that condenses in the low-temperature zones of a gasifier
- It clogs the gas passage and leads to system disruptions.
- It can lead to:
 - ❖ Condensation and subsequent plugging of downstream equipment
 - ❖ Formation of tar aerosols
 - ❖ Polymerization into more complex structures

Tar Content

- Tends to deposit in the carburetor and intake valves causing sticking and troublesome operations in the case of IC engine applications
- A product of highly irreversible process taking place in the pyrolysis zone
- The physical property of tar depends upon temperature and heat rate and the appearance ranges from brown and watery (60% water) to black and highly viscous (7% water)
- Approximately 200 chemical constituents that have been identified in tar so far
- Major effort has been devoted to cleaning tar by filters and coolers
- A well-designed gasifier should generate less than 1 g/m³ of tar
- Downdraft gasifiers produces less tar than other gasifiers

Tolerance level of tar

Application	Particulate (g/Nm ³)	Tar (g/Nm ³)
Direct combustion	No limit specified	No limit specified
Syngas production	0.02	0.1
Gas turbine	0.1–120	0.05–5
IC engine	30	50–100
Pipeline transport		50–500 for compressor
Fuel cells		< 1.0

Source: Data compiled from Milne et al. (1998).

Levels of tar

Gasifier Type	Average Tar Concentration in Product Gas (g/Nm ³)	References
Downdraft	0.01–6	Hasler (1999)
Circulating fluidized bed	1–30	Han and Kim (2008)
Bubbling fluidized bed	1–23	Han and Kim (2008)
Updraft	10–150	Milne and Evans (1998), p. 15
Entrained flow	Negligible	

Ash and Slagging Characteristics

- The mineral content in the fuel that remains in oxidized form after complete combustion is usually called ash
- The ash content of a fuel and the ash composition have a major impact on trouble free operation of gasifier
- Ash basically interferes with gasification process in two ways :
 - a) It fuses together to form slag and this clinker stops or inhibits the downward flow of biomass feed.
 - b) Even if it does not fuse together it shelters the points in fuel where ignition is initiated and thus lowers the fuel's reaction response.
- Ash and tar removal are the two most important processes in gasification system for its smooth running

Cooling and Cleaning of Gas

- The temperature of gas coming out of generator is normally between 300-500°C
- This gas has to be cooled in order to raise its energy density
- Various types of cooling equipment have been used to achieve this end
- Most coolers are gas to air heat exchangers where the cooling is done by free convection of air on the outside surface of heat exchanger
- Since the gas also contains moisture and tar, some heat exchangers provide partial scrubbing of gas
- Thus ideally the gas going to an internal combustion engine should be cooled to nearly ambient temperature.

Gasifier efficiency

- The average energy conversion efficiency of wood gasifiers is about 60-70% and is defined as

$$\eta_{\text{Gas}} = \frac{\text{Calorific value of gas/kg of fuel}}{\text{Avg. calorific value of 1 kg of fuel}}$$

1 kg of wood produces 1.5 m³ of gas with average calorific value of 5.4 MJ/m³.
Average calorific value of wood (dry) is 19.8 MJ/kg

$$\eta_{\text{Gas}} = \frac{2.5 \text{ (m}^3\text{)} \times 5.4 \text{ (MJ/m}^3\text{)}}{19.80 \text{ (MJ/kg)} \times 1 \text{ (kg)}} = 68\%$$

- Cold gas efficiency,

$$\eta_{cg} = \frac{Q_g M_g}{LHV_f M_f}$$

- Hot gas efficiency,

$$\eta_{hg} = \frac{Q_g M_g + M_g C_p (T_f - T_0)}{LHV_f M_f}$$

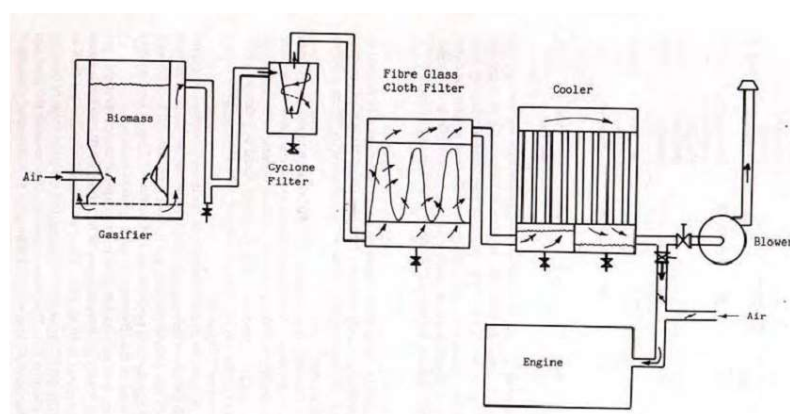
APPLICATIONS OF GASIFICATION: DIRECT HEAT SYSTEMS

- The producer gas is directly burned.
- Furnaces, boilers, klins etc.
- Gas quality is not critical so less demanding on cooling and cleaning equipment.
- Direct heat system is used for drying.
- Controlled heating and high flame temperatures

POWER GENERATION

- Driving IC engines
- **Gas engines** – Single fuel mode
- Derated to 40 to 50 %
- Ignition timing has to be advanced to 30 to 40°
- 1500- 2500 rpm
- **Diesel engines** – Dual fuel mode
- Derated to 15 to 30 %
- Best suited when compared to gas engines.

Schematic of a Producer Gas Plant



- Maximum usage of producer gas has been in driving internal combustion engine, both for agricultural as well as for automotive uses
- Direct heat applications like grain drying etc. are very attractive for agricultural systems
- A spark ignition engine running on producer gas on an average produces 0.55-0.75 kWh of energy from 1 kg of biomass
- Compression ignition (diesel) engines cannot run completely on producer gas. Thus to produce 1 kWh of energy they consume 1 kg of biomass and 0.07 liters of diesel. Consequently they effect 80-85% diesel saving

APPLICATION IN VEHICLES



Saab 900, 1946-1948
Fot. A. P. 1946



A LARGE BIOMASS GASIFICATION PLANT



LIMITATIONS OF GASIFICATION

- Complex multi-stage process
- Fuel is bulky and frequent refueling is often required for continuous running of the system
- Syngas must be cleaned/purified
- Initial setup is expensive

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