Principles of Biomass Gasification

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What is Biomass Gasification

- Conversion of Solid biomass to a gaseous fuel through thermal route
- Biomass contains carbon, hydrogen, oxygen, and small quantities of other elements
- On combustion with air CO_2 and H_2O are generated
- With sub-stoichiometric combustion (limited supply of air) products like CO and H_2 can be generated.
- The gas, thus generated is called producer gas

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

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

A hydrocarbon fuel leads to stoichiometric ratio (S)

$$S = \left\{(32+3.7628)\left(1+\frac{n}{4}\right)\right\} \Big/ (12+n)$$

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]

If we take a typical biomass

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

We get s = 6.3

In general

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

$$\frac{A}{F} = \frac{(32+3.7628)\left[1+\frac{n}{4}-\frac{m}{2}\right]}{12+n+16m}$$

	n	m	Ash (%wt)	(A/F) 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.

Gasification?

Combustion vs. Gasification

What is Gasification?

Sub-stoichiometric combustion of fuel with oxidant; it is not simply pyrolysis of the fuel elements; it is stoichiometric combustion (oxidation) + reduction reaction leading to typical products - Hydrogen, Carbon monoxide, Methane, Carbon dioxide, some HHC, water vapour and rest Nitrogen - in proportions depending on the feed stock and reactant used.

Most biomass + Air = 20% $\pm$ 2 H_2, 20% $\pm$ 2 CO, 2% CH_4, 12% $\pm$ 2 CO_2, 8% $\pm$ 2 H_2O, rest N_2.

Most biomass with water vapour with added heat from external sources $\rightarrow$ 55-65 % H_2 , 25 - 30 % CO, rest HHC.

Combustion

$$CH_{1.4}O_{0.74}N_{0.005} + 0.98\,(O_2 + 79/21\,N_2) \rightarrow CO_2 + 0.7\,H_2O + 3.69\,N_2,$$

$$A/F = 5.25$$

Gasification

$$CH_{1.4}O_{0.74}N_{0.005} + 0.337\,(O_2 + 79/21\,N_2)$$

$$\rightarrow 0.57\,CO + 0.485\,H_2 + 0.028\,CH_4 + 0.343\,CO_2 + 0.157\,H_2O + 1.27\,N_2 + 0.028\,C$$

$$\rightarrow 2.857\,(0.2\,CO + 0.17\,H_2 + 0.01\,CH_4 + 0.12\,CO_2 + .055\,H_2O + 0.445\,N_2 + 0.01\,C)$$

$$\rightarrow 0.157\,H_2O + 0.028\,C + 2.7\,(0.211\,CO + 0.18\,H_2 + 0.0105\,CH_4 + 0.1275\,CO_2 + 0.471\,N_2)$$

$$A/F \simeq 1.805;\ \text{Hot gas/Fuel} = 2.805;\ \text{Cold gas/Fuel} \simeq 2.62$$

Steps in Gasification

- Heating of biomass and release of volatile matter from biomass
- Combustion of volatile matter with air
- Reduction of combustion products (CO_2 and H_2O) with carbon to CO and H_2

$$C + CO_2 \rightarrow 2\,CO$$

$$C + H_2O \rightarrow H_2 + CO$$

The Gasification Process

- Biomass when heated looses volatiles leaving fixed carbon (about 20–25 %)
- The volatile matter reacts with air providing energy for biomass heating and to raise the temperature of gases to about 1200–1400°C.
- The hot gases thus produced, which contains CO2 and H2O react further with the fixed carbon to generate CO and H2.
- These are endothermic reduction reactions and brings down the temperature to about 600–700°C.
- The IISc open top reactor has a second stage of oxidation-reduction process to minimize the tar in the product gases and to improve the carbon conversion.

Composition of Producer Gas

- The producer gas contains CO, H_2, CH_4, CO_2, H_2O and N_2 with the composition given in the table

CO	18–20 %
H_2	18–20 %
CH_4	1–2 %
CO_2	11–12 %
N_2	Rest

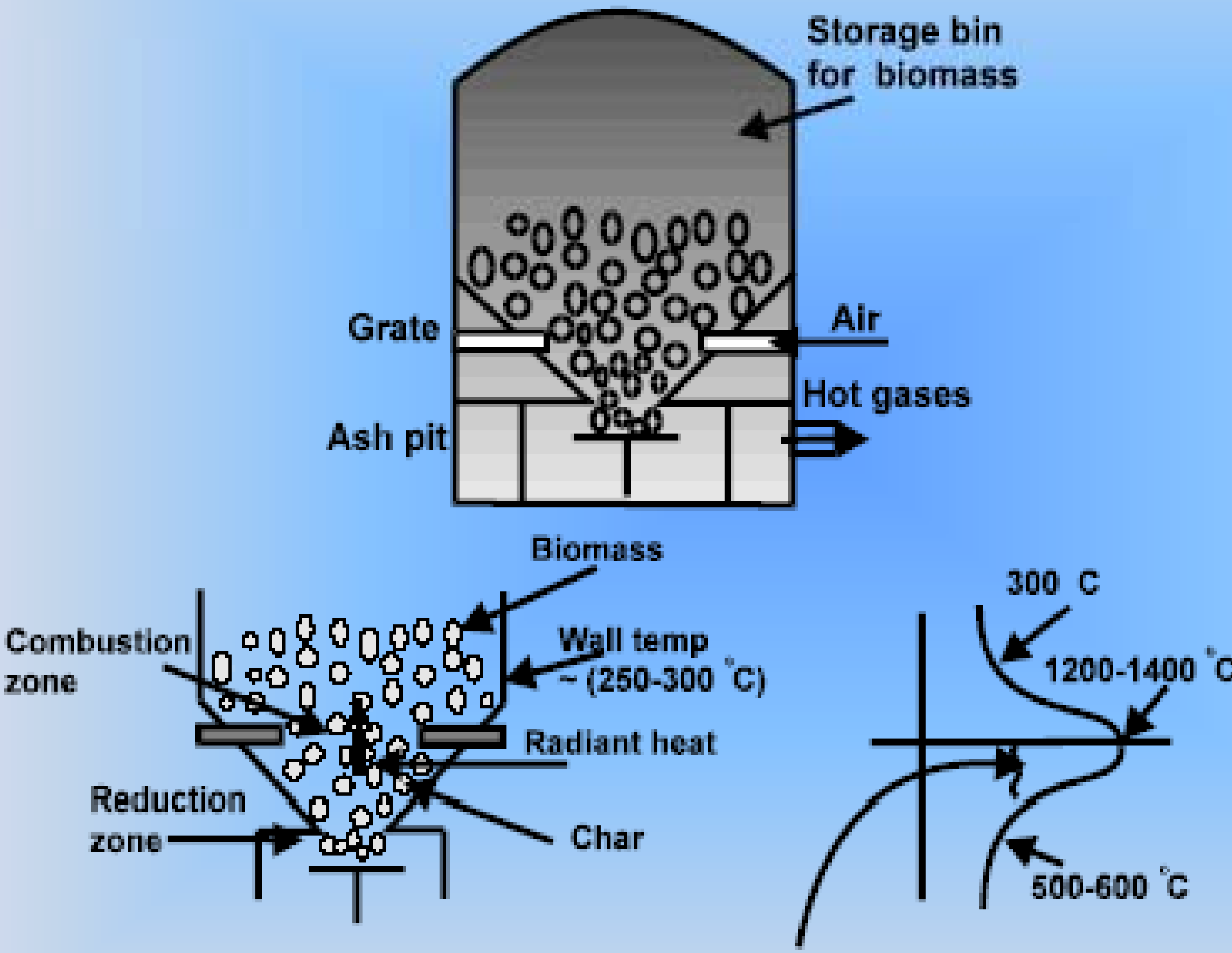
Impurities in the gas

- Tar — unconverted volatile matter
  - Gets condensed and deposited in various passages
  - Causes difficulty in engine operation. Should be brought down less that 10 ppm for satisfactory engine operation
- Dust — Carbon/ ash particles carried along with gas
  - Needs to be separated for high quality applications such as engine

Types of gasifiers

- Fixed bed
  - Up draft — high tar content in the gas
  - Down draft
    - Open top
    - Closed top
- Moving bed
  - Fluidized bed — Suitable for large installations. High tar content in the gas.
    - Bubbling
    - Circulating

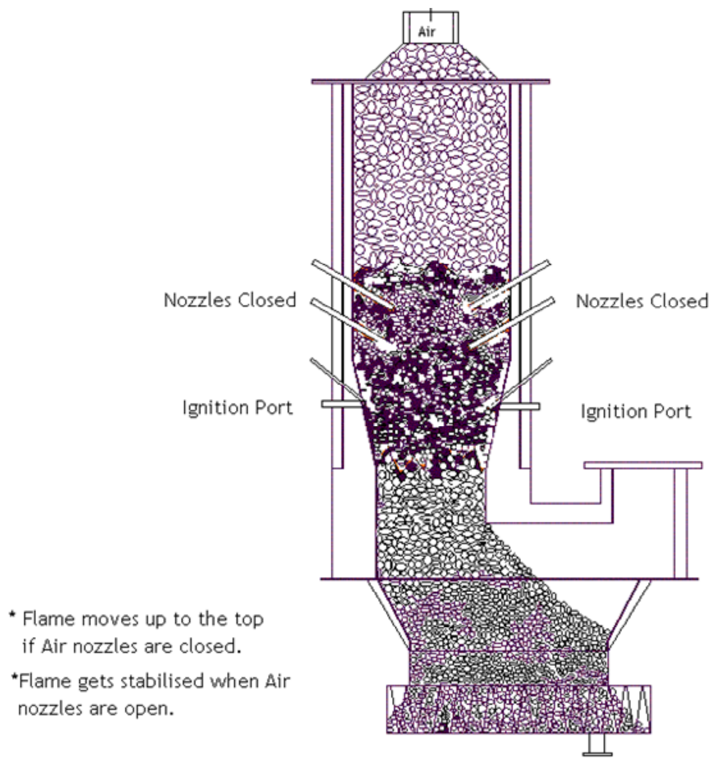
Closed top design



$C + CO_2 = 2\,CO$

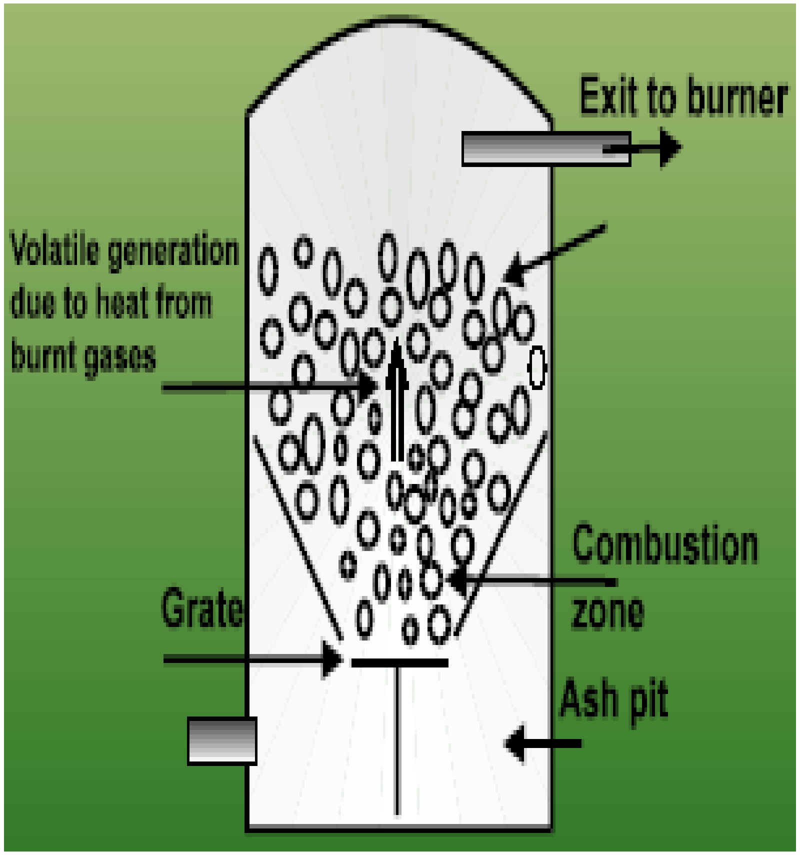
$C + H_2O = CO + H_2$

Open top gasifier



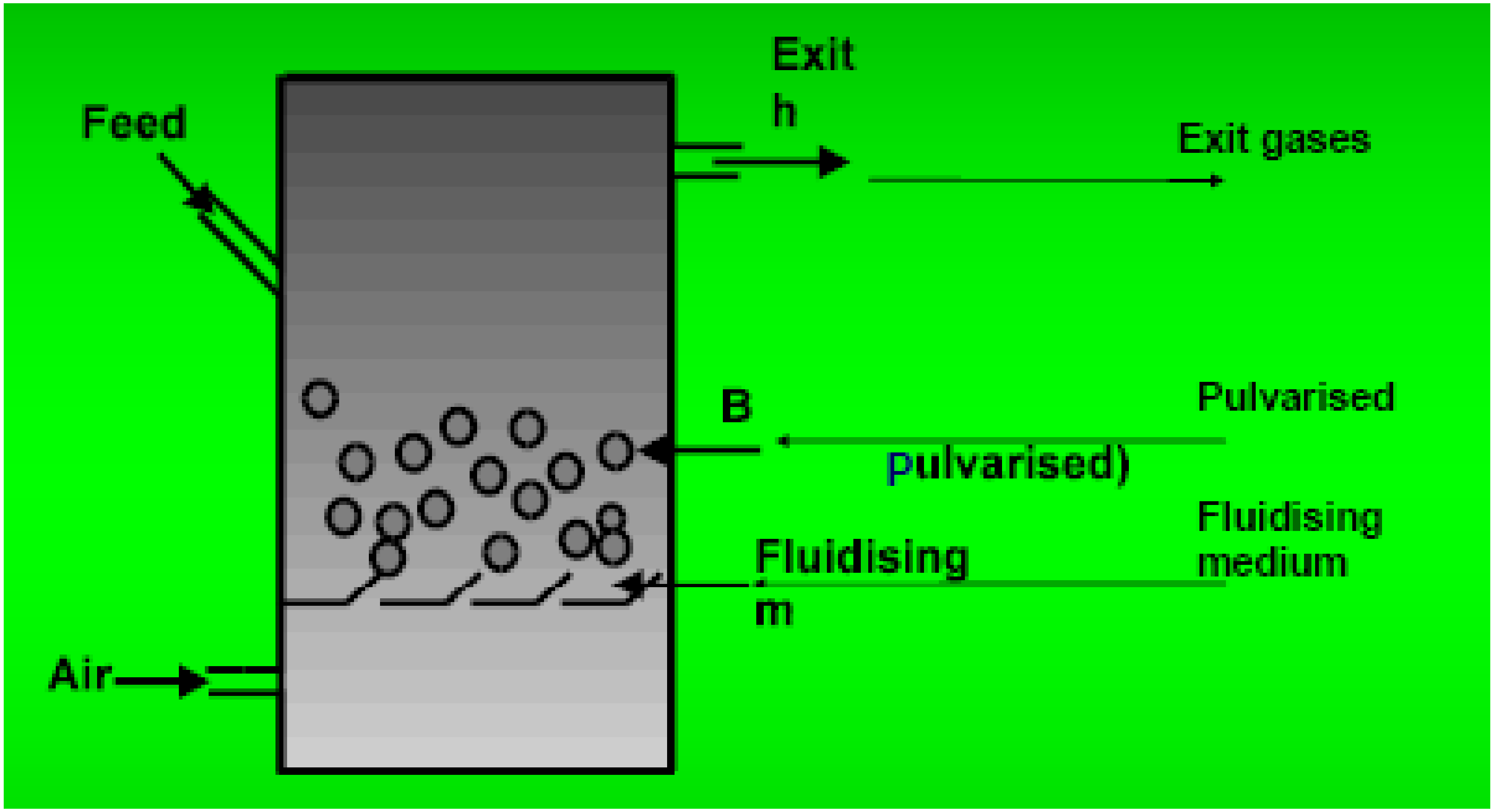
Comparison of open and closed top designs

	Closed top	Open top
Nature of biomass (size)	Pieces of 20 – 100 mm depending on power level	same
Top region	Volatile matter and fuel rich conditions	Air and lean environment
Uniformity of A/F at a cross section	Non-uniforn	Relatively uniform
Regions of tar rich zones	Yes	Relatively low



- The combustible gases at the exit have a large amount of volatiles. If the combustible gases are cooled to ambient temperature, the tar in the gas condenses and leads to problems of blockage. The gas is fit for direct use in burners. This technique is useful if the downdraft kind cannot be used. It has been used for waste contaminated wood.

Fluidized bed gasifier



Gas cleaning - process

- Gas has to be cooled and cleaned for end use application

  T and P levels of 100 ppm and 1000 ppm respectively in the raw gas at 350 – 650°C

  - Cooling and cleaning is achieved by using a number of components
  - These are cyclones and cooling devices by spraying water in scrubbers
  - Further cleaning is achieved using chilled scrubbers

With this gas cleaning process it is possible to restrict the contaminants to ppb levels

Gas cleaning

- After cooling
  - Gas is saturated with moisture
  - Contains fine dust and condensable (~ 25 ppm) even after filtering – not acceptable to turbo charged engines
- Use the principle of condensation nuclei
  - Scrub the gas using cold water (< 10 C)
    - Dries the gas by condensing the water vapor
    - This happens using the particles (Cloud Condensation Nuclei) – thus removing the particulate < 10^{-3} microns
    - The gas is dry and clean to ppb level

Chilled scrubbers are currently being used in all the systems

Properties of Producer Gas vis-à-vis other Gaseous Fuels

Fuel + Air	Fuel LCV, MJ/kg	Air/Fuel @ (Φ =1)	Mixture, MJ/kg	Φ, Limit		S_L (Limit), cm/s		S_L Φ =1, cm/s	Peak Flame Temp, K	Product/ Reactant Mole Ratio
				Lean	Rich	Lean	Rich			
H_2	121	34.4	3.41	0.01	7.17	65	75	270	2400	0.67
CO	10.2	2.46	2.92	0.34	6.80	12	23	45	2400	0.67
CH_4	50.2	17.2	2.76	0.54	1.69	2.5	14	35	2210	1.00
C_3H_8	46.5	15.6	2.80	0.52	2.26	-	-	44	2250	1.17
C_4H_{10}	45.5	15.4	2.77	0.59	2.63	-	-	44	2250	1.20
PG	5.00	1.35	2.12	0.47 a	1.60 b	10.3	12	50 c	1800 d	0.87

PG: H_2 - 20%, CO - 20%, CH_4 - 2%; a: $\pm$0.01, b: $\pm$0.05, c: $\pm$5.0, d: $\pm$50 ;

Applications of Gasification Process

Process that converts solid fuel to gaseous fuel

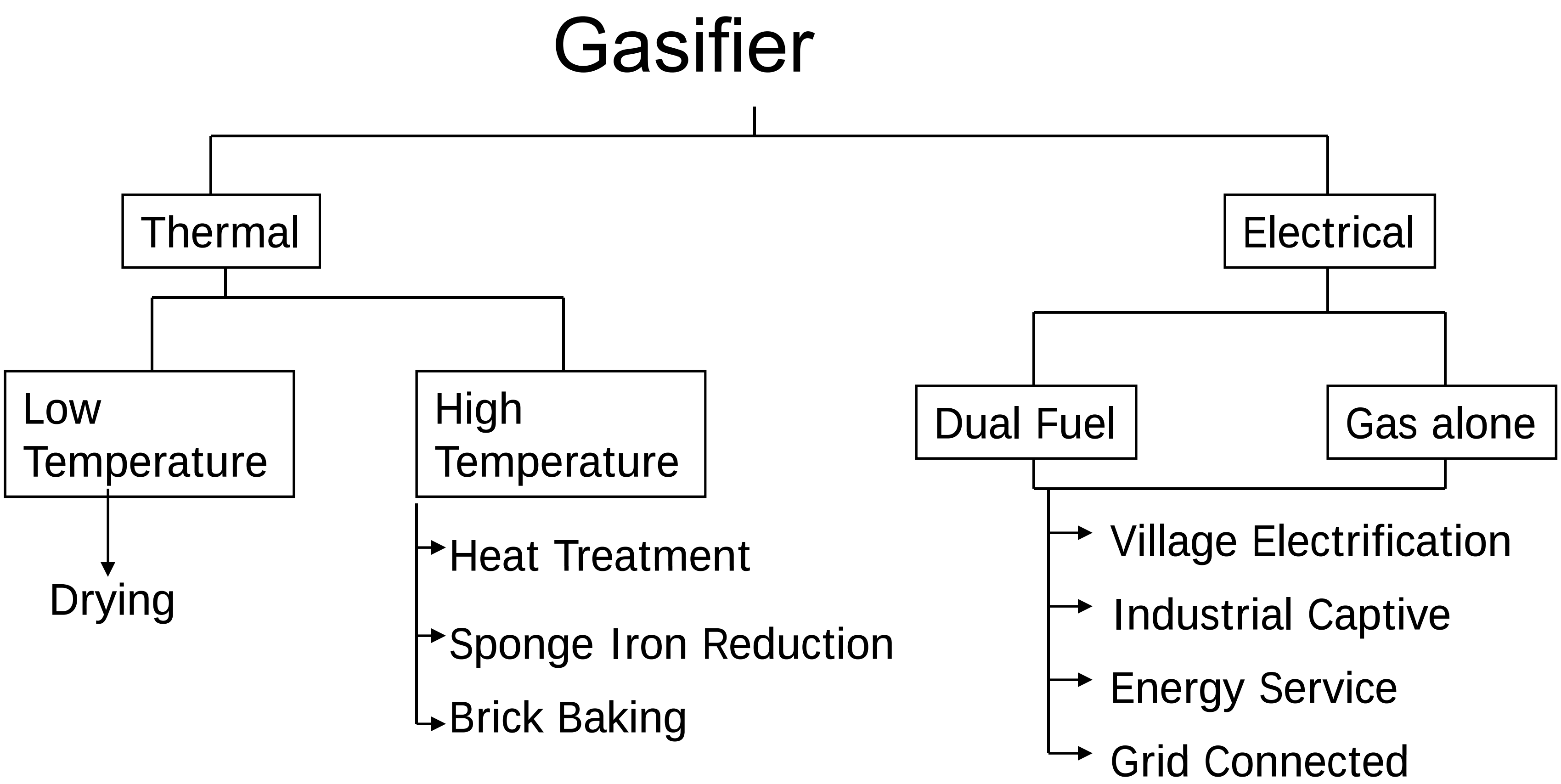
- Used in an internal combustion engine for power generation to substitute fossil fuel
  - Diesel engine – for dual fuel application
  - Gas engine – for single fuel
- Used in heat application
  - Low temperature – drying, etc
  - High temperature – furnaces, kilns, etc

Biomass for Gasification






Applications Serviced



Summary of gasification

- **Gasifiers are devices which convert solid biomass into gaseous fuels for combustion in furnaces or in engines**
- **Gasifiers give a precise control of instantaneous power some thing not possible in combustors (for solid fuel)**
- **Woody biomass gasifiers are of down draft, updraft types Downdraft gasifiers can be either closed or open top**
- **For engine applications downdraft gasifier is the most suitable. For engine applications involving variable load/ power demand, open top downdraft gasifiers are most suitable.**
- **Updraft gasifiers may be the most appropriate if the biomass is contaminated, unsized and of a variety of shapes making downdraft gasification difficult. The applications are only thermal.**