



# Biomass Gasification Systems

## Training Manual



**US-Pakistan Center of Advanced Studies in Energy (USPCAS-E),  
National University of Sciences and Technology (NUST),  
Islamabad, Pakistan**



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2016

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# **Foreword**

## **(UNIDO)**

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## (NUST)

National University of Sciences & Technology (NUST) is executing a project component “Capacity Building & Strengthening of Biomass Gasification Technology Support Systems” to contribute for the promotion of “Biomass to energy technologies in Pakistan” through a UNIDO-GEF project “Promoting sustainable energy production and use from biomass in Pakistan”.

The vitality part in Pakistan is portrayed by low levels of access to present day vitality benefits, a high reliance on customary fills and an unsustainable reliance on transported in fossil energizes for power generation. Biomass, a natural constituent obtained from agriculture waste predominantly includes rice husk, wheat straw, bagasse, cotton and wood shredding’s (saw dust) and other carbonaceous waste materials including municipal waste. UNIDO has taken an initiative to strengthen the industrial sector in Pakistan by using biomass/crop residue as an efficient energy material through advanced Biomass Gasification Technologies (BGTs).

As compared to biomass gasification for energy purposes, direct burning of biomass causes severe environmental pollution and health problems among workers. Keeping in view the advance nature and beneficial aspects of biomass gasification, capacity building is a key element to spread awareness and establish optimized and skilled technical services to promote training centers and research institutions, and promotion and maintenance of installation of BGTs at industrial sector. The project will be of great help to create awareness and set the trends towards “Biomass to Energy” among industrial networks. The venture is required to bring critical financial and natural advantages both at neighborhood and worldwide level.

This manual consists of seven sections, comprising numerous units and draws upon the working operation, monitoring & maintenance of installed Biomass Gasifier. The training of BGT broadly cover fundamentals Small & Medium Enterprises (SMEs) and Technology Providers from all over Pakistan. While the manual aims to provide market driven services of biomass gasification technologies to SMEs and to establish the enhanced capacity of key market players in the local supply chain.

We are sure that the manual will be useful for all cooperative trainers towards facilitating BGTs and thereby ensuring the participation and understanding of all the trainees in biomass gasification technologies (BGTs) at all levels of cooperatives.

**Note:** *This manual is in draft form, errors and omissions are expected. Any feedback will be highly appreciated. It can be sent on [mzubair@casen.nust.edu.pk](mailto:mzubair@casen.nust.edu.pk)*

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# **1 Introduction**

Gasification has been reliably used on a commercial scale worldwide for more than 60 years in the refining, fertilizer, and chemical industries, and for more than 35 years in the electric power industry.

It is a flexible, reliable, and commercial technology that can turn a variety of low-value feedstock into high-value products, help reduce a country's dependence on imported oil and natural gas, and can provide a clean alternative source of base load electricity, fertilizers, fuels, and chemicals.

## **1.1 Units used in the Manual**

This manual uses the SI (Le Systeme International d'Unites) metric units of measure.

## **1.2 The Manual**

The manual covers the basics of biomass as fuel, biomass conversion technologies, gasification, applications of gasification, gasifiers, design guidelines, operational and maintenance guidelines, and safety measures.

Chapter 1 is the brief introduction to this manual. Chapter 2 introduces the fossil and biomass fuels, and characteristics of biomass fuels. Chapter 3 describes biomass conversion technologies. Chapter 4 discusses operations .

The manual aims to prompt the managers, professionals, technical staff, and service providers to adopt sustainable, viable, environment friendly, and economically feasible technologies. However, it must be well understood that it is not a replacement of textbooks and handbooks on the subject. It will serve as a useful guide for energy engineers, service providers, and small and medium scale entrepreneurs.



## **2 Fuels**

The main function of the fuels is to provide thermal energy, which is used directly in the form of heat or transformed into other forms of energy, i.e. mechanical or electrical energy according to the needs. The major sources of thermal energy, at this point in time, are fossil fuels and biomass fuels. These are briefly discussed in here.

### **2.1 Fossil Fuels**

Fuels such as coal, oil and natural gas were formed over millions of years from organic matter like plankton, plants and other life forms. Over time, sand, sediment and rock buried the organic matter and it eventually formed large quantities of fuels. These underground resources, known as fossil fuels, are still the primary fuel source for electricity, heating and powering vehicles around the globe.

There are three major forms of fossil fuels: coal, oil and gas.

Coal is a combustible black or brown sedimentary rock made mostly of organic carbon. It is typically found as layers (coal beds) or veins (coal seams).

There are two main types of coal: 'thermal' coal is mostly used for power generation, and 'metallurgical' coal is mostly used for steel production. Thermal coal is more abundant, has lower carbon content and is higher in moisture than metallurgical coal.

Natural gas is a combustible mix of hydrocarbon gases. It is colorless and consists mainly of methane ( $\text{CH}_4$ ). 'Conventional gas' is easily extracted; 'unconventional gas' requires more sophisticated extraction technologies.

Conventional natural gas is found in permeable sandstone reservoirs and is easy to get out of the ground through traditional well drilling techniques.

Unconventional gas is just standard natural gas, but found in places other than permeable sandstone reservoirs. There are two main types of 'unconventional gas': (1) coal seam gas (CSG), found in coal deposits, usually 200 to 1,000 meters below the ground; and (2) shale gas, found in shale rock deposits. The wells for extracting this gas are generally a lot deeper than those for CSG.

Oil is liquid fuel made of hydrocarbons. It is mostly known as crude oil or condensate, but includes all liquid hydrocarbon fossil fuels and other liquid organic compounds. Petroleum and liquefied petroleum gas (LPG) are the most common types of fuel obtained from oil extraction and refining. LPG is heavier than natural gas. The term petroleum refers to both naturally occurring unprocessed crude oils and petroleum products made of refined crude oil.

### **2.2 Biomass Fuels**

Biomass is biological material derived from living, or recently living organisms. In the context of biomass for energy this is often used to mean plant based material, but biomass can equally apply to both animal and vegetable derived materials.

It is any organic matter-wood, crops, forestry residues, seaweed, animal wastes – that can be used as an energy source. Biomass is probably our oldest source of energy after the sun. For thousands of years, people have burned wood to heat their homes and cook their food. Biomass is a renewable energy source because its supplies are not limited. People can always grow trees and agriculture crops and waste will always exist.

A generally accepted definition is difficult to find. However, the one used by the United Nations Framework Convention on Climate Change (UNFCCC, 2005) is relevant here:

*(Biomass is a) non-fossilized and biodegradable organic material originating from plants, animals and microorganisms. 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.*

### **2.2.1 Chemical Composition**

Biomass is carbon based and is composed of a mixture of organic molecules containing hydrogen, usually including atoms of oxygen, often nitrogen and small quantities of other elements, including alkali, alkaline earth and heavy metals. These metals are often found in functional molecules such as the porphyrins, which include chlorophyll, which contains magnesium.

The carbon used in the formation of biomass is absorbed from the atmosphere as carbon dioxide ( $\text{CO}_2$ ) by plant life, using energy from the sun. Plants may subsequently be eaten by animals and thus converted into animal biomass. However the primary absorption is performed by plants. If plant material is not eaten it is generally either broken down by microorganisms or burned:

- If broken down it releases the carbon back to the atmosphere, mainly as either carbon dioxide ( $\text{CO}_2$ ) or methane ( $\text{CH}_4$ ), depending upon the conditions and processes involved.
- If burned the carbon is returned to the atmosphere as  $\text{CO}_2$ .

These processes have happened for as long as there have been plants on earth and is part of what is known as the carbon cycle. A continuous program of replanting with the new growth will take up  $\text{CO}_2$  from the atmosphere at the same time as it is released by combustion of the previous harvest. This maintains a closed carbon cycle with no net increase in atmospheric  $\text{CO}_2$  levels. However, biomass also includes plant or animal matter used for production of fibers or chemicals.

The vital difference between biomass and fossil fuels is one of time scale.

## **2.3 Categories of biomass materials**

There are five basic categories of material:

- Virgin wood: from forestry, from wood processing
- Energy crops: high yield crops grown specifically for energy applications
- Agriculture residues: residues from agriculture harvesting and processing
- Food waste: from food and drink manufacture, preparation and processing, post-consumer waste, animal waste and municipal solid waste (MSW)
- Industrial waste and co-products from manufacturing and industrial processes.

## **2.4 Thermal Properties of Biomass Materials**

Each type of biomass has specific properties that determine its performance as a fuel in combustion or gasification devices or both. The most important properties relating to the thermal conversion of biomass are as follows:

- Moisture content
- Ash content

- Volatile matter content
- Elemental composition
- Heating value
- Bulk density

## 2.4.1 Proximate Analysis

Proximate analysis of biomass or any solid fuel measures its four parameters, i.e. moisture content (MC), ash (A), volatile matter (VM) and fixed carbon (FC), all expressed as %age.

### 2.4.1.1 Moisture Content (MC)

The moisture content of biomass is the quantity of water in the material, expressed as a percentage of the material's weight. This weight can be referred to as the following:

- Wet basis,
- Dry basis, and
- Dry and ash-free basis

The terminology used is:

$W_{mc}$	= Weight of moisture content
$W_{wet}$	= Weight of wet mass
$W_{dry}$	= Weight of dry mass (oven-dried)
$W_{ash}$	= Weight of ash
$MC_{wet}$	= Moisture content on Wet basis
$MC_{dry}$	= Moisture content of Dry Basis
$MC_{daf}$	= Moisture content on dry and ash-free basis
$W_{daf}$	= Weight of dry and ash-free mass

Moisture is calculated as the difference between the weight of the sample as received and the oven-dried sample at a temperature equal to  $105 \pm 2$  °C till the variation on weight is negligible. The useful relationships are as the following:

$$W_{mc} = W_{wet} - W_{dry}$$

$$W_{wet} = W_{dry} + W_{mc}$$

$$W_{dry} = W_{daf} + W_{ash}$$

$$W_{daf} = W_{dry} - W_{ash}$$

Moisture content on Wet basis as fraction and %age:

$$MC_{wet} = \frac{W_{mc}}{W_{wet}}$$

$$MC_{wet} \% = \frac{W_{mc}}{W_{wet}} \times 100$$

Moisture content on Dry basis

$$MC_{dry} = \frac{W_{mc}}{W_{dry}}$$

$$MC_{dry} \% = \frac{W_{mc}}{W_{dry}} \times 100$$

Relationships between  $MC_{dry}$  and  $MC_{wet}$  are:

$$MC_{dry} = \frac{MC_{wet}}{1 - MC_{wet}}$$

$$MC_{dry} \% = \frac{MC_{wet}}{1 - MC_{wet}} \times 100$$

$$MC_{wet} = \frac{MC_{dry}}{1 + MC_{dry}}$$

$$MC_{wet} \% = \frac{MC_{dry}}{1 + MC_{dry}} \times 100$$

Finally, the moisture content can be expressed as percentage for the “dry-and-ash-free” matter content basis, as the following:

$$MC_{dafb} \% = \frac{W_{mc}}{W_{wet} - W_{mc} - W_{ash}} \times 100$$

$$MC_{dafb} \% = \frac{W_{mc}}{W_{daf}} \times 100$$

Since, the moisture content affects the quality of biomass as a fuel, the basis on which the moisture content is measured must always be mentioned. This is of particular importance because biomass materials exhibit a wide range of moisture content (on a wet basis), ranging from less than 10 percent for cereal grain straw up to 50-70 percent for forest residues.

#### 2.4.1.2 Ash (A)

It is the residual mass obtained after combustion in the air, under controlled conditions of time and temperature.

The inorganic component (ash content) can be expressed in the same way as the moisture content on a wet, dry and dry-and-ash-free basis. In general, the ash content is expressed on a dry basis as shown below.

$$A_{dry} = \frac{W_{ash}}{W_{dry}}$$

$$A_{dry} \% = \frac{W_{ash}}{W_{dry}} \times 100$$

$W_{ash}$  and  $W_{dry}$  are the weight of ash and dry mass respectively.

The inherent ash value, an integral part of the plant structure, which consists of a wide range of elements; represent less than 0.5 percent in wood, 5 to 10 percent in diverse agricultural crop materials and up to 30 to 40 percent in rice husk.

The total ash content in the biomass and the chemical composition of the ash are both important. The composition of the ash affects its behavior under the high temperatures of combustion and gasification.



#### 2.4.1.3 Volatile Matter (VM)

Volatile matter refers to the part of the biomass that is released when the biomass is heated (up to 400 to 500°C) in the absence of oxygen and in strictly controlled conditions. It is calculated using the following equation:

$$\text{VM \%} = \frac{W_1 - W_2}{W_1} \times 100$$

Where:

$W_1$  = Weight of oven-dried sample before heating

$W_2$  = Weight of sample after heating

During this heating process, the biomass decomposes into volatile gases and solid char. Biomass typically has a high volatile matter content (up to 80 percent on oven-dried basis), whereas coal has a low volatile matter content (less than 20 percent) or in the case of anthracite coal, a negligible one.

Volatile matter as well can be expressed on wet basis, dry basis, and dry and ash-free basis.

#### 2.4.1.4 Fixed Carbon (FC)

It is determined by the difference, i.e.

$$\text{FC \%} = 100 - (\text{MC \%} + \text{A \%} + \text{VM \%})$$

All quantities in percentage are taken on wet basis.

Further, the % content of Moisture, Ash (A), Volatile Matter (VM), Fixed Carbon (FC) – also Sulfur (S) and Calorific Value (CV) – can be expressed on any of the above basis.

### 2.4.2 Ultimate Analysis / Elemental Composition

The composition of the ash-free organic component of biomass is relatively uniform. The major components are carbon, oxygen and hydrogen. Most biomass also contains a small proportion of nitrogen, sulfur and other inorganic constituents. Following table presents the average range of percentages.

Elementary composition of typical biomass as derived from Ultimate Analyses:

Element	Symbol	Weight percent (dry-and-ash-free basis)
Carbon	C	44-51
Hydrogen	H	5.5-6.7
Oxygen	O	41-50
Nitrogen	N	0.12-0.60
Sulfur	S	0.0-0.2

Ultimate analysis is lengthy, laborious and costly, while proximate analysis is easy and cost effective. In most cases, the proximate analysis suffices and serves the purpose for understanding the properties of the feedstock (raw material) specific to its use as a source of thermal energy.

#### 2.4.3 Heating Value

The heating value of a fuel is an indication of the energy chemically bound in the fuel with reference to a standardized environment. The standardization involves the temperature, state of water (vapor or liquid) and the combustion products ( $\text{CO}_2$ ,  $\text{H}_2\text{O}$  etc.). The energy

chemically bound in the fuel is given by the heating value of the fuel in energy (Joules) per unit amount of matter (kg). This energy cannot be measured directly but only with respect to a reference state. Reference states may differ, so a number of different heating values exist. The best knowns are the higher heating value (HHV) and lower heating value (LHV).

### HHV

For the HHV, the reference state of water is liquid. It is the amount of heat released by the unit mass or volume of fuel at “reference state” (say initially at 25°C) when it is combusted, and the products of combustion are returned to the “reference state” (initial temperature of 25°C in this case). In fact, it includes the latent heat of vaporization of water.

### LHV

For the LHV, the reference state of water is steam (vapor state). In practice, the products of combustion are rarely cooled to the initial temperature of the fuel, which is generally below the condensation temperature of steam. So the water vapor in the flue gas does not condense, and therefore the latent heat of vaporization of water is not recovered. The effective heat available for use, therefore, is a lower amount. Simply, it is defined as the amount of heat released by fully combusting a unit quantity of fuel less the heat of vaporization of the water in exhaust flue gases.

The glaring example is that the temperature of exhaust flue gas of a boiler is normally maintained in the range of 120 - 180°C.

The relationship between HHV and LHV is given by (Basu, ----)

$$\text{LHV} = \text{HHV} - 540 \times \left( \frac{\text{H \%}}{100} + \frac{\text{MC \%}}{100} \right)$$

Where LHV, HHV, H, and M are lower heating value, higher heating value, hydrogen percentage, and moisture percentage, respectively, on as-received basis. Here, the units of LHV and HHV in kcal/kg. The value 540 is the heat of evaporation of water in kcal/kg.

Other commonly used substitutes for LHV and HHV are:

LHV = Net heating value (NHV), net calorific value (NCV), low calorific value (LCV)

HHV = Gross heating value (GHV), gross calorific value (GCV), high calorific value (HCV)

Biomass always contains some water, which is released as vapor upon heating. This implies that some of the heat liberated during the chemical reactions is absorbed by the evaporation process. For this reaction, the net heating value (LHV) decreases as the moisture content of the biomass increases (even apart from the fact that a higher moisture content of combustible matter, which on a wet basis also decreases the net heating value per kilogram of biomass). The only effect of moisture content on HHV is the lower content of combustible matter per kilogram of biomass fuel. The heat of evaporation is recovered completely by condensation of the water vapor when the flue gases are brought into the reference state belonging to HHV.

## 2.4.4 Bulk density

Bulk density refers to the weight of material per unit of volume. For biomass, this is commonly expressed on an oven-dry-weight (moisture content= 0 percent) or an as-is basis, with a corresponding indication of moisture content (MC<sub>wet</sub>). Similar to biomass moisture contents, biomass bulk densities show extreme variation from lows of 150-200 kg/m<sup>3</sup> to 600-900 kg/m<sup>3</sup>. Together, heating value and bulk density determine the energy density, i.e. the potential energy available per unit volume of the biomass. In general, biomass energy densities are approximately one-tenth that of fossil fuels, e.g. petroleum or high quality coal.

Bulk density of biomass is expressed as:

$$\text{Bulk Density, } \frac{\text{kg}}{\text{m}^3} = \frac{\text{Weight}}{\text{Volume}} = \frac{\text{Weight of Biomass, kg}}{\text{Volume of Biomass, m}^3}$$

Exhibit 2–1 lists the properties of common biomass resources.

**Exhibit 2–1: Properties of Different Biomass Resources**

<b>Biomass Resource</b>	<b>Moisture Contents (%)</b>	<b>Volatile Matter (%)</b>	<b>Ash Contents (%)</b>	<b>Fixed Carbon (%)</b>	<b>Gross Calorific Value (kcal/kg)</b>
Rice Husk	10.4	64.25	14.08	11.27	3826.96
Cotton Stalk	20.86	60.66	6.28	12.2	3296
Wheat Straw	6.34	61.73	17.64	14.29	3712.37
Bagasse	25.25	48.98	13.45	12.32	3673.6



## **3 Processing of Biomass Fuels**

Prior to its use, the biomass fuel needs to be conditioned according to its application, and optimum utilization. The conditioning of the biomass fuel involves the processes such as:

- Drying,
- Powdering,
- Pelleting, and
- Briquetting

These processes are discussed in the following sections.

### **3.1 Drying of Biomass Fuels**

There are several established methods, plus some promising technology, for drying biomass fuels for use in combustion boilers and gasifiers. Drying biomass fuel provides significant benefits to boiler operation, but they must be balanced against increased capital and operating costs. Using dry fuel in a direct combustion boiler results in improved efficiency, increased steam production, reduced ancillary power requirements, reduced fuel use, lower emissions, and improved boiler operation. (NREL, 1998)

### **3.2 Dryer Principles**

There are three requirements for drying:

1. A source of heat,
2. A method of removing the water evaporated, and
3. Some form of agitation to expose new material for drying.

#### **3.2.1 Types of Dryers**

Dryers can be broadly divided into two categories based on how heat is provided for drying. In direct dryers, the material gets heat from direct contact with a fluid providing the heat--either hot air or hot steam. With indirect drying, the material being dried is separated from the heat source by a heat exchange surface. One important consequence of indirect drying is that it is possible to recover the latent heat of evaporated water because the water vapor is not diluted by air.

#### **3.2.2 Stages of Drying**

There are several steps to drying. First, the material must be heated from the temperature at which it entered the dryer, up to the wet bulb temperature, to produce a driving force for water to leave the wet material (see Glossary for the description of dry bulb and wet bulb temperatures). Next, any surface moisture on the material is evaporated--this occurs fairly quickly. Once all the surface moisture is removed, the material must be heated to drive water from the inside of the biomass to the surface so it can evaporate. This occurs during the "falling rate period" when the rate of drying drops as the material becomes drier. During the falling rate period, the surface temperature of the material remains close to the wet bulb temperature. Once the material is completely dry, it begins to heat up to the surrounding temperature, because water is no longer present to keep its temperature low.

Description of simple type of driers is provided in the following sections.

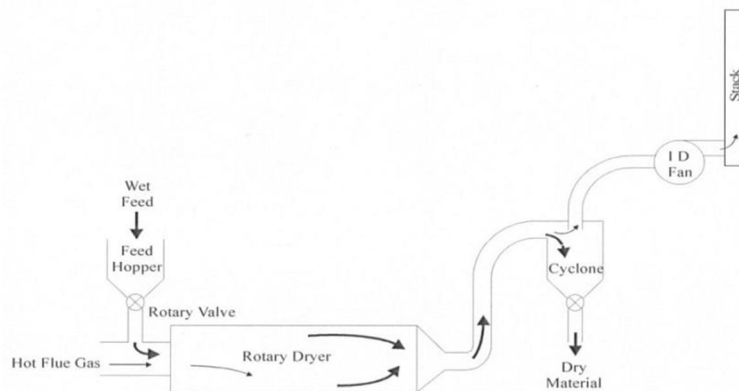
### 3.3 Dryers Description

#### 3.3.1 Rotary Dryers

Rotary dryers are the most common type used for biomass drying. There are several variations of rotary dryers, but the most widely used is the directly heated single-pass rotary dryer (see Exhibit 3-1). In this dryer, hot gases come into contact with biomass material inside a rotating drum. Rotation of the drum, with the aid of flights, lifts the solids in the dryer so they tumble through the hot gas, promoting better heat and mass transfer. If contamination is not a concern, hot flue gas can be fed directly into the dryer. Other options include using a burner or a steam heater to raise the temperature of incoming air.

The biomass and hot air normally flow co-currently through the dryer so the hottest gases come in contact with the wettest material, but for materials where temperature is not a concern, the flue gas and solids flow in opposite directions, so the driest solids are exposed to the hottest gases with the lowest humidity. This latter configuration produces the lowest moisture leaving the dryer, but for biomass this exposes essentially dry material to a high flue gas temperature, which would increase the fire risk.

**Exhibit 3-1: Single-Pass Rotary Dryer**



Source: (NREL, 1998)

The exhaust gases leaving the dryer may pass through a cyclone, multicyclone, baghouse filter, scrubber or electrostatic precipitator (ESP) to remove any fine material entrained in the air. An ID (induced draft) fan may or may not be required depending on the dryer configuration. If one is needed, it is usually placed after the emissions control equipment to reduce erosion of the fan, but may also be placed before the first cyclone to provide the pressure drop through downstream equipment.

Single-pass dryers can take larger material. The basic single-pass rotary dryer design can be modified to allow three passes of the air and material through the dryer.

Indirectly heated rotary dryers use a heat source--steam or hot air--passing through the outer wall of the dryer or through an inner central shaft to heat the dryer by conduction. This is more common with materials that would be contaminated by direct contact with flue gases or with materials that react with air.

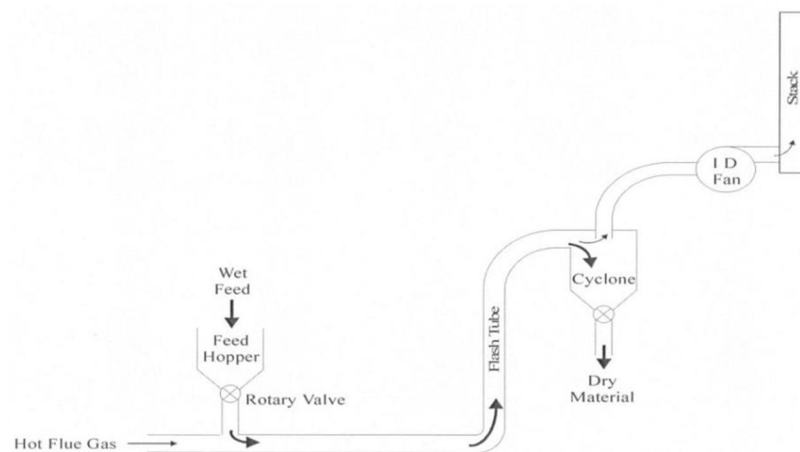
The inlet gas temperature to rotary biomass dryers can vary from (225° - 1,000°C). Outlet temperatures from rotary dryers vary from (70° - 110°C), with most of the dryers having outlet temperatures higher than 104°C to prevent condensation of acids and resins. Retention times in the dryer can be less than a minute for small particles and 10-30 minutes for larger.

### 3.3.2 Flash Dryers

In a flash or pneumatic dryer, the solids are mixed with a high-velocity hot air stream. The intimate contact of the solids with the air results in very rapid drying. The solids and air are separated using a cyclone, and the gases continue through a scrubber to remove any entrained particulate material. Exhibit 3-2 shows a simple flash dryer (without a scrubber).

Because of the short drying time in a flash dryer, the equipment is more compact than for a rotary dryer. However, the electricity consumption is higher because of the faster air flows through the unit, and because biomass must pass through a shredder or grinder to reduce its size so it can be suspended in the air stream. For wet or sticky materials, such as sludge, some of the dry material can be recycled back and mixed with the incoming wet material to improve material handling.

**Exhibit 3-2: Typical Flash Dryer Configuration**



Source: (NREL, 1998)

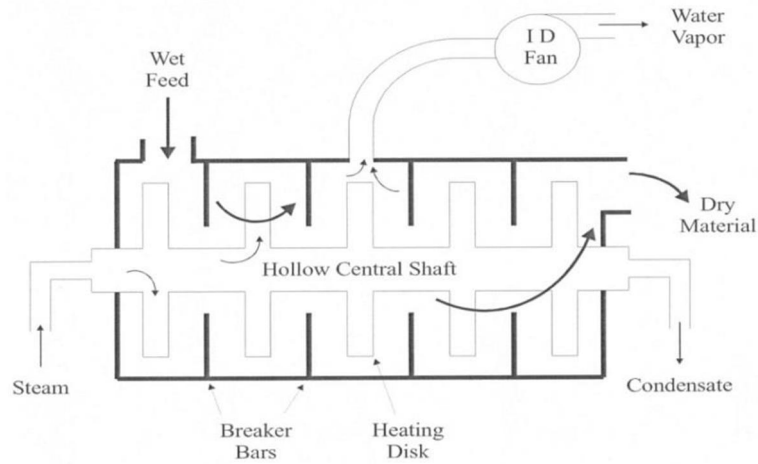
Flash dryers have been used successfully for drying most biomass materials, including wood, sludge, and bagasse.

Gas temperatures are slightly lower for flash dryers than for rotary dryers, but they still operate at temperatures above the combustion point. The solids retention time in a flash dryer is typically less than 30 seconds, minimizing the fire hazard.

### 3.3.3 Disk Dryers

For smaller flows of material, a disk dryer or "porcupine" dryer (Exhibit 3-3) is an option. In a disk dryer, solids are heated by condensing steam inside of a central shaft with many hollow disks that increase the area for heat transfer. Fingers or "breaker bars" mix the material and act to keep the heat transfer surfaces free of buildup. The disk dryer can be operated under a vacuum or under pressure, and the condensate from inside the heating shaft can be recovered and returned to the boiler.

**Exhibit 3-3: Side View of a Disk Dryer**

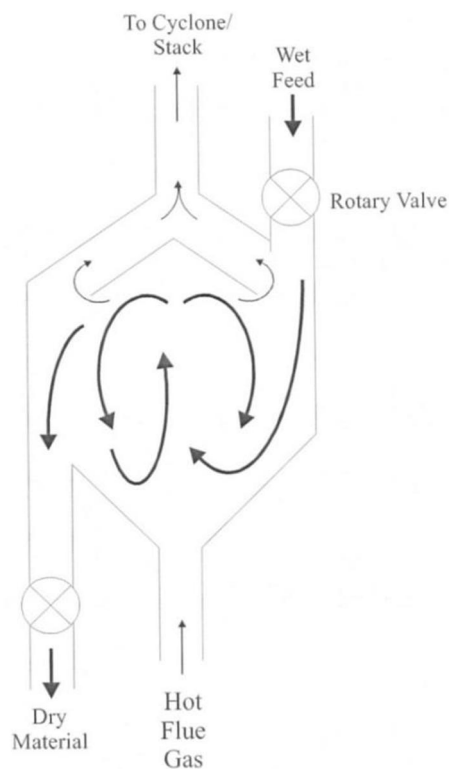


Source: (NREL, 1998)

### 3.3.4 Cascade Dryers

Cascade or spouted dryers (Exhibit 3-4) are commonly used for drying grain, but they can also be used for other types of biomass. Material is introduced to a flowing stream of hot air as it enters an enclosed chamber. The material is thrown into the air, then falls, or cascades, back to the bottom to be lifted again. Some of the material is drawn out through openings in the side of the chamber that control the residence time and amount of drying. The typical residence time for a cascade dryer is a couple of minutes.

**Exhibit 3-4: Side View of a Cascade Dryer**



Source:



### 3.4 Heat Recovery

Drying tends to be energy intensive because, in addition to the heat of vaporization of the water removed, energy goes into heating the biomass solids and into heating the air or steam used for drying. Recovery of some of this heat improves the overall efficiency of the drying process and boiler, but usually requires a significant capital investment.

### 3.5 Drier Choices

The choice of dryers will depend on the characteristics of the material being dried, the source of heat for the dryer, and integration options available.

An important consideration is the size of the material to be dried. For flash dryers and most SSDs, a small particle size is needed to suspend the material in a moving air or steam stream. Triple-pass rotary dryers will accept larger material, but may experience plugging with very large material. Cascade dryers need a very uniform particle size. For large or variable material, a single-pass rotary dryer might be best. For some materials, reducing the size of the material may be an option, but often this is an energy-intensive operation.

The heat source and temperature for drying are important considerations. Flue gas is an efficient source of heat, but the temperature may be too low to provide enough heat for complete drying. Using a process stream for heating may be energy efficient, but will require the capital investment in a heat exchanger and the interactions between the dryer and process must be considered. SSDs typically require a high-temperature heat source. If saturated steam is available, the disk dryer or modified SSD dryer would be an option. The goal should be to determine what excess heat is available in the system, then design the drying system to take advantage of it. If all else fails, a burner can be installed with an auxiliary fuel source to provide the heat for drying.

High-pressure operation can improve material handling in many cases when dealing with gasifiers. In those cases, the basic or modified superheated dryer would be favored. Again, SSDs have advantages when used for combined heat and power plants or combined cycle plants.

### 3.6 Benefits and Disadvantages of Different Types of Dryers

As mentioned earlier, the choice of dryers depends on many factors. A brief summary of the benefits and disadvantages of each type of dryer follows. The particular type of dryer, its configuration, and operating conditions should be determined case-by-case.

#### Rotary Dryers

Rotary dryers are less sensitive to particle size and can accept the hottest flue gases of any type of dryer. They have low maintenance costs and the greatest capacity of any type of dryer. However, material moisture is hard to control in rotary dryers because of the long lag time for material in the dryer. Rotary dryers also present the greatest fire hazard and require the most space. Compared to single-pass dryers, triple-pass dryers have higher capital costs, higher maintenance costs, higher blower costs and pose more of a fire hazard.

#### Flash Dryers

Flash dryers are much more compact than rotary dryers, but have higher installation costs. They can be used on most types of biomass, but have high blower power costs in addition to the heat requirements for drying. The particles being dried must be small to be suspended in the air stream. With the short retention time in the dryer, the hydrocarbon emissions may be slightly lower than for a rotary dryer. Like the rotary dryer, heat recovery can be difficult because of the air mixed with the water vapor. Flash dryers, because of their shorter retention time and lower operating temperature, have a lower fire risk than rotary dryers.

### Disk Dryers

The main advantage of disk dryers is that saturated steam can be used for heating. Because they are indirectly heated, condensing the vapor from the dryer is possible to recover some of the latent heat of vaporization. Operation is fairly straightforward and maintenance costs are reasonable. The main disadvantage is the limited capacity because of the relatively low operating temperature compared to other dryers.

### Cascade Dryers

Cascade dryers are similar to flash dryers, except they can handle slightly larger particles. However, for a good cascading effect in the dryer, the particle size must be fairly uniform. Like other air-heated dryers, heat recovery is difficult and expensive.

Exhibit 3–5 summarizes the main considerations in choosing among the dryer types.

**Exhibit 3–5: Summary of the Advantages and Disadvantages of Each Dryer**

Dryer Type	Requires Small Material?	Requires Uniform Size?	Ease of Heat Recovery	Fire Hazard	Steam Use
Rotary Dryer	No	No	Difficult	High	Can use steam
Flash Dryer	Yes	No	Difficult	Medium	None
Disk Dryer	No	No	Easy	Low	Saturated steam
Cascade Dryer	No	Yes	Difficult	Medium	None

Source: (NREL, 1998)

## 3.7 Fuel Powdering, Pelleting and Briquetting

Depending on the combustion technology used fuel products must fulfill different requirements. The demand to get the fuel product either powdered or as fluff, in pelletized form, or as briquettes or chips of defined size is not uncommon.

### 3.7.1 Powdering

Fuel material of small particle size (e.g. sawdust) is being generated by many production processes. With the appropriate utilization technology in place, such fuels can be directly utilized. The storage of fuel products with a small particle size can be done in flat bunkers and in silos. However, special provisions are also made with respect to fire protection and prevention of explosions during the storage of these materials.

However, in case the size of available material needs to be reduced, it can be done by using suitable equipment.

### 3.7.2 Pelletizing and Briquetting

Pellets are a solid biomass fuel with consistent quality – low moisture content, high energy density and homogeneous size and shape. The problems of conventional biomass fuels as an alternative to coal, oil or gas, which are attributed mainly to their low energy density, high moisture content and heterogeneity, can be lessened or even prevented altogether by the use of pellets. Consistent fuel quality makes pellets a suitable fuel type for all areas of application, from stoves and central heating systems to large-scale plants, and with practically complete automation in all these capacity ranges.

Advantages of solid biomass fuels are:

- Reduced storage volume through an increased bulk density of the loose fuel material,
- Better flow properties and dosage,
- Avoidance of bridges and clumping in silos and conveyor aggregates

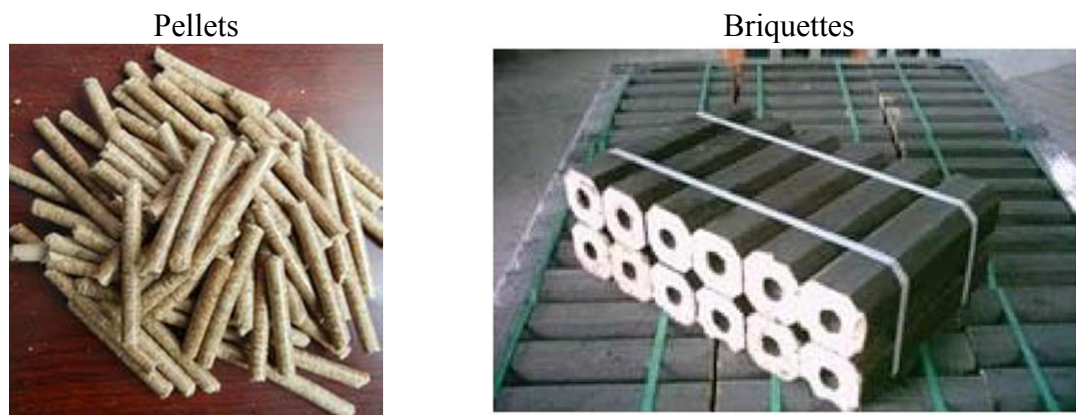
- Enhancement of the energy density and calorific content by pressure and heat.

Aside from compression pressure and grain size, also water content plays an essential role in the process. Adding binding agents can help to improve the physical and chemical quality and enhance the burnout.

The shape and particle size of a fuel usually determine the correct choice of feeding and furnace technologies as they influence the conveying and combustion behavior of the fuel. The bigger the fuel particles are, the more robust feeding appliances have to be and the longer becomes the required time for complete combustion.

Biomass pellets are usually 6-8mm diameter cylindrical high density sticks, while briquettes can be 22-70mm diameter cylindrical blocks, or cuboid and hexagon shape with a hole in the middle.

**Exhibit 3-6: Pellets and Briquettes**

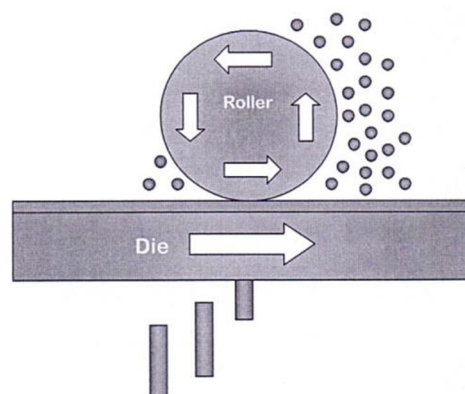


Different types of pellets mills include:

#### **Flat Die Pellet Mill**

The image to the right depicts the basic design and process of the flat die pellet mill. A solid metal plate sits below a series of compression rollers. Material enters from above and falls between the rollers, which is then compressed through the die. The finished pellets then emerge from the base of the die and leave the pellet mill.

**Exhibit 3-7: Flat Die Pellet Mill**



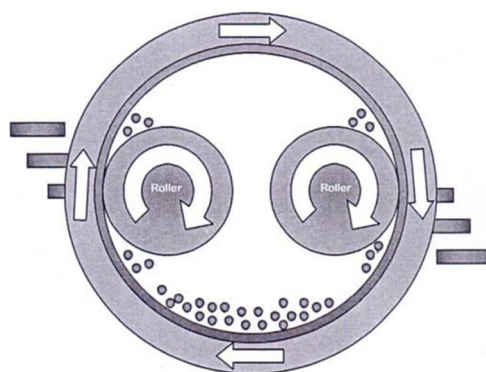
**Exhibit 3-8: Effect of pelletizing**

Material	Average diameter	Ash content	Average density	Moisture content	Calorific value
Rice husk	2-3mm	15-16%	500kg/m <sup>3</sup>	About 12%	10-13 MJ/kg
Rice husk pellet	8-10mm	6-7%	1120kg/m <sup>3</sup>	10-12%	15-16 MJ/kg

### **Ring Die Pellet Mill**

The image to the right depicts the basic design and operation of the ring die pellet mill. Unlike the flat die pellet mill design the ring die is positioned vertically instead of horizontally. The raw material enters the center of the die and is compressed through the die with a series of compression rollers. Most ring die pellet mills have two compression rollers, however some ring die pellet mills have three maybe four compression rollers. The most common design of ring die pellet mill is where the die is powered and rotating, and the rollers move due to the friction and movement of the die.

**Exhibit 3-9: Ring Die Pellet Mill**



### **Briquetting**

Briquetting presses operate as piston compressors with a fly wheel, slider crank, crosshead and plunger or with a hydraulic drive. After initial compression in a screw conveyor the material passes under pressure batch wise through the compression tools, cone for pre-compression and the press nipper. Within the press nipper a heating or cooling can be done. The briquette is wedged from the pneumatic press nipper in a pressure variable way

Piston rod presses are being used for the compression of sawdust, splinter, straw, paper fibers and similar materials.

Through the production of briquettes in various shapes, an optimal burning (burnout, burning duration) of the fuel material can be achieved.

## 4 Biomass conversion technologies

The conversion of biomass to energy (also called bioenergy) encompasses a wide range of different types and sources of biomass, conversion options, end-use applications and infrastructure requirements.

Biomass conversion technologies are broadly divided into the following prime categories:

- Thermochemical conversion
- Biochemical conversion

These technologies are briefly described in the following sections.

### 4.1 Thermochemical conversion

There are three major options under thermochemical conversion, namely:

- Combustion
- Gasification
- Pyrolysis

#### 4.1.1 Combustion

Combustion is basically an oxidation process, in which the flammable materials burn in the presence of air or oxygen, and as a result produce heat. Reactions producing heat are termed as exothermic.

In the combustion process, the oxidation carbon (C) and hydrogen (H<sub>2</sub>) predominantly present in the biomass takes place, and they are converted to dioxide (CO<sub>2</sub>) and water (H<sub>2</sub>O). Biomass also contains traces of other elements. Some of these are also oxidized, and released as gas in the flue gasses, or as solid as ash or slag.

The biomass is burnt in stoves, furnaces, and boilers. The temperature of hot gases produced is around 800 1000°C. The heat generated, as a result of combustion of biomass, is utilized over a wide range of applications, such as, cooking, heating of materials, and producing steam. Steam produced is then utilized for heating purposes in industrial and commercial facilities, for producing mechanical or electrical power by operating steam turbines and turbo-generators.

It is possible to burn any type of biomass but in practice combustion is feasible only for biomass with moisture content <50%. Therefore, in case of very high moisture content, the biomass is pre-dried.

#### 4.1.2 Gasification

Gasification is a partial oxidation process whereby a carbon source such as coal, natural gas or biomass, is broken down into carbon monoxide (CO) and hydrogen (H<sub>2</sub>), plus carbon dioxide (CO<sub>2</sub>) and possibly hydrocarbon molecules such as methane (CH<sub>4</sub>).

This mixture of gases is known as 'producer gas' or product gas (or wood gas or coal gas, depending on the feedstock), and the precise characteristics of the gas will depend on the gasification parameters, such as temperature, and also the gasification agent used, such as air or steam or oxygen or a mixture of these.

When using air as the gasification medium, the resulting high nitrogen (N<sub>2</sub>) content doubles the volume of the product gas and increase the size of the downstream gas cleaning equipment.

#### **Low temperature gasification**

If the gasification takes place at a relatively low temperature, such as 700°C to 1000°C, the product gas will have a relatively high level of hydrocarbons compared to high temperature gasification (see below). As a result it may be used directly, to be burned for heat or electricity generation via a steam turbine or, with suitable gas clean up, to run an internal combustion engine for electricity generation.

#### **High temperature gasification**

Higher temperature gasification (1200°C to 1600°C) leads to few hydrocarbons in the product gas, and a higher proportion of CO and H<sub>2</sub>.

This is commonly known as synthesis gas as it can be used to synthesize longer chain hydrocarbons using special conversion techniques.

Gasification technology can be used for:

- Heating water in central heating, district heating or process heating applications
- Steam generation
- Electricity generation or motive force
- As part of systems producing electricity or motive force

Gasification process is actually composed of four distinct processes, namely, combustion, drying, pyrolysis and reduction. Since, the gasification is the subject of this manual, these will be discussed in detail throughout this manual.

### **4.1.3 Pyrolysis**

Pyrolysis consists of thermal decomposition of biomass in the absence of oxygen at temperatures in the vicinity of 500°C. The products of pyrolysis include gas, liquid and a solid char, with the proportions of each depending upon the parameters of the process.

It can lower or higher temperature pyrolysis.

Lower temperatures (around 400°C) tend to produce more solid char (slow pyrolysis), whereas somewhat higher temperatures (around 500°C) produce a much higher proportion of liquid.

## **4.2 Biochemical conversion**

The prominent biochemical technologies are:

- Anaerobic digestion
- Fermentation

### **4.2.1 Anaerobic digestion (AD)**

Anaerobic digestion (AD) is the process whereby bacteria break down organic material (biomass) in the absence of air into methane, carbon dioxide, and solid residue. In this process, the bacteria utilize oxygen from biomass itself instead of from the ambient air. Its product gas is called biogas.

There are three basic AD processes, which take place over different temperature ranges.

**Psychrophilic digestion**

It takes place below 25°C, and rate is slower. It takes 70 to 80 days.

**Mesophilic digestion**

It takes place between 20°C and 40°C and can take 30 to 40 days to complete.

**Thermophilic digestion**

It takes place from 50-65°C and is faster, but the bacteria are more sensitive. This process takes 15 to 20 days to complete.

Parameters affecting the anaerobic digestion are temperature, pH (acidity/alkalinity) of the digestate, and concentration of ammonia. High concentration of ammonia inhibits the digestion process.

The methane can be burned for heat or electricity generation.

The solid residue of the AD process can be used as a soil conditioner. In fact, it is an excellent fertilizer

The digesters are simple, cheap, robust, easy to operate and maintain, and can be constructed with local produced materials. Usually, there are no control instruments and no process heating (psychrophilic or mesophilic operation temperatures).

## **4.2.2 Fermentation**

In this process, biomass is converted into sugar using acid or enzyme. Sugar is then converted into ethanol or other chemicals with the help of yeast.

*More information on fermentation to be included.*





## 5 Biomass gasifiers

Two principal types of gasifiers have emerged: fixed bed and fluidized bed. Fixed bed gasifiers are typically simpler, easy to operate and less expensive. They produce a lower heat content producer gas. Fluidized bed gasifiers are more complicated and more expensive. However, they produce a product gas with a higher heating value.

### 5.1 Fixed bed gasifiers

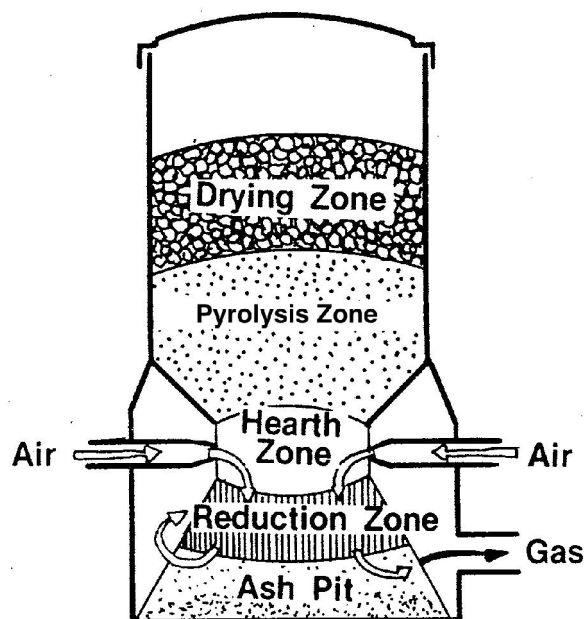
Fixed bed gasifiers typically have a fixed grate inside a refractory-lined shaft. The fresh biomass fuel is typically placed on top of the pile of fuel, char, and ash inside the gasifier. A further distinction is based on the direction of flow of the gasifying agent (air or oxygen).

Schematics of the primary section of the fixed bed gasifier types are described and shown in the following sections.

#### 5.1.1 Downdraft or co-current gasifier

In the downdraft gasifier (Exhibit 5-1), the air flows down through the bed and leaves as producer gas under the grate, while the feedstock is charged from the top.

Exhibit 5-1: Typical Downdraft or concurrent gasifier



Source: Kaupp

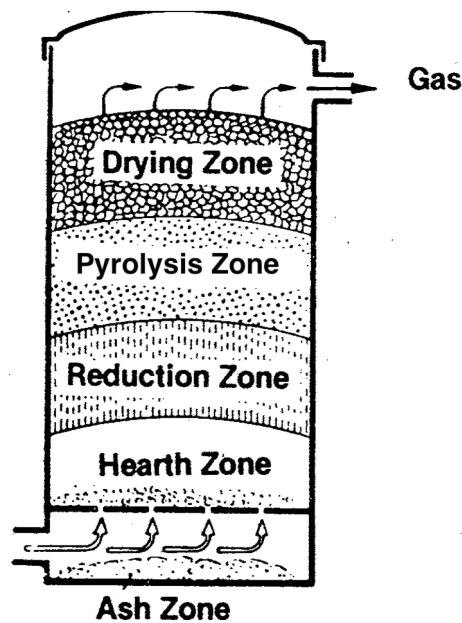
#### 5.1.2 Updraft or counter-current gasifier

In this type of gasifier (Exhibit 5-2), the air enters into the gasifier below the grate, flows up through the grate, and producer gas is collected above the bed.

#### 5.1.3 Cross-draft or cross-flow gasifier

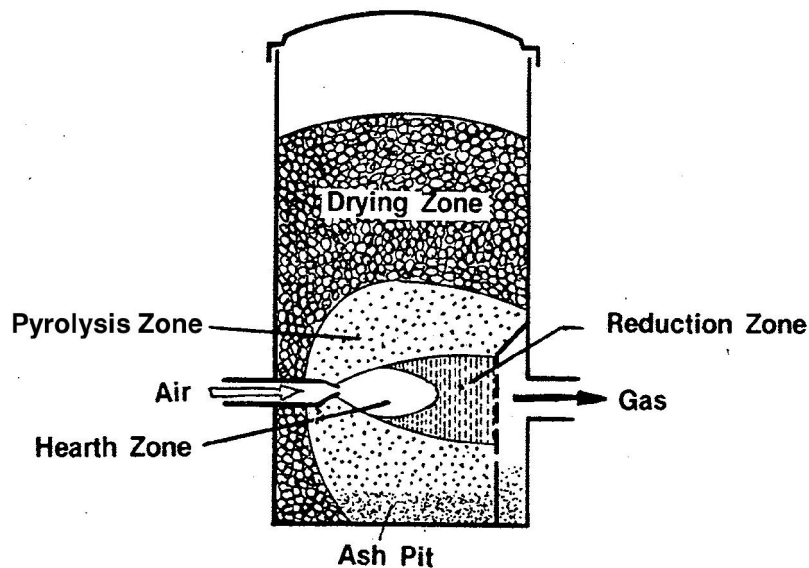
In the cross-draft gasifier (Exhibit 5-3), the air flows across the bed, exiting as product gas, i.e. gasifying agent enters from one side of the gasifier and leaves from the other side.

Exhibit 5-2: Updraft gasifier



Source: Kaupp

Exhibit 5-3: Cross-flow gasifier



Source: Kaupp

#### 5.1.4 Comparison and characteristics of fixed bed gasifiers

Fixed bed gasifiers are usually limited in capacity, typically used for generation systems that are able to produce less than 5 MW. The physics of the refractory-lined shaft reactor vessel limits the diameter and thus the throughput. Developers have identified a good match between fixed bed gasifiers and small-scale distributed power generation equipment. However, the variable economics of biomass collection and feeding, coupled with the gasifier's low efficiency, make the economic viability of the technology particularly site-specific.

Exhibit 5-4 compares fixed bed gasifier types, while Exhibit 5-5 provides typical physical characteristics of a fixed bed gasifier.

**Exhibit 5-4: Comparison of fixed bed gasification technologies**

	Type of gasifier		
	Downdraft	Updraft	Crossflow
Operation	Biomass is introduced from the top and moves downward. Oxidizer (air) is introduced at the top and flows downward. Syngas is extracted at the bottom at grate level.	Biomass is introduced from the top and moves downward. Oxidizer is introduced at the bottom and flows upward. Some drying occurs. Syngas is extracted at the top.	Biomass is introduced from the top and moves downward. Oxidizer is introduced at the bottom and flows across the bed. Syngas is extracted opposite the air nozzle at the grate.
Advantages	Tars and particulate in the syngas are lower, allowing direct use in some engines without cleanup. The grate is not exposed to high temperatures.	Can handle higher-moisture biomass. Higher temperatures can destroy some toxins and slag minerals and metal. Higher tar content adds to heating value.	Simplest of designs. Stronger circulation in the hot zone. Lower temperatures allow the use of less expensive construction materials.
Disadvantages	Biomass must be very dry (<20 percent moisture content). The syngas is hot and must be cooled if compression or extensive cleanup is required. About 4 to 7 percent of the carbon is unconverted and remains in the ash.	Higher tar content can foul engines or compressors. The grate is exposed to high temperatures and must be cooled or otherwise protected.	More complicated to operate. Reported issues with slagging. High levels of carbon (33%) in the ash.

Source: EPA Combined Heat and Power Partnership Biomass CHP Catalog

**Exhibit 5-5: Typical Characteristics of a Fixed Bed Gasifier**

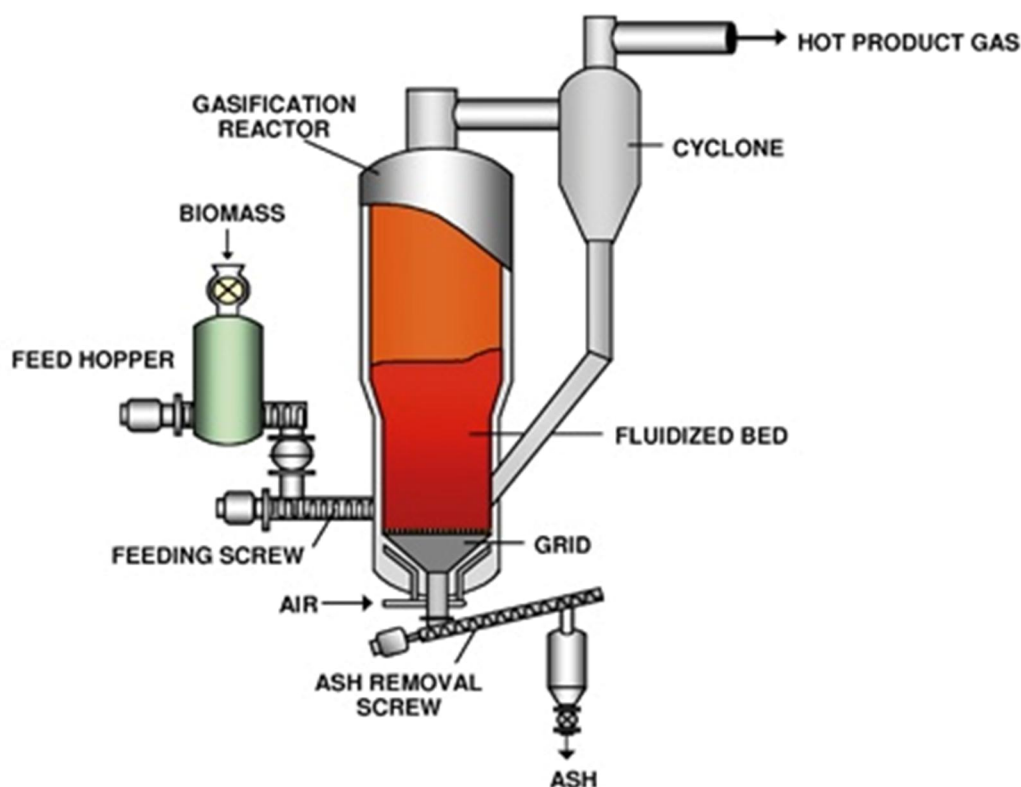
Parameter	Fixed Bed, Downdraft
Fuel size (mm)	10 – 100
Fuel ash content (% weight)	<6
Operating temperature (°C)	780 – 1400
Control	Simple
Turn-down ratio	4:01
Construction material	Mild steel + refractory
Capacity, MW <sub>thermal</sub>	< 5
Biomass, tonnes /day)	< 30
Start-up time	Minutes
Operator attention	Low
Tar content (kg/GJ product gas)	< 0.5
Heating value (MJ/Nm <sup>3</sup> ) HHV	4.8

Source: GasNet, n.d.; EPA Combined Heat and Power Partnership Biomass CHP Catalog

## 5.2 Fluidized bed gasifiers

Fluidized bed gasifiers utilize the same gasification processes and offer higher performance than fixed bed systems, but with greater complexity and cost. Similar to fluidized bed boilers, the primary gasification process takes place in a bed of hot inert materials suspended by an upward motion of oxygen-deprived gas (Exhibit 5–6). As the amount of gas is augmented to achieve greater throughput, the bed will begin to levitate and become “fluidized.” Sand or alumina is often used to further improve the heat transfer. Notable benefits of fluidized bed devices are their high productivity (per area of bed) and flexibility. Fluidized bed gasifiers can also handle a wider range of biomass feedstock with moisture contents up to 30 percent on average.

Exhibit 5–6: Fluidized Bed Gasifier



Source: Andritz AG

There are three stages of fluidization that can occur on the gasifier depending on the design:

- Bubbling,
- Recirculating, and
- Entrained flow.

At the lower end of fluidization, the bed expands and begins to act as a fluid. As the velocity is increased, the bed will begin to “bubble.” With a further increase in airflow, the bed material begins to lift off the bed. This material is typically separated in a cyclone and “re-circulated” to the bed. With still higher velocities, the bed material is entrained (i.e., picked up and carried off in the airflow).

Fluidized bed gasifiers can be designed to use a portion of the pyrolysis gases to generate the heat to drive the process, or they can be externally fired. Operating the gasifier at higher pressures increases the throughput; however, this also increases the gasifier's complexity and cost. In these units, the biomass is fully converted after going through the pyrolysis and char conversion processes.

By reducing the quantity of air and process temperature, it is possible to operate fluidized bed boilers as gasifiers. In this operating mode, the gasifiers produce a gas with a heating value of slightly more than 100 Btu/ft<sup>3</sup>. This gas is burned above the bed as additional air supply is injected upstream of the boiler tube section.

Exhibit 5-7 lists typical physical characteristics of a fluidized bed gasifier. A number of advanced-concept fluidized bed gasifiers aiming to produce a syngas with a heating value between 250 and 400 Btu/ft<sup>3</sup> are under development. This type of syngas would be more appropriate for use in gas turbines, fuel cells, and reciprocating internal combustion engines; however, these advanced concept gasifiers have not reached the point where they are proven in commercial operation.

**Exhibit 5-7: Typical Characteristics of a Fluidized Bed Gasifier**

Parameter	Fluidized Bed
Fuel size (mm)	0 - 20
Fuel ash content (% weight)	<25
Operating temperature (°C)	700 - 950
Control	Average
Turn-down ratio	3
Construction material	Heat-resistant steel
Capacity, MW <sub>thermal</sub>	5 and up
Biomass, tonnes/day	> 30
Start-up time	Hours
Operator attention	Average
Tar content (kg/GJ product gas)	< 0.86
Heating value (MJ/Nm <sup>3</sup> ) HHV	5.6

Source: GasNet, n.d.; EPA Combined Heat and Power Partnership Biomass CHP Catalog

### 5.3 Advantages and disadvantages of gasifier types

Fixed bed and fluidized bed gasifiers have specific operating advantages and disadvantages with biomass fuels depending on the biomass characteristics and site requirements. Exhibit 5-8 provides a qualitative comparison of gasifier characteristics and operating issues for fixed bed and fluidized bed systems.

**Exhibit 5–8: Relative advantages/disadvantages of gasifier types**

Gasifier	Advantages	Disadvantages
Updraft fixed bed	Mature for heat Small-scale applications Can handle high moisture No carbon in ash	Feed size limits High tar yields Scale limitations Low heating value Slagging potential
Downdraft fixed bed	Small-scale applications Low particulates Low tar	Feed size limits Scale limitations Low heating value Moisture-sensitive
Bubbling fluid bed	Large-scale applications Feed characteristics Direct/indirect heating Can produce higher heating value gas	Medium tar yield Higher particle loading
Circulating fluid bed	Large-scale applications Feed characteristics Can produce higher heating value gas	Medium tar yield Higher particle loading
Entrained flow fluid bed	Can be scaled Potential for low tar Potential for low methane Can produce higher heating value gas	Large amount of carrier gas Higher particle loading Particle size limits

Source: EPA Combined Heat and Power Partnership Biomass CHP Catalog

## 5.4 Factors influencing gasification

The performance of a well-controlled gasification process aims to minimize the production of tar and char and optimize the formation of product gas of high heating value. It depends on many factors and operational parameters, such as:

- Properties of the Biomass – composition, heating value, moisture content, bulk density, particle size
- Gasifier design
- Gasification agent
- Equivalence ratio
- Hearth load
- Turndown ratio
- Superficial gas velocity
- Operating temperature
- Operating pressure
- Catalyst (if used)

These factors are discussed in the following sections and other chapters as appropriate.

### 5.4.1 Equivalence Ratio (ER)

ER is defined as the ratio of oxygen supplied per kg wood to the stoichiometric requirement. ER fixes the amount of air supplied for gasification. The equation for calculating ER is (Kaupp, 1984):

$$\text{Equivalence Ratio (ER)} = \frac{\frac{(\text{Oxidant})}{(\text{Dry Fuel})} (\text{Actual Weight Ratio})}{\frac{(\text{Oxidant})}{(\text{Dry Fuel})} (\text{Stoichiometric Weight Ratio})}$$

As the ER value approaches 1.0, combustion reaction is predominant, and as it tends to zero, pyrolysis is the major process.

The ER for gasification processes as they take place in practice lies between those two extremes and within a range of 0.2 to 0.4 for steady state operation. This range refers to the partial combustion zone of the gasification process. A value of 0.3 ER is the theoretical optimum (Jenkins, B.M. 1980) [FAO; 19].

All the gasifier designs are based on the above-mentioned optimum. For a given biomass consumption rate, the volumetric rate of air can be calculated from ER value (Kaupp, A. and Goss, J.R. 1981) [FAO; 20].

For example, normally, the value of ER for wood is 0.255.

### 5.4.2 Hearth load / Specific gasification rate (SGR)

It is defined as the amount of producer gas to be obtained in a unit time per unit cross-sectional area of the gasifier throat, which is the smallest cross-sectional area in the gasifier. It is also referred as specific gasification rate (SGR).

It is expressed as: Nm<sup>3</sup>/cm<sup>2</sup>-h (normal cubic meters of producer gas produced per cm<sup>2</sup> minimum cross-sectional area of the gasifier (throat) in one (1) hour. Mathematically,

$$SGR = \frac{Nm^3}{cm^2 \times h}$$

The hearth load varies between an upper limit, SGR<sub>max</sub>, above which the gas quality is poor because of charcoal dusting in the combustion zone and a lower limit, SGR<sub>min</sub> below which due to too low temperature in the hearth, the gas will contain unacceptably large quantities of tar. For the satisfactory and continuous operation of specifically Imbert gasifiers, and other similar reactors, the limits for SGR<sub>max</sub> and SGR<sub>min</sub> are:

$$SGR_{max} = \frac{0.9 Nm^3}{cm^2 \times h} \quad SGR_{min} = \frac{0.3 \sim 0.35 Nm^3}{cm^2 \times h}$$

### 5.4.3 Fuel consumption rate (FCR) and SGR relationship

Fuel consumption rate (FCR) is defined as the amount of fuel consumed in a unit time per unit cross-sectional area of the gasifier throat, which is the smallest cross-sectional area in the gasifier.

It is expressed as: kg/cm<sup>2</sup>-h (kg of fuel consumed in the gasifier per cm<sup>2</sup> minimum cross-sectional area of the gasifier (throat) in one (1) hour. Mathematically,

$$FCR = \frac{kg}{cm^2 \times h}$$

Depending on properties of fuel used, one (1) kg of biomass fuel consumed in a gasifier, under normal operating conditions, generated producer gas in the range of 2 -2.5 Nm<sup>3</sup> of producer gas. Accordingly, the relationship between SGR and FCR is expressed as:

$$SGR = 2.5 \times FCR$$

(When 2.5 Nm<sup>3</sup> of producer gas is generated per kg of fuel, especially for wood.)

$$SGR = 2.0 \times FCR$$

(When 2.0 Nm<sup>3</sup> of producer gas is generated per kg of fuel, especially for rice husk.)

The relationship is the function of amount of gas generated per kg of fuel consumed.

When 2.5 Nm<sup>3</sup> gas produced per kg of fuel, and SGR<sub>max</sub> is 0.9, rearranging the equation:

$$SGR = 2.5 \times FCR$$

$$FCR_{max} = 0.4 \times SGR_{max}$$

$$FCR_{max} = 0.4 \times 0.9 = 0.36 \frac{kg}{cm^2 \times h}$$

For the other extreme case, when 2.0 Nm<sup>3</sup> gas produced per kg of fuel, and SGR<sub>max</sub> is 0.9, rearranging the equation:

$$SGR = 2.0 \times FCR$$

$$FCR_{max} = 0.5 \times SGR_{max}$$

$$FCR_{max} = 0.5 \times 0.9 = 0.45 \frac{kg}{cm^2 \times h}$$

#### 5.4.4 Gasification efficiency

The maximum dilution of gas takes place because of presence of nitrogen. Almost 50-60% of gas is composed of non-combustible 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. Nevertheless where the end product is methanol – a high-energy quality item, then the cost and use of oxygen can be justified.

On an average 1 kg of biomass produces about 2.5 m<sup>3</sup> of producer gas at normal conditions. In this process it consumes about 1.5 m<sup>3</sup> of air for combustion. For complete combustion of wood about 4.5 m<sup>3</sup> of air is required. Thus biomass gasification consumes about 33% of theoretical stoichiometric ratio for wood burning.

The average energy conversion efficiency of biomass gasifiers (especially wood based gasifiers) is about 60-70% and is defined as:

$$\eta_{gas} = \frac{\text{Calorific Value of gas per kg of fuel}}{\text{Avg. Calorific Value of 1 kg of fuel}}$$

#### 5.4.5 Turndown ratio (TDR)

It is the ratio between SGR<sub>max</sub> and SGR<sub>min</sub>. Its range under these conditions can be calculated as the following for SGR<sub>max</sub> = 0.9 and SGR<sub>min</sub> = 0.3 – 0.35:

$$TDR = \frac{SGR_{max}}{SGR_{min}}$$

$$TDR = \frac{0.9 SGR_{max}}{0.3 SGR_{min}} = 3$$



$$TDR = \frac{0.9 SGR_{max}}{0.35 SGR_{min}} = 2.57 \text{ (say 2.5)}$$

So, in this case, the TDR ranges between 2.5 and 3.0.

#### 5.4.6 Superficial Gas Velocity (SGV)

It is expressed in m/s. SGR is the velocity of gas at the throat of the gasifier in the gasification zone considering the throat to be empty. The relationship between hearth load (SGR) and SGV is:

$$SVG = 0.36 SGR$$

The superficial velocity corresponding to a hearth load (SGR) of 0.9 Nm<sup>3</sup>/cm<sup>2</sup>-h is 2.5 m/s, calculated as:

$$SGV = \frac{0.9 \text{ Nm}^3}{\text{cm}^2 \times h} \times \frac{10,000 \text{ cm}^2 \times h}{\text{m}^2 \times 3,600 \text{ s}} = 2.5 \frac{\text{m}}{\text{s}}$$

The actual gas velocity at the throat of the gasifier is much more compared to this value due to presence of char/biomass particles and high temperature in the oxidation zone of the gasifier.

It is an important parameter influencing the performance and behavior of the gasifier. It controls the following aspects of the gasification process:

- Fuel consumption rate
- Gas production rate
- Char production
- Tar production
- Product gas heating value

#### 5.4.7 Operating temperature

Temperature control of the gasification is an essential variable. It corresponds to the ER, TDR and biomass consumption rate.

Increase in temperature increases the formation of combustible gases, decreases the yield of char and tar and leads to more complete conversion of the fuel into product gas.

Hydrocarbon gases (especially methane and ethylene) increase with temperature while the yields of higher hydrocarbons decrease at temperatures above 650°C. The energy content of the product gas increases steadily up to 720°C then decreases at higher temperatures.

Hence, the optimum temperature generally ranges from 650°C to 720°C. In fact, while depending upon other variables, it is very much biomass specific to fuel properties.

#### 5.4.8 Operating pressure

Operating pressure of the gasifier is another important variable.

The rate of char gasification and yields of methane increase with increasing pressure, and the impacts are most significant at high temperatures (900°C to 950°C).

Small scale gasifiers are normally operated at slightly negative pressure (Vacuum), while large scale gasifier integrated with gas turbines operate at high pressures, since the gas turbines operate at elevated pressures.

## 5.5 Gasifiers population and sizes

Downdraft gasifiers are most common (Exhibit 5–9). The population of various types of gasifiers is:

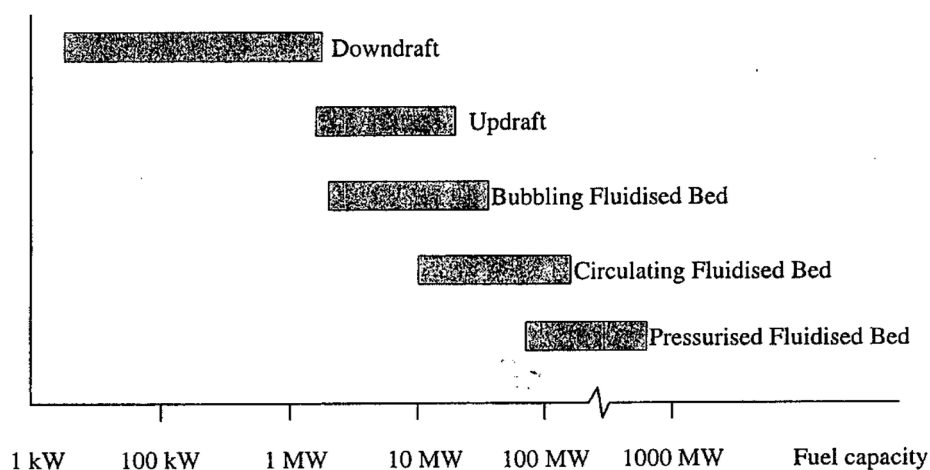
**Exhibit 5–9: Population of gasifiers by design**

Downdraft	75%
Fluidized bed	20%
Updraft	2.5%
Other designs	2.5%

Source: Knoef, 2000 (**Basu**)

Preferred gasification technologies at different sizes is illustrated in Exhibit 5–10

**Exhibit 5–10: Sizes of biomass gasifier for different designs for application ranges**



Source: TPS, Inc., Nykoping, Sweden

## **6 Auxiliary equipment**

Gasifiers are very fuel specific and they are tailored according to the fuel. There is no such thing as a universal gasifier. Further, fuel used, gasifier design and operating conditions influence the quality and quantity of product gas. For a specific fuel, a well-designed and properly operated gasifier will tend to produce good quality product gas with fewer impurities. Impurities usually present in the product gas are discussed below.

### **6.1 Producer gas impurities**

The product gas leaving the gasifier is hot and may contain a number of impurities, including:

- Moisture
- Particulates
- Tar
- Trace impurities

#### **6.1.1 Moisture Content**

It is desirable to use fuel with low moisture content because heat loss due to its evaporation before gasification is considerable and the heat balance of the gasification reaction is disturbed. High moisture content also puts extra load on cooling and filtering equipment by increasing the pressure drop across these units because of condensing of moisture vapors. Thus, as the situation demands, the fuel should be pre-dried / treated to reduce / limit its moisture content. Generally, moisture content for fuel should be less than 20%, preferably 15%.

#### **6.1.2 Particulate Content**

All gasifier fuels produce dust particulates in varying quantity. It is a nuisance since it can clog the end-use equipment, where the product gas is used. Hence, it must be removed to the permissible limits specified for end-use of the product gas. Through gasifier design and control of operating parameters, it should be ensured that the gasifier does not produce more than 2-6 g/m<sup>3</sup> of dust. Higher dust levels pose additional load on cleaning systems, therefore, necessitating their large size and frequent maintenance.

#### **6.1.3 Tar Content**

Tar is another most unpleasant constituent of the gasification process. On cooling of product gas, it condenses, and tends to deposit and clog the system, e.g. the carburetor and intake valves of internal combustion engine causing sticking and troublesome operations. The physical property of tar depends upon temperature and heat rate of the gasifier and the appearance ranges from brown and watery (60% water) to black and highly viscous (7% water).

#### **6.1.4 Trace impurities**

Trace impurities present in the product gas depend on the composition of biomass fuel used. They are mostly, nitrogen compounds, sulfur compounds, and alkali compounds, besides oxides of other heavy metal present in the biomass gasified. Nitrogen compounds are

present mainly as ammonia. Alkali components consist of particularly Na and K compounds. Oxides of sulfur and hydrochloric acid are other impurities. These impurities cause many problems including corrosion.

## 6.2 Producer gas quality

Gasification systems are employed in integrated configuration. The product gas may be used for heating purposes in a furnace or steam generation, driving an internal combustion engine, and in a gas turbine. Depending on the application of the producer gas, a certain level of gas conditioning (cleaning and cooling) is required.

When a gasifier system is used in conjunction with an internal combustion engine or cold gas transfer is used, it is important that the engine is supplied with a gas that is sufficient free from dust, tars and acids. The tolerable amounts of these substances will vary depending on the types and outfit of the engine. Average tolerable values of impurities for currently available engines are as the following (Tiedema et al., 1983):

Dust:	Lower than 50 mg/m <sup>3</sup> gas preferably 5 mg/m <sup>3</sup> gas
Tars:	Lower than 500 mg/m <sup>3</sup> gas
Acids:	Lower than 50 mg/m <sup>3</sup> gas (measured as acetic acid).

(The acid value is measured as acetic acid, which can be tested by a testing laboratories.)

Gas turbines also require high quality product gas. However, gas turbines are less sensitive to tar as compared to internal combustion engines, because the gas entering the gas turbine is usually at high temperature and therefore the tar is in vapor state.

Meanwhile, higher limits of impurities are tolerable for the heating applications.

## 6.3 Cooling and cleaning of product gas

The two processes are described in the following sections.

### 6.3.1 Cooling process

It is invariably done in water scrubbers, where partial cleaning takes place simultaneously along with cooling of gas.

### 6.3.2 Gas Cleaning Options

As discussed earlier, the end-use of the gas determines the degree of cleanup required and can be achieved by either of the following two options:

#### Hot gas cleaning

The benefit of hot-gas cleaning is that more energy is gained from the gas but the process poses significant technical challenges.

#### Cold gas cleaning

The cold-gas cleaning is technically simpler but produces a wastewater contaminated with tar, which is likely to pose a disposal problem. It is discussed in the following section.

### 6.3.3 Tar removing options

There are two options of the removal of tar present in the product gas.

### **Tar cracking**

Tar can be cracked into lower molecular weight compounds using either catalytic or thermal processes.

Catalytic cracking takes place at 800-900°C and thermal cracking at 900-1100°C. As gasification is usually in the range 800-900°C, thermal cracking requires additional energy to heat the gas, which is usually achieved by introducing a small volume of air to enable combustion of part of the gas to raise the temperature. While an effective method, thermal cracking reduces the overall efficiency of conversion of biomass-to-energy gasification process. Catalytic cracking is therefore preferred, using catalysts such as dolomite, olivine and nickel compounds. A uniform and high temperature has been found to be the ideal combination to achieve the total cracking of tar.

### **Removal of tar by cleaning unit**

Production of a very low tar content gas is best achieved by cooling the gas to 60-80°C with water and using electrostatic precipitators to capture any aerosols. However this approach also collects water condensed from the gas phase during cooling, resulting in a wastewater heavily contaminated with dissolved organic substances, which require appropriate treatment and/or disposal.

## **6.3.4 Cooling and cleaning train**

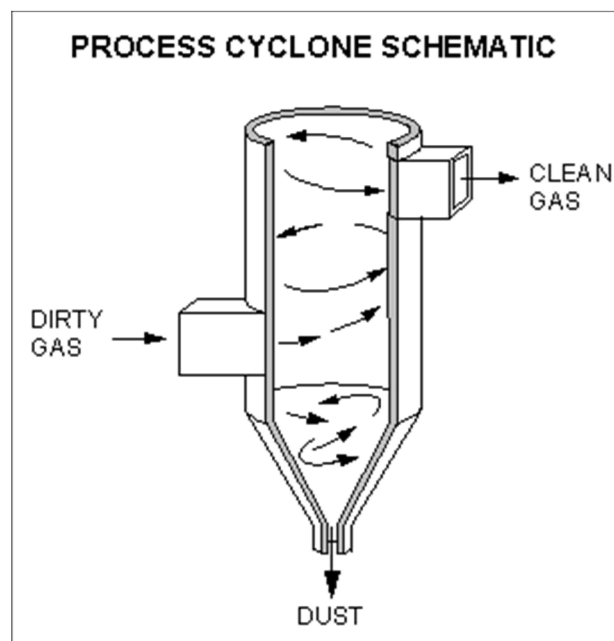
Depending on the size of gasification system and quality of product gas needed, the cooling and cleaning train may consist of the following units:

- Cyclone separator (one or two units)
- Water scrubbers (one or two units)
- Filtration units (one or two)

## **6.4 Cyclone separator**

As system requires, the gas just leaving the gasifier is sent to the cyclone separator to separate dust particulates, before the gas enters the water based cooling and scrubbing unit.

**Exhibit 6-1: Typical cyclone separator**

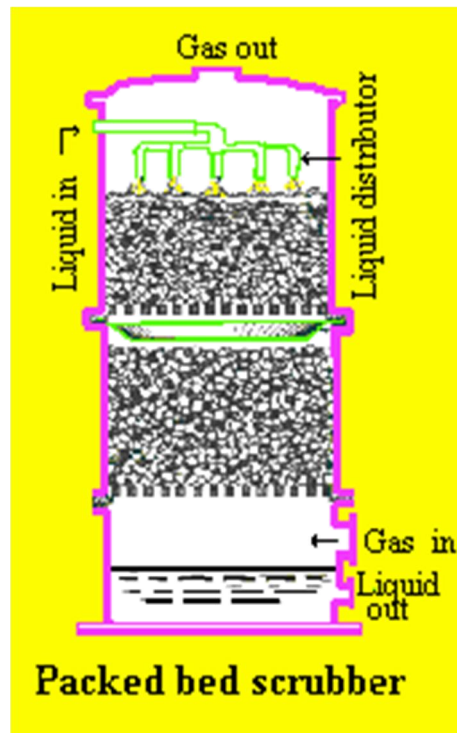


## 6.5 Water showering/cooling unit

Temperature of the product gas leaving the gasifier is normally in the range of 350°C to 450°C. When the gas cools to 150°C, the tar condenses, solidifies and settles.

Cooling and scrubbing unit is cylindrical vessel as shown in Exhibit 6-2. Raw hot gas enters the unit from bottom and cool scrubbed gas leaves from the top. Gas. While, from the top, pressurized water is sprayed through nozzles in the form of mist (fine water droplets). Contaminated hot water flows downward and is collected from the bottom. The flow of water and gas is countercurrent.

Exhibit 6-2: Cylindrical unit of scrubbing and cooling



Pebbles may be used as the filling medium in the cooling vessel. It will need flushing of the system / pebbles at appropriate regular intervals.

## 6.6 Gas Cleaning Unit

For small sized gasification systems, the gas cleaning filter units are simple, cost effective and can be easily operated. A reliable filter medium should meet the following criteria:

1. Neutral and non-reactive
2. Easily available in different grain size grades
3. Inexpensive and easily available
4. Can withstand high gas temperature
5. Easy to clean and recycle i.e. regenerative material

The filter consists of following five compartments (Pathak et al., 2007) as shown in Exhibit 6-3:

1. First compartment: Raw gas collection
2. Second compartment: 1st filtration material
3. Third compartment: 2nd filtration material

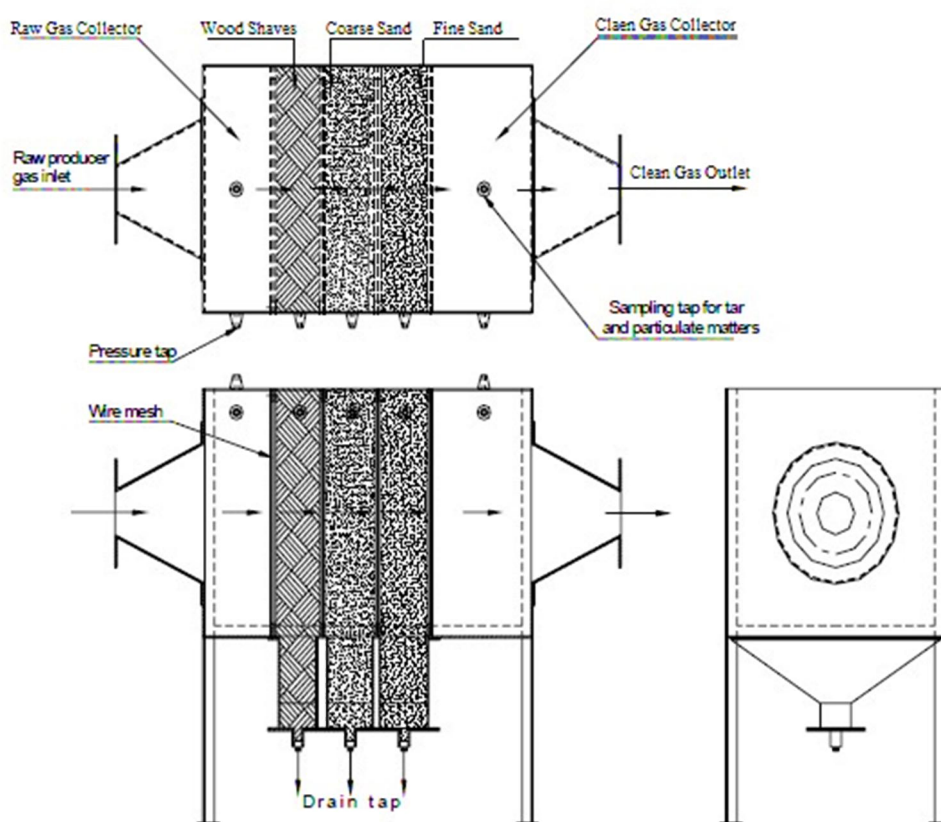
4. Fourth compartment: 3rd filtration material
5. Fifth compartment: Clean producer gas collection

The second, third and fourth compartment are filled with, wood sheaves, small pieces of charcoal and sawdust respectively.

The area of gas cleaning filter is designed for superficial velocity of 0.1 m/s and for maximum designed gas flow rate of the gasifier in m<sup>3</sup>/h. Area of the filter, in m<sup>2</sup>, can be easily calculated for the two known quantities. (Pathak et al., 2007)

The sand/biomass bed filter can be designed and fabricated in rectangular shape from 3 mm thick mild steel or stainless steel sheet. Wire meshes fabricated from stainless steel may be used to separate filter bed. Most of the gas contaminants (particulates and tar) are deposited in the initial 20 to 30 mm layers of bed height (Pathak et al., 2007). Therefore, to be on safe side, the height of each bed in the filter should be increased 2 to 3 times the actual size.

**Exhibit 6–3: Schematic Diagram of sand bed filter to clean producer gas (Pathak et al., 2007)**



In the three respective stages of the filter: (1) sun dried wood shave is used to remove the moisture from the producer gas, (2) coal is used to remove coarse particulates and tar, and (3) wood saw dust or fine sand is used to remove fine particulates and tar. Wire meshes having size equivalent to that of respective material size is used to separate the beds. The three beds of wood shaves, charcoal and fine wood saw dust should be easily removed and replaced by fresh material by opening the door provided at the upper side of the filter. As shown in the exhibit, the entrance and exit of the producer gas is on opposite sides.

Pressure drop across the filtration units will indicate their status. It can be measured by using a suitable manometer. Excessive pressure drop calls for the maintenance.

#### **Special note**

For continuous operation, the cooling / scrubbing units and filtering units should have standby units (placed in parallel). The arrangement will facilitate, the flushing, maintenance and replacement of the cooling and filtering mediums and regular intervals.

## 7 Instrumentation, measurement and controls

Instruments and controls are essential for a gasification system to assume safe, efficient and reliable operation. The subject of instruments and controls is extremely broad, and this section limits itself to some brief concepts and underlying fundamentals.

Controls range from simple manual systems to completely automatic computer-assisted systems, and hence the type of control system used in a gasification system would depend upon the requirements of the total operation and the cost involved. The following sections cover many of the typical instruments and controls.

### 7.1 Gasification Instrumentation

Important control parameters in a gasification plant are :

- Pressure
- Temperature
- 

Other desirable measurements include producer gas analysis, exhaust flue gas analysis, \_\_\_\_\_, and \_\_\_\_\_. The completeness and sophistication of the instrumentation used is usually proportional to the size and complexity of the unit.

### 7.2 Pressure Measurement

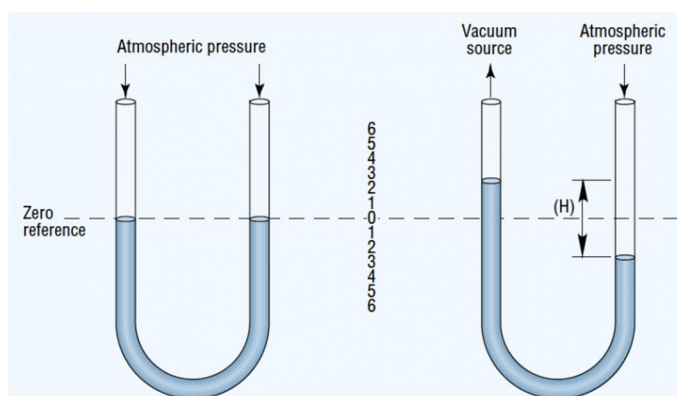
Normally pressure gauges are used to measure pressure at different points. Pressure gauge is a device to indicate the pressure of a fluid. Commonly Bourdon-Tube gauges are for pressure measurements. It indicates the amount of deflection under internal pressure of an oval tube bent in an arc of circle and closed at one end.

Other modes of pressure measurements are:

- Manometer method
- Elastic Element Method
- Bellows Elements
- Diaphragm Elements
- Electrical / Electronic Methods

Fixed bed gasifiers mostly operate under vacuum (negative pressure), close to atmospheric pressure. Under these conditions, the use of manometers is proper and useful. Other alternative is the use of sensitive vacuum gauge.

**Exhibit 7-1: Manometer**





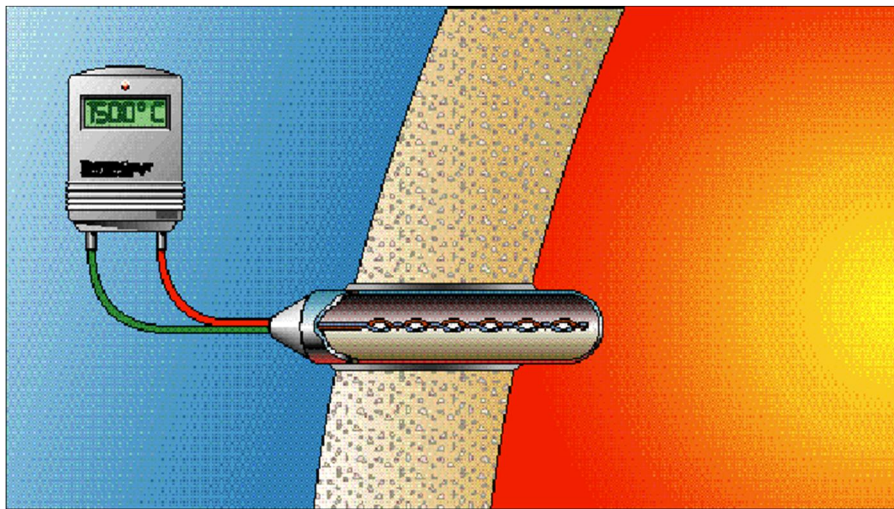
## 7.3 Temperature Measurement

Temperatures are measured by:

- Thermocouples
- Resistance Thermometers
- Filled-system Thermometers
- Bi-metallic Thermometers
- Liquid-in-glass Thermometers
- Pyrometers

For measurement of high temperatures, thermocouples or resistance thermometers are used. For lower temperature range, filled system or liquid-in-glass thermometers are appropriate. See Exhibit 7-2.

**Exhibit 7-2: Digital Thermometer and Probes for Different Applications**



Where access to hot surface or pipe-work is not easy, it is often possible to achieve good results using a non-contact temperature measuring instruments such as an infrared thermometer, illustrated in Exhibit 7-3.

**Exhibit 7-3: Typical Infrared Thermometer for Non-contact Temperature Measurement**



## 7.4 Producer gas analyzer

Analysis of the producer gases is a very useful mean to optimize and control the gasifier operation. For this purpose, digital based and very handy analyzers can be used. A typical portable producer gas analyzer is shown in Exhibit 7-4.

**Exhibit 7-4: A portable producer gas analyzer**



Measuring range of these analyzers is:

CO: 0-100%, CO<sub>2</sub>: 0-50%, CH<sub>4</sub> : 0-10%, C<sub>n</sub>H<sub>m</sub> : 0-10%, O<sub>2</sub>: 0-25%, H<sub>2</sub>: 0-50%

Gas fed to the analyzers must be free from dust, water vapor and tar. Otherwise, they are reliable, accurate and have quick response time.

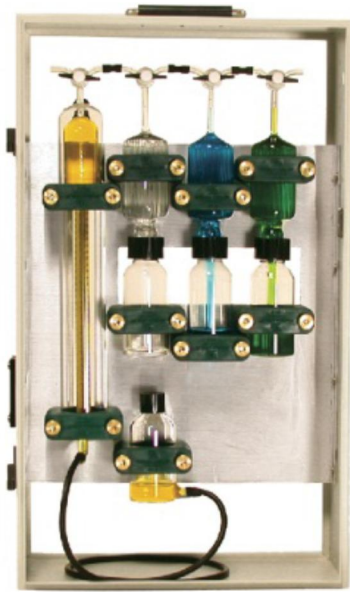
## 7.5 Flue Gas Analysis

For flue gas analysis, there are a number of methods available. The traditional method is the "Orsat" apparatus (Exhibit 7-5a), which uses chemical solutions to absorb carbon monoxide, carbon dioxide and oxygen from a flue gas sample. Changes in volume of the sample indicate the gas composition. A simplified version of the Orsat is shown in Exhibit 7-5b. This particular model is the "Fyrite" analyzer (other proprietary names are used by other manufacturers). Each Fyrite kit contains two plastic containers, each with an appropriate chemical fluid, one for oxygen analysis and one for carbon dioxide analysis. A gas sample is introduced into the container through a non-return valve and thoroughly mixed with the absorbing solution. A change in volume indicates directly the volume percentage of the particular component in the flue gas.

While the wet chemical test methods are quite inexpensive to use there are many new instruments available for oxygen measurement based on sensors which give an electronic signal proportional to the oxygen content of the gas. Examples of a typical electronic instrument are shown in Exhibit 7-6. These particular models use a sensor based on an electrolytic cell (similar to a battery): the sensor is inexpensive and robust, and relatively insensitive to contaminants in the flue gas such as sulfur dioxide. The life of a sensor is typically nine months to one year. Similar sensors are available for carbon monoxide (and also other gases, such as hydrogen sulfide and nitrogen oxides).

### Exhibit 7-5: Orsat Apparatus and Fyrite Gas Analyzer

a) Orsat Apparatus



b) Fyrite Gas Analyzer



### Exhibit 7-6: A Typical Portable Electronic Combustion Analyzer



Other instruments for oxygen measurement are based on zirconium oxide (zirconia), which conducts oxygen ions at temperatures above 650°C. The sensor is maintained at a high temperature, ideally about 800°C, and consists of a heated cell with two electrodes: one electrode is surrounded by a reference gas (usually air) and the other electrode has the sample gas passed over it. Any difference in oxygen content at the electrodes is translated into a potential difference and hence an electronic signal

Because a zirconia cell must have a heater and controls to ensure operation at affixed high temperature, instruments based on zirconia tend to be bulky and heavy. Portable analyzers are available, but the zirconia system is normally restricted to fixed gas analyzers mounted in the stack of medium to large boilers and furnaces, and more recently, package boilers. The life of a zirconia probe in a typical boiler stack should be five years or more.

In addition to ease of operation, the main advantage of the electronic analyzers is the ability to obtain continuous instant feedback on excess air and boiler efficiency while the sensor is in the stack. This greatly facilitates the boiler tuning process.

### 7.5.1 Sampling

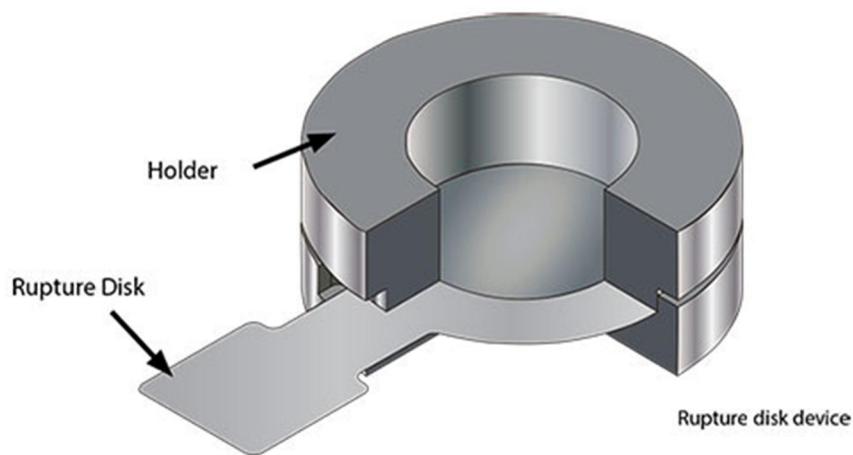
Regardless of what stack measurement is being made, whether it is CO, CO<sub>2</sub>, excess O<sub>2</sub>, smoke, temperature, etc., it is imperative that the measurement be made on a representative sample of the bulk of the gas flow. The location of the site at which the sample of flue gas and the stack temperature are obtained is as important as the measurement itself

## 7.6 Safety valve / rupture disc / explosion disc

Safety devices should be installed wherever the maximum allowable working pressure (MAWP) of a system or pressure-containing vessel is likely to be exceeded.

In case of small gasifiers, the use of rupture disc, also called as burst disc is suitable and must be used.

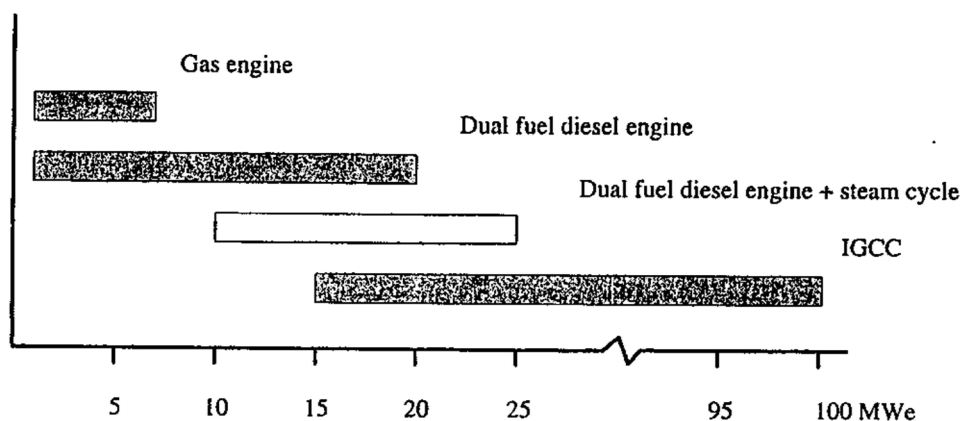
**Exhibit 7-7: Rupture disc**



## 8 Gasifier sizing guidelines

Since, the population of downdraft gasifiers is approximately 75%, and they are employed in the small sized applications. They are simple, cost effective and easy to operate. However, they are less efficient. With the passage of time specially designed gasifiers for large applications have been successfully developed, installed and being operated. However, they are expensive, costly, specialized, and fully automatic with electronic control. In fact, they are efficient. Exhibit 8-1 illustrates the gasifier sizes and their application.

Exhibit 8-1: Technology options with gasification



Source: TPS, Inc., Nykoping, Sweden

Therefore, the guidelines for the sizing of downdraft biomass gasifier are discussed in the following sections. However, it is imperative to have some fundamental information.

### 8.1 Composition of air

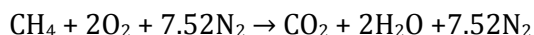
If one ignores the components, which are present in the range of parts per million (ppm), the air mainly consists of about 0.9% by volume argon, 78.1% nitrogen and 20.9% oxygen (ignoring water vapor). Carbon dioxide is present at 0.038%.

For the purposes of combustion calculations the composition of air is approximated as a simple mixture of oxygen and nitrogen:

Oxygen	21%
Nitrogen	79%

The ratio of oxygen and nitrogen in the air is 1:3.76 (79 divided by 21); while the ratio between oxygen and air is 1:4.76 (100 divided by 21)

For example, the stoichiometric relationship for complete combustion is:



As the volume of nitrogen is:  $2 \times 3.76 = 7.52$ , while the volume of air required for complete combustion is:  $2 \times 4.76 = 9.52$ .

### 8.2 Gases present in the producer gas

Exhibit 8-2 contains information on the properties of gases commonly present in the product gas. The last two columns provide the information on air requirement for complete

combustion of respective gasses in volumetric ratio and the heating value in kcal per normal cubic meter. Heating value of the combustion mixture is obtained by dividing the heating value of gas by the sum of the amount of gas and the air required, i.e., 1 + the amount of air required.

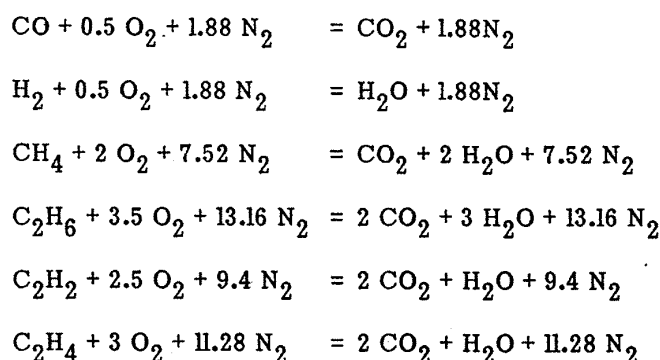
**Exhibit 8-2: Properties of gases present in the producer gas**

Gas	Chemical Symbol	Molecular Weight	Molecular Volume Nm <sup>3</sup> /kmol	Density kg/Nm <sup>3</sup>	Effective Heat Value		Stoichiometric Air Ratio Nm <sup>3</sup> /Nm <sup>3</sup>	Heat Value of Stoichiometric Mixture kcal/Nm <sup>3</sup>
					kcal/kmol	kcal/Nm <sup>3</sup>		
Carbon monoxide	CO	28.00	22.40	1.250	67,700	3,020	2.38	895
Hydrogen. . . .	H <sub>2</sub>	2.016	22.43	0.0899	57,590	2,570	2.38	760
Methane . . . .	CH <sub>4</sub>	16.03	22.36	0.717	191,290	8,550	9.52	812
Ethane. . . . .	C <sub>2</sub> H <sub>6</sub>	30.05	22.16	1.356	340,530	15,370	16.66	871
Acetylene . . .	C <sub>2</sub> H <sub>2</sub>	26.02	22.22	1.171	302,240	13,600	11.90	1,053
Ethylene. . . .	C <sub>2</sub> H <sub>4</sub>	28.03	22.24	1.261	318,490	14,320	14.28	937
Oxygen. . . . .	O <sub>2</sub>	32.000	22.39	1.429	--	--	-4.76	--
Nitrogen, pure	N <sub>2</sub>	28.02	22.40	1.251	--	--	--	--
Nitrogen mixed with argon as in air . .	--	(28.16)	22.40	1.257	--	--	--	--
Air . . . . .	--	(28.97)	22.40	1.293	--	--	--	--
Carbon dioxide	CO <sub>2</sub>	44.00	22.26	1.977	--	--	--	--
Water vapor . .	H <sub>2</sub> O	18.016	(22.4)	(0.804)	--	--	--	--

Source: Generator gas, the Swedish experience from 1939 to 1945, SERI, US Department of Energy

The equations for the complete combustion of various gases with air are:

**Exhibit 8-3: Complete combustion of various gases with air**



The values from Exhibit 8-3 can be used in Exhibit 8-4 for the producer gas of known composition to obtain heating value and density of the air gas mixture.

Exhibit 8-5 contains information on theoretical air required for complete combustion of given producer gas.

So, the air required is 0.984 Nm<sup>3</sup> per Nm<sup>3</sup> of dry producer gas. For general calculations, the stoichiometric air -fuel-ratio (AFR) for complete combustion can be assumed as 1:1.

Exhibit 8-4:

Analysis	Effective Heat Value (kcal)	Density (g/L)
CO <sub>2</sub> 11.0%		$0.110 \cdot 1.977 = 0.2175$
O <sub>2</sub> 0.1%		$0.001 \cdot 1.429 = 0.0014$
CO 19.0%	$0.190 \cdot 3,020 = 573.8$	$0.190 \cdot 1.250 = 0.2375$
H <sub>2</sub> 18.8%	$0.188 \cdot 2,570 = 483.2$	$0.188 \cdot 0.090 = 0.0169$
C <sub>n</sub> H <sub>m</sub> <sup>a</sup> 0.1%	$0.001 \cdot 14,320 = 14.3$	$0.001 \cdot 1.261 = 0.0013$
CH <sub>4</sub> 0.8%	$0.008 \cdot 8,550 = 68.4$	$0.008 \cdot 0.717 = 0.0057$
Residue		
N <sub>2</sub> 50.2%		$0.502 \cdot 1.257 = 0.6310$
100.0%	1,139.7	1.1113

Source: Generator gas, the Swedish experience from 1939 to 1945, SERI, US Department of Energy

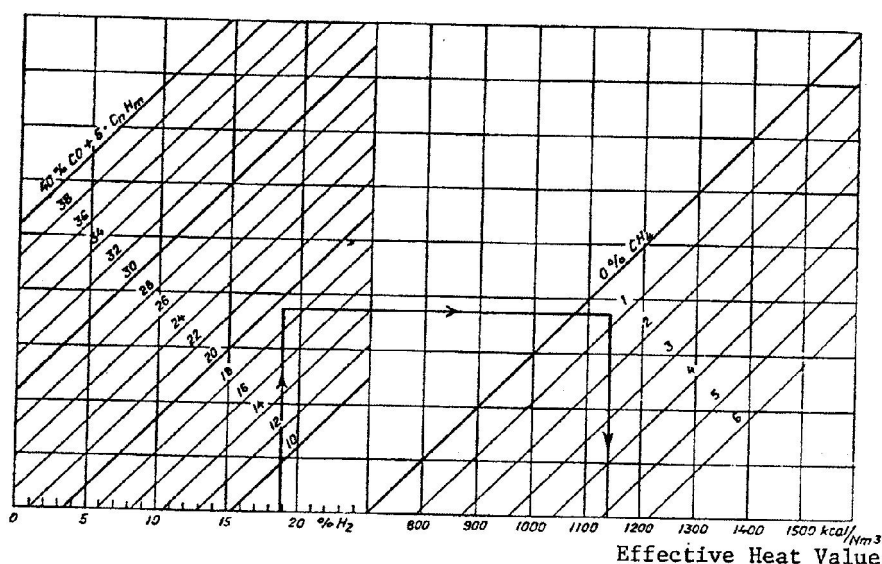
a C<sub>n</sub>H<sub>m</sub> denotes so-called heavy hydrocarbons present in the producer gas. In calculations, the values for ethylene may be used.

Exhibit 8-5: Air required for complete combustion

CO . . . . .	$0.190 \cdot 2.38 = 0.452$
H <sub>2</sub> . . . . .	$0.188 \cdot 2.38 = 0.447$
C <sub>2</sub> H <sub>4</sub> . . . . .	$0.001 \cdot 14.28 = 0.014$
CH <sub>4</sub> . . . . .	$0.008 \cdot 9.52 = 0.076$
O <sub>2</sub> . . . . .	$-0.001 \cdot 4.76 = -0.005$
	<u>0.984</u>

Exhibit 8-6 is the nomograph for determining the effective heat value for the produced gas. It shows the use of the nomograph for above example.

Exhibit 8-6: Nomograph for determining effective heat value of producer gas



Source: Generator gas, the Swedish experience from 1939 to 1945, SERI, US Department of Energy

## 8.3 Difference in engine output using different fuels

Heating values of producer gas and air mixtures are around 2500 kJ/m<sup>3</sup>, while the heating value of a stoichiometric mixture of gasoline (petrol) and air, which is about 3800 kJ/m<sup>3</sup>. When these values are compared with each other, the difference in power output between a given engine fuelled by gasoline and by producer gas becomes obvious. Therefore, a power reduction of about 35% can be expected as a result of the lower heating value of a producer gas and air mixture. (FAO, 1986)

## 8.4 Sizing of internal combustion engine (ICE)

The following example demonstrates the electrical power output of the given ICE running on producer gas for small-scale applications.

3,000 cc internal combustion engine (SI)	3	liter
Revolutions per minute	1,200	RPM
Revolutions for one suction	2	
Volume Displacement	1,800	liters/minute
Volume Displacement	30	liters/s
Volume Displacement	0.03	M <sup>3</sup> /s
Intake volume (Gas + Air)	0.03	M <sup>3</sup> /s
Intake Efficiency	80.00%	
Actual volume intake (Gas + Air)	0.024	M <sup>3</sup> /s
Air to fuel ratio	1.1:1	AFR
Air ratio based AFR	1.10	
Gas ratio based on	1.00	
Total Air + Gas intake based on AFR	2.10	1.1
Actual volume intake (Air)	0.0126	M <sup>3</sup> /s
Actual volume intake (Air + Gas)	0.0114	M <sup>3</sup> /s
Actual volume intake (Gas)	0.0240	
Producer gas HHV	5,000	kJ/m <sup>3</sup>
Thermal power of gas supplied to engine	57.14	kW <sub>th</sub> (kJ/s)
Efficiency of the engine	25.00%	
Mechanical power output of engine	14.29	kW <sub>mech</sub>
Generator efficiency	90.00%	
Power generated	12.86	kW <sub>elec</sub>
Power consumed by Auxiliary equipment	10.00%	
Actual power available	11.57	kW <sub>elec</sub>

*Note: Efficiency and its values at various stages of the overall process; and overall efficiency will be explained properly. Similarly, the assumption in the calculations; and explanation of calculation will be included in the final version of the manual.*

## 8.5 Sizing of gasifier

The calculations for the gasifier for producing 11.57 kW<sub>elec</sub> are illustrated, where the kW<sub>th</sub> (thermal) in terms of 57.14 kJ/s have been calculated in the above sheet.



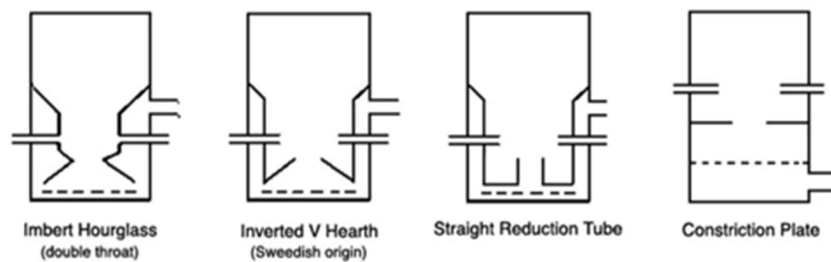
Thermal power of gas supplied to engine	57.14	kWth (kJ/s)
Gasifier efficiency	70.00%	
Thermal power input to gasifier by fuel	81.63	kWfuel (kJ/s)
HHV of biomass fuel	14,500	kJ/kg
Biomass fuel consumed	0.0056	kg/s
Biomass fuel consumed	20.27	kg/h
Actual power available	11.57	kWelec
Biomass fuel consumed/h for 1 kWelec	1.75	kg/kWh
Biomass fuel consumed	20.27	kg/h

Hence, the downdraft gasifier is to be sized based on 20.27 kg/h of biomass fuel gasified.

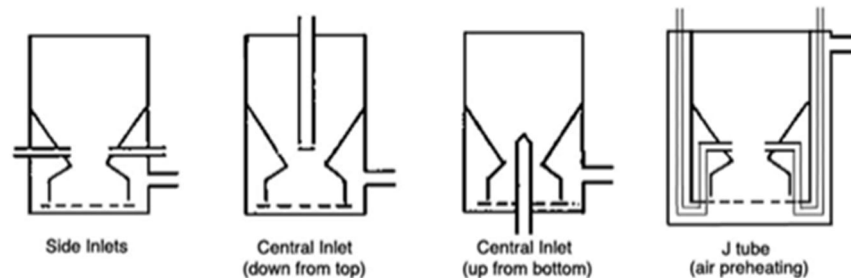
*Note: Calculations for hearth diameter and other parameters are to be included in the manual. For this purpose the following exhibits are to be used on the basis of biomass consumption (20.27 kg/h).*

#### Exhibit 8-7: Types of

##### Nozzle and Constriction Closed Top Designs (aka: Imbert type)



##### Air Inlet Variations (shown with Imbert Hourglass single throat type)



##### Open Core Designs

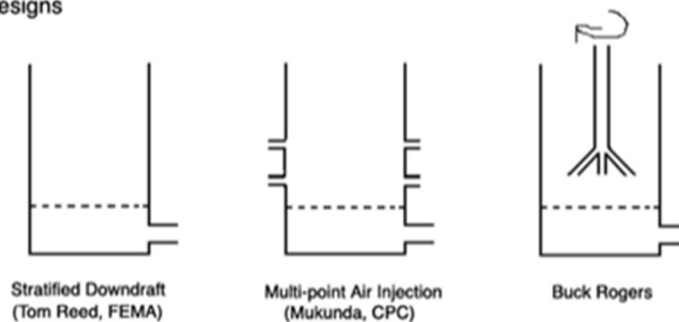


Exhibit 8-8: Sketch of Imbert downdraft gasifier

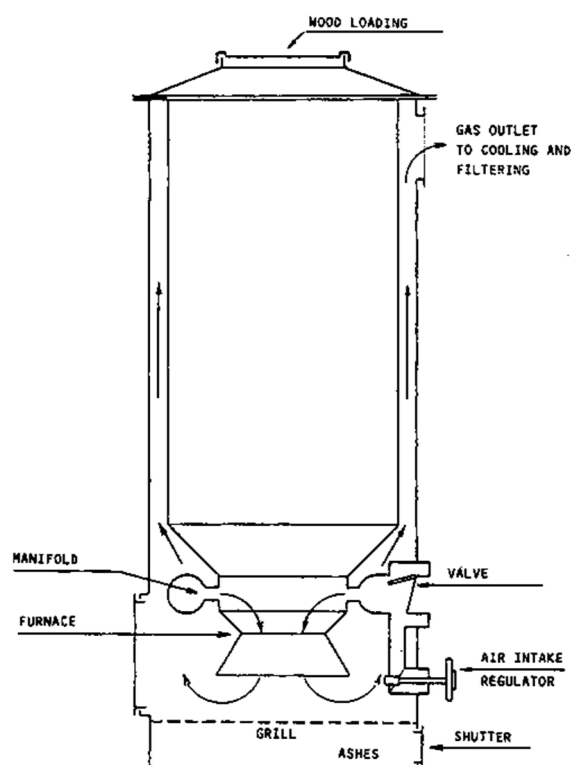
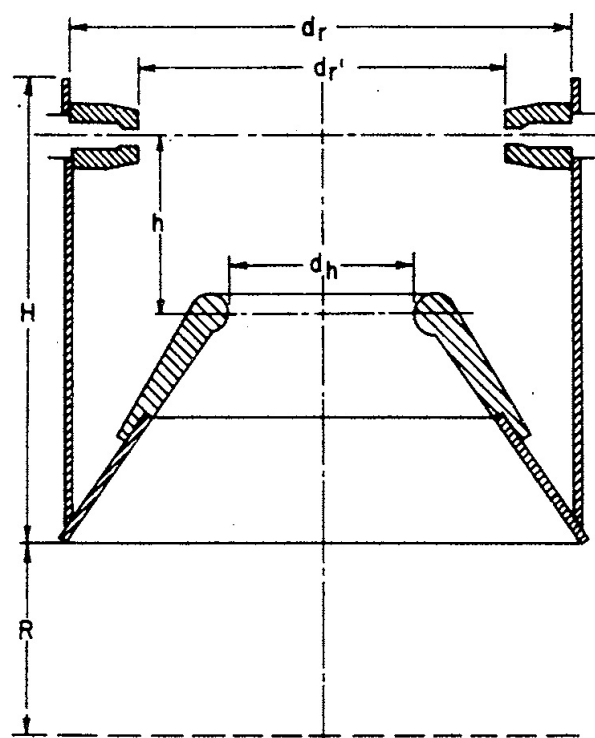


Exhibit 8-9: Detailed view of the hearth



Variable not given in the exhibit are defined as:

$d_m$  = the inner diameter of the tuyere

$A_m$  = sum of cross-sectional areas of the air jet opening in the tuyeres

$A_h$  = cross-sectional area of the throat

$A$  = number of tuyeres

Exhibit 8-10: Imbert downdraft gasifier nozzle and hearth diameters

$d_r/d_h$	$d_h$ mm	$d_r$ mm	$d'_r$ mm	h mm	H mm	R mm	A no.	$d_m$ mm	$\frac{A_m \times 100}{A_h}$	$\frac{d_r}{d_h}$	Range of gas output		Maximum wood consumption kg/h	Air blast velocity $v_m$ m/s
											max. $Nm^3/h$	min. $Nm^3/h$		
268/60	60	268	150	80	256	100	5	7.5	7.8	4.5	30	4	14	22.4
268/80	80	268	176	95	256	100	5	9	6.4	3.3	44	5	21	23.0
268/100	100	268	202	100	256	100	5	10.5	5.5	2.7	63	8	30	24.2
268/120	120	268	216	110	256	100	5	12	5.0	2.2	90	12	42	26.0
300/100	100	300	208	100	275	115	5	10.5	5.5	3.0	77	10	36	29.4
300/115	115	300	228	105	275	115	5	11.5	5.0	2.6	95	12	45	30.3
300/130	130	300	248	110	275	115	5	12.5	4.6	2.3	115	15	55	31.5
300/150	150	300	258	120	275	115	5	14	4.4	2.0	140	18	67	30.0
400/130	130	400	258	110	370	155	7	10.5	4.6	3.1	120	17	57	32.6
400/150	135	400	258	120	370	155	7	12	4.5	2.7	150	21	71	32.6
400/175	175	400	308	130	370	155	7	13.5	4.2	2.3	190	26	90	31.4
400/200	200	400	318	145	370	153	7	16	3.9	2.0	230	33	110	31.2



## 9 Application of gasification systems

Due to its convenience in use like other gaseous or liquid fuels, producer gas finds many applications, particularly where the process specifically demands the use of gaseous or liquid types of fuels. It is being successfully used in a variety of thermal processes, and mechanical / electrical power generation systems.

The producer gas can be conveniently applied in various applications, such as:

- Decentralized power generation
- Water pumping, and other irrigation / agricultural applications
- Captive power generation, e.g., by rice mills, sugar mills, etc.
- Drying in industrial processes, where soot-free environment is essential
- Utilization where smokeless and soot-free environment is a must
- Utilization in kilns, such as, for firing of tiles, potteries and refractories requiring hot environment in temperature range of 800–950°C.
- Industrial thermal applications requiring high flame temperatures, such as, heating medium in steel re-rolling mills, non-ferrous metallurgical foundry industries, and high temperatures furnace / heating operations
- Co-firing applications
- Utilization in steam boilers replacing solid conventional fuels
- Used in dual fuel mode in diesel engines
- Used as replacement fuel in natural gas and gasoline engines with some necessary modifications
- Chilling/cold storage applications, wherein, both thermal energy (for washing/absorption refrigeration) as well as power could be produced and utilized in requisite proportions

Power generation applications where the producer gas is being utilized efficiently and environment friendly atmosphere are presented below. There are some challenges in applying producer gas in the power generation systems.

As with all engine fuels, there are specific limits to different components present in the input fuel gas. Gas contaminants in producer gas, most notably dust, tar and humidity, are a key technical challenge to its utilization in power generation applications. The contaminant limitations for turbines are even narrower as compare to internal combustion engines (ICE).

### 9.1 BIG/ICE and CHP system

Biomass integrated internal combustion engine (BIG/ICE) system is a comparatively simple technology applied for captive power generation and combined heat and power (CHP) system.

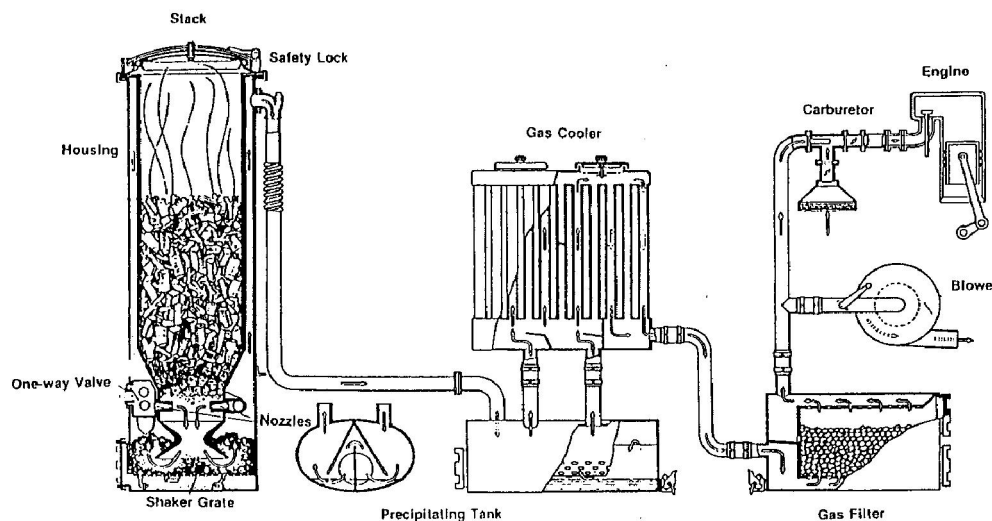
CHP an internal combustion engine (ICE) or simple-cycle gas turbine (GT) with a heat recovery/heat exchanger system that recovers the heat from the ICE or GT exhaust (as the case may be) and converts it to useful thermal energy, usually in the form of steam or hot water.

A typical BIG/ICE power generating system includes three basic elements: a gasifier, gas

cooling/cleaning, and the engine/generator. For CHP arrangement, heat recovery system is added to BIG/ICE power generating system.

It is schematically presented in Exhibit 9–1. For achieve better performance and efficiency of such systems, it is desirable that the load on the gasifier should be nearly constant.

**Exhibit 9–1: BIG/ICE power generating system**



Varying compositions, as well as calorific values and the combustion behavior of the gases present in the producer gas, put greater demands on engine design. Special features of the engines, operated on producer gas, may include flame arrestors for the prevention of backfiring, special gas mixers to improve gas mixing and to be more robust to dirt. In general, the stable composition of producer gas makes it advantageous as an engine fuel. The high hydrogen content of a producer gas however, means the combustion process is very fast, which increases the danger of engine pre-ignition, knocking or engine backfiring. To avoid this risk, an engine control system is needed that is able to fuel the engine with a very lean mixture and, at the same time, react very quickly to variations in the engine load. Producer gas can be used to create hot water, steam and electricity. The hot water and exhaust gases from the engines are fed into boilers. The resulting steam can be used within other localized industrial processes. Producer gas electrical efficiencies in the range of 25 % to 37% can be achieved.

Advantages of fuelling gas engines with producer gas include:

- Independent power supply
- Reduced energy costs, and greater predictability and stability
- Efficient and economic combined heat and electricity supply
- High electrical efficiency compared to other power generation technology (i.e. steam or gas turbines)
- Low gas pressure required
- Alternative disposal of a problem gas while simultaneously harnessing it as an energy source
- Substitute to conventional fuels
- Environmental benefits by greenhouse gas reduction

CHP is the sequential or simultaneous generation of multiple forms of useful energy (usually mechanical and thermal) in a single, integrated system. CHP systems consist of a number of individual components—prime mover (heat engine), generator, heat recovery, and electrical interconnection— configured into an integrated whole. The type of equipment that drives the overall system (i.e., the prime mover) typically identifies the CHP system. Prime movers for CHP systems include steam turbines, gas turbines (also called combustion turbines), spark ignition engines, diesel engines, microturbines, and fuel cells. These prime movers are capable of burning a variety of fuels, including biomass/biogas, natural gas, or coal to produce shaft power or mechanical energy. Additional technologies are also used in configuring a complete CHP system, including boilers, absorption chillers, desiccants, engine-driven chillers, and gasifiers. Boilers and gasifiers are discussed in Chapter 5 of this document.

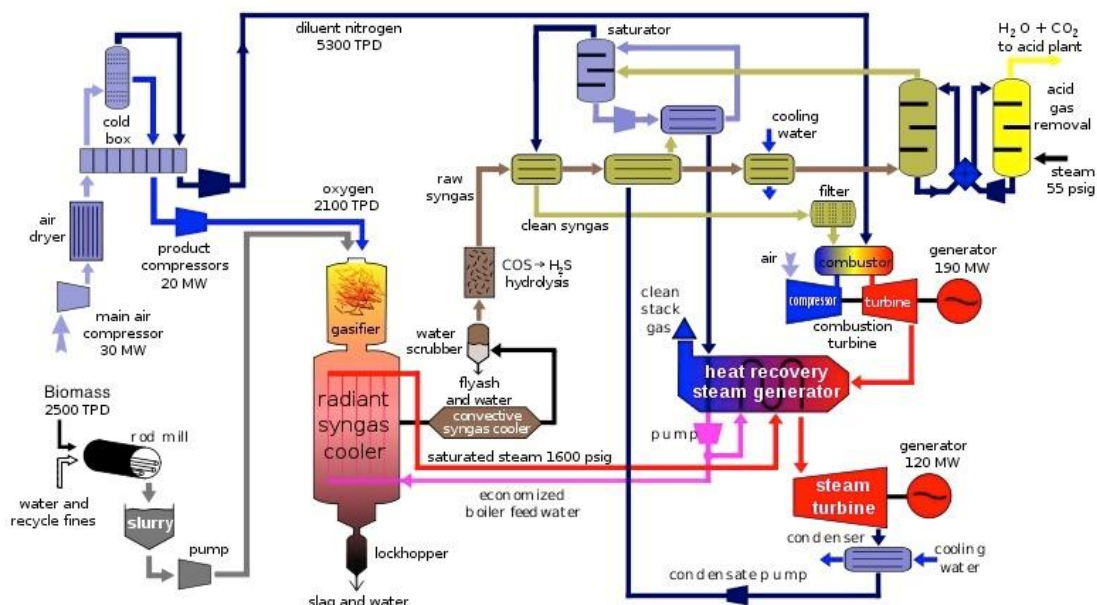
Although mechanical energy from the prime mover is most often used to drive a generator to produce electricity, it can also be used to drive rotating equipment such as compressors, pumps, and fans. Thermal energy from the system can be used in direct process applications or indirectly to produce steam, hot water, hot air for drying, or chilled water for process cooling.

The industrial sector currently produces both thermal output and electricity from biomass in CHP facilities in the paper, chemical, wood products, and food processing industries. These industries are major users of biomass fuels—utilizing the heat and steam in their processes can improve energy efficiencies by more than 35 percent. In these applications, the typical CHP system configuration consists of a biomass-fired boiler whose steam is used to propel a steam turbine in addition to the extraction of steam or heat for process use.

## 9.2 BIG/CC system

Exhibit 9-2 shows a typical biomass integrated gasification and combined cycle (BIG/CC) system.

### Exhibit 9-2: Typical BIG/CC plant



Source: en.wikipedia.org

The plant is called integrated because:

- The product gas produced in the biomass gasification section is used as fuel for the gas turbine in the combined cycle, and
- Steam produced by the syngas coolers in the gasification section is used by the steam turbine in the combined cycle.

In this example the product gas produced is used as fuel in a gas turbine, which produces electrical power. In a normal combined cycle, so-called "waste heat" from the gas turbine exhaust is used in a Heat Recovery Steam Generator (HRSG) to make steam for the steam turbine cycle. BIG/CC plant improves the overall process efficiency by adding the higher-temperature steam produced by the gasification process to the steam turbine cycle. This steam is then used in steam turbines to produce additional electrical power.



## **10 Gasification plant – operation and maintenance**

### **10.1 Typical Downdraft Gasifier Operational Instructions**

The gasifiers operate at negative pressure, which result from the suction of either the engine or a blower. The stepwise guide to the operation of a gasifier is as follows:

#### **10.1.1 Step1: Fuel Preparation:**

- The first thing in the gasifiers operation is the fuel preparation.
- Gasifier's efficiency is as best as the fuel is well prepared.
- A best-prepared fuel is that which contains moisture contents within 14 % to 20 % on dry weight basis.
- For better results fuels having moisture content more high should be dried before feeding.
- To accelerate the drying process it is advantageous to spread the fuel in open air.
- Using wood fuel a fresh cut wood has a moisture content of 40-42 % and it dries in sixty days to moisture content about 20 % it means for safety at least wood fuel should be stored for roughly three months consumption in the site.

#### **10.1.2 Step2: Fuel Feeding:**

- The fuel was fed into the gasifier from the top and it descended through the gasifier by gravity.
- At start-up, some charcoal was loaded in and below the hearth zone for quick gas production. It was recommended to put charcoal in the gasifier from the bottom grate to 10 cm above the nozzle plane, with wood or other biomass on top.
- It was better and advantageous to fill the gasifier up to full capacity. In this way the oxygen present in the empty place of fuel hopper was removed and the risk of blasting was decreased.
- For lightening first the blower was started, it run for some time for that the excess air in the gasifier was removed, then the air regulating inlet valves were opened and a cloth soaked with kerosene oil is lighted with a simple match and it was brought near the air inlets.
- Due to negative pressure in the reactor it sucked the air inward and the burning of the fuel was fully started in about 4-5 minutes.
- The full gas supply started after about 15-20 minutes.

#### **10.1.3 Step 3: Filling water in hopper water seal**

- Fill the water in the water channel provided on the top of the gasifier
- Water filling acts as the preventive measure for the gas leakage from the top

- Water filling must be done to the position so that it may not tip down from the gasifier top
- Water level has to be monitored for every 4 hours
- At the start of the gasifier and also before shutting down the gasifier, check the water level to avoid any kind of gas leakage

#### **10.1.4 Step 4: Gas ignition at flare port and the gasifier**

- First, the gasifier was filled with the fuel to its full capacity.
- Fasten the airtight covers (top cover and ash removal cover) with the help of screws.
- All the sealing was checked carefully for air leakage.
- Closing of valve which was on the gas delivery pipe to engine and opening of valve of blower suction pipe. The both valves were manually operated.
- An induced blower with speed regulator was provided for start up the gasifier.
- Started the blower by switching the fan button control.
- Waited about 2 to 3 minutes so that all the accumulated gases in the gasifier should release.
- After ignition of the biomass in the gasifier fire chamber, place the torch at the flare port
- Open the one side valve and brought the torch near it, as there will be negative pressure in the gasifier so it sucks the fire inside the gasifier and the fuel will be started to burn.
- The flame sustains for about 10-15 minutes in the flare port otherwise the high impurity gas may enter in the gasifier chamber.
- Producer gas was escaped through the blower exhaust with whitish appearance.
- The fire was burn very bright because of the plenty of the suction. The suction rate was also controlled by the flow regulating valves.

#### **10.1.5 Step 5: Gas Transfer**

- Transfer the gas towards cleaning and cooling train
- Open the valve of cleaning and cooling train when a refined quality starts coming in the flare port
- Close the valve of flare port
- Allow the gas to pass through the train for cooling process

#### **10.1.6 Step 6: Gas Feeding**

- Open the gas line valves gradually and close the airline valve simultaneously to maintain the frequency in between 48-52 Hz.

#### **Step 7: Grate Shaking**

- Shake the grate at every 15-20 minutes
- Handle the grate shaker smoothly without pulling or pushing it

- 3-4 number of terms are necessary for grate shaking
- Grate shaking can also reduce the accumulation of ash, this is how the gas production rate can be made efficient

## **10.2 Gasifier Efficiency Testing**

The following parameters will

- Moisture Content (MC %)
- Bulk Density
- Biomass Consumption Rate
- Specific Fuel Consumption
- Auxiliary Consumption
- Plant Load Factor

## **10.3 4.11 Maintenance of Gasifier**

Regular system maintenance is also required to keep the gasifier working for long and continuous operation. Maintenance can be categorized as follows:

### **10.3.1 Daily Maintenance**

- Clean ash pit of the gasifier
- Clean the heat exchanger by removing the dust penetrated in it by opening the end plug from the bottom of the heat exchanger
- Clean the centrifugal part (cyclone separator) of the gasifier chamber by removing the dust

### **10.3.2 Alternate Day Basis Maintenance**

- Clean the sawdust filter, gravel bed filter and venturi scrubber ash pit
- Before refilling and fitting the filter media which is composed of gravel, sawdust should be taken out
- Clean the water thoroughly in the ash pit of the venturi scrubber

### **10.3.3 Maintenance after 200 Hours**

- Remove the biomass present in the gasifier before cleaning the grate of a gasifier
- Remove all the dust and ash from the gas carrying ducts
- Installed cleaning and cooling systems must be cleaned thoroughly and fit those back
- Before the re-installment of the air filter clean it

### **10.3.4 Cleaning and Cooling Train Maintenance**

#### **10.3.4.1 Cleaning of Heat Exchanger (HE)**

- The HE can be cleaned if the pressure dropped across it is raised up to certain limits
- By opening the end plug at the bottom of the HE, the inlet and outlet gas ducts should be cleaned at regular intervals

#### **10.3.4.2 Cleaning of Cyclone Separator**

- The end plug of cyclone can be opened with spanner and can be refitted after cleaning
- Cleaning of cyclone separator is preferred to be done on daily basis

#### **10.3.4.3 Cleaning of Venturi Scrubber**

- The venturi scrubber removes the tar through condensation that gets collected in the water pit
- The cleaning of venturi scrubber doesn't require much attention, but the mesh fitted in the pit to segregate the dust particles etc.
- Venturi scrubber should be cleaned after every four days to prevent any blockage

#### **10.3.4.4 Maintenance of Gravel Bed**

- The bed of gravels does not create much pressure drop in the gas line, but needs to be cleaned after every 100 hours
- The cleaning can be done after opening the top flange of the filter with one and half inched spanner, taking out the gravels on the mesh
- Before refitting the gravels in the filter casing, sun drying of gravel is obligatory

#### **10.3.4.5 Maintenance of Packed Bed Filter**

- The required maintenance for this type of filter should be done after 100 hours in case the pressure drop across the filter increases

#### **10.3.4.6 Engine Maintenance**

- Check for leaks and observe the air cleaner restriction indicator

#### **10.3.4.7 Gas Pipeline Maintenance**

- Check for leaks and correct it
- Check gas pressure in inlet

#### **10.3.4.8 Maintenance of Lubrication System**

- Check for leaks and correct it
- Check engine oil level and governor oil level

#### **10.3.4.9 Maintenance of Cooling System**

- Check for leaks and correct it

- Check coolant level and top up with pre mixed coolant if required

#### **10.3.4.10 Maintenance of Ignition System**

- Make sure that wiring connections are proper

#### **10.3.4.11 Miscellaneous Checks**

- Check governor and mixture valves and gas valves linkages are free
- Guidelines of a Gasifier Operation

### **10.3.5 Guidelines for Continuous Operation**

- Charge the biomass feedstock every four hours or as per requirement
- Keep the water level up to the mark in ash pit, water seals and venturi scrubber
- Add water as per requirement
- Shake the grate at 15-20 minutes or as per requirement
- Remove ash from the ash pit at regular intervals
- Regulate the water temperature in the venture scrubber
- When the temperature limit reaches 450C, drain off the water and simultaneously fill the fresh water in venture by opening the water pump

### **10.3.6 Guidelines for Charging during Operation**

- While charging the gasifier make sure that the main blower is switched off and only suction blower is working
- Open the lid of the hopper
- Charge the dried biomass/ pallets of appropriate size in gasifier hopper
- Ensure that the biomass is dries
- Charge the required of quantity of biomass as per ease of operation
- Charge the gasifier at regular intervals of four hours
- Close the gasifier lid and place it so that it sits in the annular groove or water seal provided on top of the gasifier
- Switch on the main blower

## **10.4 Safety Measures for Downdraft Gasifier Operation**

The gasifier installation must provide with the following features, which helped to minimize the usual hazards of gasifier operation:

- Pressure relief valve must be provided at the top of the gasifier to reduce the excessive internal pressure because in most cases pressure builds up in the bunker section.
- The gasifier should house and operated in an open shed so that concentration of the carbon monoxide cannot develop.

- Cold system should always be carefully ventilated by running the blower for 2 to 3 minutes before igniting the fuel.

Generic operational procedure for the fluidized bed gasification plant shown in Exhibit ----- are described below:

[illegible]

6. Biomass fuel hopper
7. Screw-type biomass feeder
8. Fluidized bed biomass gasifier
9. First dry-type cyclone separator
10. Second dry-type cyclone separator

11. First wet-type spray scrubber
12. Second wet-type spray scrubber
13. First venturi scrubber
14. Second venturi scrubber
15. Filling washing tower
16. Alkali water washer G/W separator
17. Tar and dust filter
18. Spray scrubber
19. Tar and dust filter
20. Wet-type pressure adjustable gas storage tank with safety water seal for over-pressure
21. Surplus gas Burner
22. Ash conveyer System
23. Over Ground Sediment Pond
24. Forced-draft fan
25. Inducing Roots Blower
26. Feed water Pump
27. Circulation Return Water Pump
28. Gasification control panel

### **10.5.1 Pre-start up preparations**

Operators should be imparted training and they should fully understand the operation.

Preparation for the gasifier start is listed as follows:

1. Turn on gasification control unit and check whether all instruments and functioning properly.
2. Start water supply pump and check if the flow rate is normal.
3. Start water return pump and regulate its flow rate through the ;water return valve to keep the flow to water balanced across the plant.
4. Check the water level of flocculating tank and supplement it in time on regular basis.
5. Check whether there is sufficient feedstock in the feeding hopper. (Delay in supply delay and fuel shortage are not allowed during the running);
6. Ash unloader should be put out of the ash remove groove;
7. Start ash remove fan;
8. Check water level of gas tank and give supplement timely;
9. Check water level of safety water seal for over-pressure and alkali water washer G/W (gas/water) separator, and keep them normal;
10. Check water level of safety water seal , observe whether there are deposited at the bottom;
11. Release condensate water deposited in lower level of gas pipes, shut off water discharge valve.

### **10.5.2 Gasifier start up (ignition)**

1. Open the gasifier door, add appropriate woodchip and oilpaper to gasifier, and then begin ignition.
2. After the woodchip start to burn , close the gasifier door and keep it sealed
3. Start Roots fan, keep the lowest rotation speed at 100rpm
4. Start force fan and speed up it gradually.

5. Start screw feeder until the temperature at the bottom of gasifier reach 500°C, to add fuel properly, and regulate air flux at the same time so that the temperature in dense phase section can be ranged from 680°C to 800°C
6. The pressure at the top should be kept normal( 200pa ~ 600pa) by above operation
7. If there is glow ash at the bottom before ignition, the blower can be started directly, meanwhile feed properly. The step1 and step 2 are unnecessary, just follow other steps.
8. When the temperature in the bottom of gasifier reaches at 550°C, operators must start screw ash conveyer and rotary valve to remove ash

### 10.5.3 Gasifier temperature control

The temperature in gasifier is influenced by air flux and fuel quantity, the temperature in tense phase sector is claimed from 680°C to 800°C strictly. It is easy to form clinker at the bottom above 800°C, while the tar will take more proportion in gas below 680°C. In normal running, the tense phase sector should range from 680°C to 800°C. Increase gas capacity at the time of load rise, air flux increase will cause temperature rise, so at the same time more fuel should be added for controlling temperature. It will cause temperature rise if the feeding is reduced due to load decline, consequently, air flux should be reduced at the same time.

The general demands can not only meet the load change, but also keep temperature of gasifier normal. To start gasifier in cold condition, gas is not allowed to enter gas storage tank until outlet temperature is above 400°C.

### 10.5.4 Gasifier Pressure control

Pressure change in gasifier caused by many factors such as draft air flux, burnt products, fuel pyrolysis and gasification speed, and so on.

For normal running, atmospheric pressure in gasifier is required, and at the bottom of gasifier has slight positive pressure, the pressure at the top is not allowed to exceed slight negative pressure of -1200pa, the exceeded one will cause accident like dry-type cyclone doesn't work and numerous small ash involve in water, as well as increase wear and tear of ash conveyer and the load of cooling system.

Generally at the bottom the positive pressure should be kept comparative high so that it do good to the fluidized burning, it is allowed ranging from +100Pa to +3000Pa.

**Pay more attention:** air flux should be decreased for safety in the process of dredging gasifier. The pressure should be adjusted ranging from -600Pa to +200Pa in the gasifier.

### 10.5.5 Ash removal from the gasifier

It is necessary to remove ash during the running.

1. Ash remove can be started after 6~8min after starting gasifier, the rotary speed of ash conveyor screw should match the load of gasifier, more load causes more ash. Generally the rotary speed should match speed of feeder motor to keep burning balanceable and remain air sealed. Once there is clinker formed at over high temperature, this need to poke ash plug through removing pipes. Take care that the high negative pressure will influence ash remove.
2. After ash removing works well, put ash unloader into convey groove
3. The electric star-shape rotary valve under cyclone ash falling pipe should be coincident with the running of ash conveyor screw, knock on ash falling pipe if there is block
4. Remove deposited ash at seal point of scrubber and cooling tower so that there is enough pressure release area to ease pressure of deflagration



5. Start and stop intake blower: before starting gasifier the intake blower should be started and lasts 5~6min for avoiding block at the elbow of ash convey pipes.

### **10.5.6 Control of gas storage tank during operation**

1. Proper gas tank pressure is below 2000Pa, if it exceeds, poise weight can be added to balance it.
2. To discharge tar regularly every shift to avoid block.
3. When gas tank rises to top, surplus gas is discharged through air drain pipe, it means capacity exceeding, this will cause fuel waste and environment pollution, so regulation should be taken
4. When gas tank is down, capacity should be increased properly or decrease load. It is absolutely NOT allowed to decrease to the lowest, this may make water enter combustion engine and cause serious consequence.
5. The running of safety water seal facility: drain waste every two shifts, meanwhile add water to regulate water level, keep the gas tank from the top, gas isn't discharged through drain pipe. The highest work pressure of gas tank depends on water level
6. Check water level of gas tank every day and make supply timely

### **10.5.7 Operation of cleaning and cooling system**

1. In this system, sundries is not allowed in order to avoid block
2. To make sure that the electric current of water supply pump motor is not below normal value, or else, it indicates there is block in some of nozzles, then dredge it after stopping gasifier. (the filter of pump's intake should be kept from block and be cleaned regularly)
3. The temperature of water supply pump's intake should not exceed 35°C, add water if necessary.
4. Regulate flux of water return pump for keeping balance between supply and return
5. In the process of running, according to circulation flux, polymerized Aluminum silicate reagent utilized as flocculating need to be added into system meanwhile keep its concentration at 0.2g/L. It conducts cooling & cleaning water by flocculation so that the suspended matter can be separated. Remove deposit from deposit tank, when float oil reach some level above water, drain it through overflow.

### **10.5.8 Routine Check during operation**

1. Check feeding situation: guard feeding delay, once feeding delay meanwhile air flux does not decrease in time, it will cause sharp temperature rise even forming clinker, and the worse is the comparative high negative pressure in gasifier will lead to deflagration.
2. Check electric current of feeder, if exceeded, maybe some sundries are involved in or moisture content of fuel is so high that causes high resistance, operators must clean timely and prevent sundries and rain from feeder
3. Check electric current of Ash conveyor screw, if exceeded which indicates overload, take action immediately.
4. Check electric current of Roots fan, if exceeded, it indicates there is one or more block in the cleaning & cooling equipment, clear work should be taken timely
5. Check the electric current of blower, water supply pump and water return pump to make sure they are proper.
6. Check gas pressure difference of U-shape pipe between entrance and exit of Venturi scrubber, if there is big difference, it indicates there is block at larynx of the Venturi, operators should dredge it after furnace stop.

## **10.5.9 Plant shutdown**

### **10.5.9.1 Furnace shutdown**

1. Decrease gas capacity at the time of load falling, stop feeder and shut off hopper flashboard to keep furnace from hopper.
2. In the process of above operation, intake and drain air flux should be decreased relatively to decrease temperature to about 600°C, after stopping intake blower, the rotary speed of Root fan will be decreased to 150rpm.
3. After the above operation are finished, stop feeder(after furnace stopped and flashboard closed, the low load running should last 1~2 minutes, make the small hopper half full, keep fuel from hopper).
4. Close intake valve of gas tank and discharge all gas.
5. Stop Root fan after 6~8 minutes of stopping feeding
6. Remove all ash in gasifier, close electric rotary valve of screw ash conveyer and ash falling pipe of cyclone
7. Close intake valve of blower
8. Close drug filling valve, clean and wash cooling & cleaning scrubber to remove deposited ash, stop water supply and return pump, and stop ash removing fan 5 minutes later.

### **10.5.9.2 Accident Tripping (interrupt of electricity for equipment) Solution.**

1. Close intake valve of gas storage tank to avoid root fan reverse and gas overflow at the bottom of gasifier and entrance of intake blower consequently.
2. Close entrance valve of intake blower.
3. Discharge all water in safety water seal

### **10.5.9.3 Operation of recovering**

1. After supplying power of equipment, firstly to start water supply and return pump, then start Roots fan at the speed of 150 rpm in order to discharge all gas of air drain system
2. To add water to safety water seal.
3. Others follow the ignition section.

## **10.5.10 Special instructions**

1. Forbid opening furnace door and clinker drain door until stopping intake blower completely.
2. Keep caution leave back way for operators at the moment of opening furnace door, it is not allowed to face furnace door at the time of opening in case fire is out. Operator must remind worker around furnace for prevent hurt by positive pressure and deflagration
3. During dredging ash, pressure should be regulated as slight negative pressure for safety reason.
4. After stopping furnace, all gas should be discharged from gas tank
5. Forbid fire around furnace
6. Forbid to lap ground electrode of welder through electric facilities or mechanical equipment.
7. If workers don't know whether there is surplus gas left or not, they are forbidden to lap ground electrode through gasification system equipment as well as using gas cutting and electric welding and fire on it.
8. Do not use high moisture content feedstock (the max. moisture content is 15%).

## **10.5.11 Biomass gasifier maintenance**

### **10.5.11.1 Routine maintenance**

Periodically check all nuts on the gasifier unit, the fuel hopper, the filter unit, and the carburetor for snugness; check all penetrations and fittings for airtightness. In addition, perform the following maintenance activities as scheduled:

### **10.5.11.2 Daily maintenance**

Open the ash cleanout port of the gasifier housing drum and remove the ashes after shaking the grate for at least thirty seconds. Replace the cover of the port after coating the threads with high-temperature silicone to ensure airtightness. Open the drain tube at the bottom of the filter container and allow any liquid condensate to drain out; remember to close the drain tube when finished.

### **10.5.11.3 Weekly maintenance (or every 15 hours of operation)**

Clean out the gasifier housing drum, the fuel hopper, and the filter. Rinse out the piping and connections to and from the filter. Replace the wood chips inside the filter, (The used wood chips from the filter can be dumped into the fuel hopper and burned to produce wood gas.) Use high-temperature silicone on all pipe connections and on the filter lid to ensure airtightness.

### **10.5.11.4 Biweekly maintenance (or every 30 hours of operation)**

Make sure that all pipe connections are secure and airtight. Check and tighten all mounting connections to the vehicle chassis. Check for rust on the outside of the gas generator housing drum, especially on the lower region. Coat with high-temperature protective paint as necessary.

Source: [femagasifier.com](http://femagasifier.com)



## **11      Safety guidelines**

*Intro to safety guidelines*

## 1. Fire

Location of Hazard Where?	Origin of Hazard When?	Potential consequences What happens?	Measure No.	Recommended counter measures Possible reduction measures
The whole plant	Fire caused by either an explosion, self-ignition, glowing particles, welding, etc.	Ignition source for explosion	1.1	Installation of fire detection/suppression equipment like: Portable systems: fire extinguishers
				Fixed systems: foam towers, large flow pumps, foam extinguishers, automatic or manual operated fire protection systems
			1.2	Make sure the gasification facilities comply with international standards for the prevention and control of fire and explosion hazards, including provisions for safe distances between tanks in the facility and between the facility and adjacent buildings
		1.3		Install anti-back firing system
		Damage or destruction of the gasifier plant and/or building	1.4	Locate fire systems in safe areas of the facility. Protect them from fire by distance or by fire walls
Physical injury to human being		Preparation of a formal fire response plan supported by the necessary resources and training, including training in the use of fire suppression equipment and evacuation. Procedures may include coordination with local authorities or neighboring facilities and training in the use of fire suppression equipment and evacuation		
Fuel storage building		Undesired fuel combustion	1.5	The fuel should be stored in a closed container or in a separate room or building. A fire resistant separation (with a specified resistance time) between the fuel storage and the gasifier may be required according to local fire protection regulations
			1.6	a humidification system at the ash removal in order to prevent fire hazard from glowing particles or nitrogen inserting on ash removal screws
Gasification facilities		Release of toxic fumes	1.7	the ventilation air intakes should prevent smoke from entering accommodation areas
			1.8	ample ventilations, preferably natural ventilation with an air change of more than 6 h <sup>-1</sup>
	1.9		Implement safety procedures for operation and maintenance, including use of fail-safe control valves and emergency shutdown equipment	

## 2. Explosive Atmosphere

Location of Hazard Where?	Origin of Hazard When?	Potential consequences What happens?	Measure No.	Recommended counter measures Possible reduction measures
The whole plant	Technical or operational problem leading to: 1. Under pressure, 2. Overpressure, 3. Dust clouds	Air ingress Gas escape	2.1	Implement measures to avoid explosions including: - Flooding with inert gas - Avoid ignition source - Removal of dust deposits - Avoid dust clouds - Maintain clean working floor - Grounding of the plant sections
		Explosion, which can lead to more explosions (i.e. dust explosions), plant destruction, fire, etc.	2.2	Gasification facilities should be designed, constructed, and operated according to international standards for the prevention and control of fire and explosion hazards, including provisions for safe distances between tanks in the facility and between the facility and adjacent buildings
	When a mixture of combustible gases and oxygen meets an ignition source	Minor explosion	2.3	Implementing safety procedures for operation and maintenance, including use of fail-safe control valves and emergency shutdown and detection equipment
		Damage or destruction of the gasifier plant and/or building	2.4	Define the maximum value of oxygen at sampling points Temperature sensors and pressure sensors should be installed before and after the main components Install oxygen sensors in the gas piping and monitor oxygen concentration, CO monitors around the plant

## 2. Explosive Atmosphere (cont.)

Location of Hazard Where?	Origin of Hazard When?	Potential consequences What happens?	Measure No.	Recommended counter measures Possible reduction measures	Measure implemented (yes/no)
	Spillage of flammable liquids	Explosion can initiate fire	2.5	Using a water seal acting as a flame arrestor Leak detection (gas sensors)	
Plant sections where fine dust and particles are handled (fuel storage, ash or dust removal systems)	Fine dust and particles	Explosion, fire	2.6	Organizational precautions to comply cleanliness, avoid dust depositions and contamination, avoid dust clouds and maintain clean working floors Good housekeeping is the key to avoid dust explosions Ban smoking, no smoking signs	
			2.7	Application of hazardous area zoning for electrical equipment in design. Ex- zoning will determine which type or category of equipment is allowed	
Gas transportation sections	Poor gas quality		2.8	Unburnt gases should be flared The ventilation must be ample, preferably natural ventilation with an air change of more than 6 times per hour	

## 3. Substance Hazards

Location of Hazard Where?	Origin of Hazard When?	Potential consequences What happens?	Measure No.	Recommended counter measures Possible reduction measures	Measure implemented (yes/no)
The whole plant	Overpressure Leakages Operation and Maintenance	Gas escape leading to gas intoxication, CO poisoning some PAH are carcinogenic danger of suffocation (CO, PAH,...) irritation to eyes, inhalation	3.1	During operation and maintenance, operators should wear portable CO monitors	
			3.2	Construct the system to be gas tight Control rooms should have positive pressure ventilation	
		CO leakage outside the plant and environmental pollution	3.3	Installation of CO monitors in the plant	
The whole plant, at start-ups and shut-downs	Flammable materials	Fire ignition, Explosion, which can lead to more explosions (i.e. dust explosions), plant destruction, fire, etc.	3.4	Operators should be instructed not to stay unnecessarily close to system components (gasifier, cyclone bins, filters, etc.) with flammable materials during start-up, normal operation and shut-down	
Storage buildings, gasifier building, and gas engine room	Overpressure	Gas escape leading to gas intoxication, CO poisoning Some PAH are carcinogenic danger of suffocation (CO, PAH,) irritation to eyes, inhalation	3.5	Install fixed online CO detectors in fuel storage buildings, gasifier building, and gas engine room giving an indication and alarm at 25/50 ppm	
			3.6	During operation, ample ventilation of gasification building with efficient air change of more than 6 times per hour	
Water seals			3.7	Gas tight construction (apply good practices for COMAH (Seveso II) sites.	
Ash removal section	Glowing carbon particles and high temperatures	Fire ignition Explosion, which can lead to more explosions (i.e. dust explosions), plant destruction, fire, etc.	3.8	Install a humidification system at the ash removal in order to prevent fire hazards from glowing particles	

### 3. Substance Hazards (continued)

Location of Hazard Where?	Origin of Hazard When?	Potential consequences What happens?	Measure No.	Recommended counter measures Possible reduction measures	Measure implemented (yes/no)
			3.9	Water spraying at ash discharge	
Gas cleaning section	Glowing particles Leakages Storage or holding tanks	Fire ignition Explosion, which can lead to more explosions (i.e. dust explosions), plant destruction, fire, etc.	3.10	Install either: a water seal or a cyclone combined with a settling chamber in order to prevent glowing particles from entering the gas cleaning section.	
Wet Scrubbing systems and Particle filter for fly- ash removal	Material toxicity + carcinogenicity resulting from tar removal/recycling	Environmental pollution by scrubbing water	3.11	Installation of a bin/tank to collect and treat the toxic liquids (treatment by a certified company, prescribed in permit documents)	
		Operators intoxication, injuries Irritation	3.12	Avoid the production of unnecessary toxic materials; only toxic products like producer gas and scrubbing water cannot be avoided. Provide personnel protective measures	
			3.13	Wear protective cloths	
			3.14	Operators should wear hand gloves, glasses and safety shoes	
Gas engine	High percentage of CO		3.15	CO can only be detected by sensors giving alarm. Then it should be described in the OM what to do when CO alarm	

### 4. Operational and Maintenance Hazards

Location of Hazard Where?	Origin of Hazard When?	Potential consequences What happens?	Measure No.	Recommended counter measures Possible reduction measures	Measure implemented (yes/no)
The whole plant	Rotating parts	Injuries	4.1	Shielding, visual signs Emergency stop button	
	Welding	Fire ignition Explosion, which can lead to more explosions (i.e. dust explosions), plant destruction, fire, etc.	4.2	Implement permit systems and formal procedures for conducting any hot work during maintenance activities, including proper tank cleaning and venting Repairs like welding must be subjected to a permit to work system	
	Flammable material Explosive mixtures/atmospheres		4.3	When performing repairs such as welding, flammable material and explosive mixtures or atmospheres must be removed or prevented	
	Toxic/suffocating gases	Gas intoxication, CO poisoning Suffocation (CO, PAH) irritation to eyes, etc.	4.4	Operators should avoid contact and inhalation of either toxic or suffocating gases / liquids. This would obviously avoid most hazards that occur during maintenance. All plant maintenance procedures should be well documented while operators should routinely follow procedures.	
	Bad operational/ maintenance practices	Various consequences	4.5	Make sure only skilled and qualified personnel are allowed to operate and maintain the plant. Provide training to the personnel	
		Grounding connections deterioration and malfunction	4.6	Include formal procedures for the use and the maintenance of grounding connections	
	Inadequate control system programming	Wrong settings and malfunction leading to various consequences	4.7	Make sure safety related-changes to the process control system are only performed by trained personnel and that the procedure is well documented (operation manual)	
			4.8	Make sure alarm settings are only re-programmed after the problem is solved	



#### 4. Operational and Maintenance Hazards (continued)

Location of Hazard Where?	Origin of Hazard When?	Potential consequences What happens?	Measure No.	Recommended counter measures Possible reduction measures	Measure implemented (yes/no)
Reactor	Malfunctioning	Pressures build-ups leading to backfiring in the previous section, to gas escape and its consequences (please refer to section 3)	4.9	Install anti backfiring system at reactor	
Gas flare	Bad weather associated to poor gas quality		4.10	Install anti back firing system: Flame arrestor or water seal (reference to EN 12874) Automatic ignition	
			4.11	The cross section area of the pressure relieve channel to the flare should be about double the area compared to the pressure relieve valve cross sectional area	
Gas inlet	Improper ignition timing		4.12	Install anti backfiring system at air inlet to the engine according to national regulation	
At valves location	Overpressure		4.13	Implementation of safety procedures for operation and maintenance including use of failsafe control valves and emergency shutdown and detection equipment of the pressure	
In the gasifier reactor	Locally higher oxygen levels may occur	Fire ignition Explosion, which can lead to more explosions (i.e. dust explosions), plant destruction, fire, etc.	4.14	Make sure there are two escape routes to an open air from the gasifier building	
After start up	Explosive atmosphere Ignition sources		4.15	Flaring the gas or purging the whole system with nitrogen	
After shutdown	Explosive atmosphere Ignition sources		4.16	Purging with nitrogen Purging with air is also applied in practice. When purging with air, explosive atmosphere is not prevented - ignition sources have to be eliminated (secondary explosion protection)	

#### 5. Thermal Hazards

Location of Hazard Where?	Origin of Hazard When?	Potential consequences What happens?	Measure No.	Recommended counter measures Possible reduction measures	Measure implemented (yes/no)
Fuel storage, transport and feeding	Temperature rise	Feedstock self-ignition	5.1	Monitor temperature in big piles of feedstock, Install CO monitors, Install sprinkler installations	
Hot surfaces of gas cooler	Chemical reactions	Malfunctioning of the process due to overheating of materials like refractory lining, valve settings, etc. which may cause all sorts of dangers in particular gas escape	5.2	Water spraying at ash discharge, Set maintenance intervals, Corrosion resistant steel material, Detect leakages by indication of temperature increase in case auto-ignition temperature exceed set limits	
Hot surfaces of reactor, cyclone	High Temperature	Thermal stress and corrosion	5.3	Regular inspection and maintenance	
		Operators injuries	5.4	Proper insulation and shielding Wear heat resistant hand gloves	

## 6. Electrical Hazards

Location of Hazard Where?	Origin of Hazard When?	Potential consequences What happens?	Measure No.	Recommended counter measures Possible reduction measures	Measure implemented (yes/no)
The whole plant	Power failure	Pressures build-up leading to gas escape and its consequences (please refer to section 3)	6.1	Safety emergency stop	
	Static electricity build up	Fire ignition Explosion, which can lead to more explosions (i.e. dust explosions), plant destruction, fire, etc.	6.2	Use proper grounding to avoid static electricity build up and lightning hazards	
	Sparks		6.3	Use of intrinsically safe electrical installations and non-sparking tools Screw conveyors should have shaft speed monitor and speed control	
Where explosive atmosphere can happen	Bad zoning practices		6.4	Instrumentation and electrical equipment should be for Zone 1, otherwise the equipment should be secured; in the gasifier itself equipment should be for Zone 2	
Gas conducting part	Sparks	Fire ignition Explosion, which can lead to more explosions (i.e. dust explosions), plant destruction, fire, etc.	6.5	All gas conducting part should be electrically grounded	
PLC Programmable Logic Controller	Static electricity	Malfunction of the PLC	6.6	Galvanic separation of measurement devices, PLC should be properly grounded to earth	
	Power failure		6.7	PLCs have to be supplied by an uninterrupted power supply unit (UPS)	
Inlet to the engine	Electrical breakdown	Backfiring in the inlet system	6.8	Shielded cables should be used in order to avoid electrical breakdowns that could cause backfiring in the inlet system.	

## 7. Mechanical Hazards

Location of Hazard Where?	Origin of Hazard When?	Potential consequences What happens?	Measure No.	Recommended counter measures Possible reduction measures	Measure implemented (yes/no)
Conveyors, electro motors	Sharp edges, sharp parts	Operator injuries	7.1	Shielding, visual signs, emergency stop button	
			7.2	Safety switches and local circuit breakers on rotating parts and switches, on access panels, on pressure relieve equipment, on critical valves with access to gas containing equipment such as feeders, cyclones and ash outlets	

# Appendices

## 12 The Project

The Global Environment Facility approved a project under its Climate Change Focal Area entitled, “Promoting sustainable energy production and use of biomass in Pakistan.” The general target of the venture is to advance business sector based selection of biomass vitality change innovations for process heat and power generation in Small and Medium Scale Enterprises (SMEs) and electrify rural areas in Pakistan. The project aims at building the capacity of SMEs through alternative means of power generation and promoting biomass gasification technology in the country.

### 12.1 1.1 Project Background

The power condition in Pakistan is categorized by a wide gap between demand and supply. The order of magnitude of unmet demand in peak demand months is over 25% of peak demand. This situation adversely affects the economy. Many SMEs have problems in retrieving contemporary energy services due to the regular electricity supply stoppage in the country, and have convinced to the diesel generators usage. Shortage of energy not only effects the production and profit but also depresses the capacity and opportunity to rise. The energy shortage results in lowering of their production, profit and capacities and opportunities to grow.

UNIDO is implementing a GEF funded project entitled “Promoting Sustainable Energy Production and Use from Biomass in Pakistan”. The conversion of biomass into producer gas can be carried out under controlled conditions of temperature and oxygen during the process of gasification and more of the heat content of the biomass is captured.

Under this project UNIDO is trying to establish the economic probability and marketable practicality through pilot projects and doing efforts in building capacity of local manufacturers/fabricators. This international conference on BGTs application in SMEs and rural areas is bringing in renowned energy experts from around the globe, technology providers, manufacturer, policy makers, financial institutions and other key market players in Islamabad. Through this technology transfer of BGTs in Pakistan, UNIDO aims at promoting the concept of “inclusive and sustainable industrial development”-ISID.

## 13 Biomass Fuels in Pakistan

In Pakistan, most common biomass fuels are cotton stalk, wheat straw, rice husk, sugarcane trash, bagasse and other crops residues. Currently, most of these biomass products are treated as biomass waste and is usually burned in the fields. Biomass burning has a significant impact on global atmosphere chemistry since it provides large sources of carbon monoxide, nitrogen oxides and hydrocarbons.

The waste products which are the main contributors to biomass burning are bagasse, rice straw and husk, cotton wastes, barley residue, maize stalks and leaves, and millet and sorghum stalks. Sugar cane provides the next sizeable residue with two major crop wastes; barbojo or the leaves and stalk and bagasse, the crop-processing residue from sugar mills. The cotton crop also gives significant residue in the form of stalks and husks.

Biomass resources, particularly residues from wood processing, agricultural crops and agro-processing, are under-utilized in Pakistan. These resources are renewable, environmentally friendly in energy production and sustainable in terms of supply.

Some of these residues are already used as raw materials for other products (e.g. particle board and fiber-board) as fodder and fertilizer or as household and industrial fuels. However, large portions are still unused and represent potential sources of energy. Energy generation technologies specifically designed to use biomass residues are available and are becoming more and more economical. Pakistan has yet to make optimum use of the additional power generation potential from its biomass residue resources, which could help it to partially overcome the long-term problem of energy supply.

Statistical data on the production of various types of biomass in Pakistan refers to the data mention in \_\_\_\_\_.

### 13.1 Bagasse

Bagasse is comprised of lingo cellulosic residues and is a by-product of Sugar cane. It is essentially the fibrous waste left containing 48-50% cellulose; after the Sugar cane is extracted for crystallizing into sugar. Bagasse has considerable potential as biomass fuel since it arises mainly at sugar factories. Each fresh ton of sugar cane on processing in the sugar factory yields around 300 kg of the residual fiber, which has useful energy content. Sugar cane top and cane trash normally range from 15 to 23% by weight of sugar cane.

Sugarcane top and trash is usually used as a fodder for animals. Presently, almost all power requirements of sugar mills are met by using bagasse as a fuel but it is pertinent to mention that some of sugar mills are producing surplus power to the grid. In fact, sugar mills in Pakistan either have established the improved technology in their existing facilities or these are in process for generating surplus power to the National Grid at the moment.

Approximately 96-98% bagasse produced from cane is consumed in all sugar mills (operating) in the country to meet the steam requirements for sugar and for in house and surplus power requirements.

Annual production of sugar cane top and trash, and bagasse is in the range of:

Average sugar cane top and trash per annum:	_____ million tonnes
Average bagasse per annum:	_____ million tonnes

## 13.2 Cotton waste and cotton stalks

Cotton is one of the most important crops of Pakistan; due to local production of raw cotton Pakistan's textile industry is dependent on its production volume. Pakistani cotton is best in the world in medium and short staple, the waste/contamination produced from cotton can be a huge source for energy generation. Significant cotton wastes are produced; one from the raw cotton at the time of ginning and the other waste produced from its lint after processing it in spinning and recycling units. These wastes can be successfully used for combustion in a biomass fired plant in order to meet energy requirements commercially.

Average annual ginning waste: \_\_\_\_\_ million tonnes  
 Average annual waste after Spinning and recycling: \_\_\_\_\_ million tonnes

## 13.3 Rice Husk

Rice husks are one of the commonest global agricultural residues and by-products of rice paddy milling industries. Rice husks have 45-53% cellulose and hemicelluloses, lignin and protein ranges 25-30%. The husks have relatively high silica content of about 13-17%, which can cause an ash problem and possible slagging within the boiler on combustion. However, their homogeneous nature lends this biomass resource to more efficient combustion.

As per the research, 100 kg of paddy contains almost 67 kg of rice and 33 kg of bran powder, and husk and dust.

Average Rice husk produced per annum: \_\_\_\_\_ million tonnes  
 Average Annual quantity of Paddy straw: \_\_\_\_\_ million tonnes

## 13.4 Wheat Straw

Cereal straw from small cereal crops as wheat is produced at around 2.5-5/ha depending on crop type, variety and the growing season. It is estimated that equivalent yield of wheat straw is produced by weight from wheat crops. Wheat straw is almost 40% cellulosic in nature. It is also pertinent to mention that almost all the wheat straw is generated in the field when the wheat crops are to be processed through ripper machines, combined harvesters or manually cutting tools and readily available to Flour Mills for producing flour. No countable/significant wastages are produced in Flour Mills or in the field that can be used as a burning fuel because all wheat is converted into flour and farina (cream of wheat). In terms of comparative gross energy values, 1 tonne of straw equates approximately 0.5 tonne of coal or 0.3 tonne of oil. It has higher silica content than other forms of biomass, leading to ash contents of up to 10% by weight.

Wheat straw produced in Pakistan is heavily consumed as fodder to about 88% of its overall production. Approximately 5% wheat straw of its overall production is utilized in the manufacture of pulp for producing paper and paperboard in the country.

Production of wheat straw: \_\_\_\_\_ million tonnes

It is to be considered that wheat straw is also abundantly used as fodder for animals, raw material for pulp, paper and paperboard manufacturing; and fuel for brick manufacturing.

## 14

The following data on gasifiers are from two manufacturers.

**1. Technical Parameters** of gasification furnace and cooling/cleaning system

Generator rated output power (Kw)	200	400	600	800	1000	1200
Production volume of biomass gas (Nm <sup>3</sup> /hr)	800	1500	2250	3000	3650	4500
Gas temperature of gasification furnace outlet (°C)	700~800	700~800	700~800	700~800	700~800	700~800
Outlet gas temperature after cleaning and cooling (°C)	<45					
Consumption of biomass fuel (ton/hr)	0.3~0.36	0.6~0.72	0.9~1.08	1.2~1.44	1.5~1.8	1.8~2.16
Circulating water flow volume (m <sup>3</sup> /hr)	6~8	12~15	18~23	24~30	30~37	36~45
Gross weight of gasification furnace(ton)	21.8	26.7	30.8	34.8	38.7	42.5
Ash removing manner	Wet or Dry type(Screw-conveyer collection & discharge)					
Device of gas cleaning & cooling system	Two cyclone separator+two Spray scrubber+ two venturi scrubber+spray scrubber+spray filter(removing dust, tar and cooling)+ roots blower+alkali water washer gas-water Separator					

**2. Technical Specifications:**

No.	Item / Power	400KW	800 KW	1MW	1.5MW	2MW
1	Building are (m <sup>2</sup> )	350	400	480	550	600
2	Main building height (m)	6	6	6	6	6
3	Total units weight (T)	22	28	32	40	50
4	Syngas production rate (Nm <sup>3</sup> /h)	1400	2800	3500	5300	7000
5	Raw material (biomass) consumption (kg/h)	800	1,600	2,000	3,000	4,000
6	Acceptable material moisture content (%)	16	16	16	16	16
7	Gasifying efficiency (%)	70	70	70	70	70
8	Self consumption (kW)	22	40	48	60	80
9	Gasifier dimensions (m)	Φ1.4,H=7.5,	Φ2.0,H=10.0	Φ2.2,H = 12.0	Φ3.0,H=12.0	Φ3.7,H=14.0
10	Ash discharging type	Dry	Dry	Dry	Dry	Dry





## **15      References**



## 16 Units Conversion Table

Conversions of SI and other commonly used units are presented in this appendix.

### Energy Units

J = Joule = 1 Watt second =  $278 \times 10^{-6}$  Wh

kJ = 1000 J

MJ =  $10^6$  J

GJ =  $10^9$  J

watt-hour = Wh = 3 600 J

kWh = 3600000 J

cal = Calorie = 4.18 J

kcal = 4.18 kJ

Btu = British Thermal Unit = 1 055 J

### Power Units

W = Watt = 1 J/second

kilowatt = kW = 1000 W

Megawatt = MW = 1000 kW

Gigawatt = GW = 1 million kW

HP = Horse Power = 745.7 W

kVA = kilo Volt-Ampere

### Force Units

N = Newton

kgf = force kilogram

1 kgf = 9.8067 N

### Pressure Units

Pa = Pascal =  $1 \text{ N/m}^2$

Bar =  $10^5$  Pa

hPa = hectopascal = 100 Pa

1 millibar = 100 Pa

1 psi = 6894,76 Pa (psi - pounds per square inch)

1 torr = 133,32 Pa

1 millimeter mercury (0°C) = 133,32 Pa

kgf/cm<sup>2</sup> = 98067 Pa

mm W = 9.8067 Pa (Wg – water gauge)

cm W = 98.067 Pa

Atmosphere =  $1.0133 \times 10^5$  Pa

### Length Units

m = meter

km = 1000 m

cm = 0.01 m

mm = 0.001 m

μ m =  $10^{-6}$  m

**Surface Units**

$\text{m}^2$  = square meter

$\text{cm} = 0.01 \text{ m}$

**Mass Units**

$\text{kg}$  = kilogram

$\text{t} = \text{tonne} = 1000 \text{ kg}$

$\text{g} = 0.001 \text{ kg}$

$\text{mg} = 10^{-6} \text{ kg}$

**Time Units**

$\text{s}$  = second

$\text{min} = \text{minute} = 60 \text{ s}$

$\text{h} = \text{hour} = 3600 \text{ s}$

$\text{yr} = \text{year}$

**Volume Units**

$\text{m}^3$  = cubic meter

1 cubic meter ( $\text{m}^3$ ) = 1 000 liter (l)

$\text{dm}^3 = 0.001 \text{ m}^3$

$\text{mm}^3 = 10^{-9} \text{ m}^3$

1 = liter =  $1 \text{ dm}^3$

**Temperature Units**

$\text{K}$  = Kelvin

$^{\circ}\text{C}$  = degree Celsius

$1^{\circ}\text{C} = 1^{\circ}\text{K}$

**Miscellaneous**

$\text{Nm}^3$  = normal cubic meter (at 1 atmosphere and  $0^{\circ}\text{C}$ )

$\text{mol}$  = quantity of matter unit

gram atom = atomic weight expressed in grams

gram molecule = molecular weight expressed in grams

$\text{ppm}$  = parts per million

$\text{rpm}$  = revolutions per minute

$^{\circ}$  = angular degrees

**Other Units**

$\text{Hz}$  = Hertz (frequency)

$\text{V}$  = Volt

## **17 Abbreviations and Glossary**

### **17.1 Abbreviations**

### **17.2 Glossary**

#### **Carburetting**

Carburetting air or gas generally comprises passing it in contact with liquid fuel and thereby mixing the air/gas and fuel. This often involves lowering the air pressure e.g. in a venturi.

#### **Destructive distillation**

The process of pyrolysis conducted in a distillation apparatus to allow the volatile products to be collected. An example is tar making from pinewood slices (which are rich in terpenes), which are heated in an airless container causing the material to decompose, leaving charcoal and turpentine as by-products.

#### **Dry bulb temperature**

The Dry Bulb Temperature refers basically to the ambient air temperature. It is called "Dry Bulb" because the air temperature is indicated by a thermometer not affected by the moisture of the air.

#### **Endothermic Reaction**

It describes a reaction in which the system absorbs energy from its surroundings in the form of heat. Expressed in a chemical equation: reactants → products - energy.

#### **Exothermic reaction**

It is a chemical reaction that releases energy in the form of light or heat. Expressed in a chemical equation: reactants → products + energy.

#### **Gasification**

Gasification is somewhat similar to pyrolysis and confusion between these terms is common. Gasification is a partial oxidation process that converts materials such as coal, biomass or plastic waste into a gaseous mixture of carbon monoxide and hydrogen (also known as synthesis gas) by reacting the raw material at high temperatures with controlled amounts of oxygen and/or steam. See also "Pyrolysis".

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**Producer gas**

It is a mixture of gases containing carbon monoxide (CO), hydrogen (H<sub>2</sub>), carbon dioxide (CO<sub>2</sub>) and nitrogen (N<sub>2</sub>). In the USA, producer gas is a generic term referring to wood gas, town gas, synthesis gas, syngas or raw gas. In the UK, producer gas, also known as suction gas, means a fuel gas made from coke or other carbonaceous material. Air is passed over the red-hot fuel and carbon monoxide is produced in an exothermic reaction which reads  $2C + O_2 \rightarrow 2CO$ . The nitrogen in the air remains unchanged and dilutes the gas, so it has a low calorific value. The gas may be used to power gas turbines which are suited to fuels of low calorific value.

**Pyrolysis**

The chemical decomposition of organic materials by heating in the absence of oxygen or any other reagents, except possibly steam. Pyrolysis is somewhat endothermic and the products can be gases, liquids (e.g. light crude oil from de-polymerization of organic waste) and/or solids (e.g. coke and volatiles produced by coking coal). See also "gasification".

**Synthesis gas (syngas)**

A gas mixture that contains varying amounts of carbon monoxide (CO) and hydrogen (H<sub>2</sub>) generated by the gasification of a carbon-containing material to a gaseous product with a heating value (but less than half the energy density of natural gas). When used as a fuel, it is produced by gasification of coal or municipal waste by the following reactions:  $C + O_2 \rightarrow CO_2$ ;  $CO_2 + C \rightarrow 2CO$ ;  $C + H_2O \rightarrow CO + H_2$ . The name comes from the gas's use as an intermediate in creating synthetic natural gas (SNG) and in producing ammonia or methanol.

**Torrefaction**

It is a thermal process that involves heating the biomass to temperatures between 250 and 300 degrees Celsius in an inert atmosphere. When biomass is heated at such temperatures, the moisture evaporates and various low-calorific components contained in the biomass are driven out.

**Town gas**

Also known as coal gas, and contains hydrogen (H<sub>2</sub>), carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrogen (N<sub>2</sub>) and volatile hydrocarbons. It is made by blowing air and steam over an incandescent fuel bed, usually of coke or coal. The words "coal gas" could also be used to mean gas made by the destructive distillation of coal. The gas was used inter alia for lighting before the advent of electric lighting, and for heating and cooking before natural gas became widely available.

**Water-gas**

A mixture of carbon monoxide (CO) and hydrogen (H<sub>2</sub>) produced by passing steam over red-hot coke using the endothermic reaction  $C + H_2O \rightarrow CO + H_2$ . This product had a lower

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calorific value than coal gas so the gas was often passed through a heated retort into which oil was sprayed; the resulting mixed gas was called carburetted water gas.

**Wet bulb temperature**

This is the temperature indicated by a moistened thermometer bulb exposed to the air flow. It can be measured by using a thermometer with the bulb wrapped in wet muslin. The rate of evaporation from the wet bandage on the bulb, and the temperature difference between the dry bulb and wet bulb, depends on the humidity of the air. The evaporation is reduced when the air contains more water vapor. The wet bulb temperature is always lower than the dry bulb temperature but will be identical with 100% relative humidity (the air is at the saturation line).

**Wood gas**

The product of thermal gasification of biomass (e.g. coal, wood chips, sawdust, charcoal) in a gasifier or wood gas generator. It is the result of a high temperature reaction (> 700 degrees C) where carbon reacts with steam or a limited amount of air producing carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), hydrogen (H<sub>2</sub>) and methane (CH<sub>4</sub>). It can be filtered, purified or scrubbed and used to power internal combustion engines, gas turbines, Stirling engines or fuel cells.

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