WBA fact sheet

THERMOCHEMICAL GASIFICATION OF BIOMASS

SUMMARY

Thermochemical Biomass Gasification is a high temperature process that produces a fuel gas, which after cleaning, can provide a good environmental performance and high flexibility in applications. The process is used to convert biomass (solid biomass, wastes) into a a combustible gas that can be used for different purposes. Typical feedstock for gasification is cellulosic biomass such as wood chips, pellets or wood powder, or agricultural byproducts like straw or husks. The produced gas is called producer gas or synthesis gas (syngas). The gasification of the feedstock takes place at 700° – 1600°C in the presence of a gasification medium. The gasification media used are air, oxygen, steam or a mixture of these. Gasifiers are available between just a few kW and up to couple of hundred MW. Gasification of biomass offers several advantages such as:

- The syngas can be used for heat and electricity generation including high temperature heat for cement kilns and brick and ceramic firing, for mechanical energy, as transport fuel, as raw material for chemicals and when cleaned and upgraded to near pure methane can be injected into gas grids.
- The electrical efficiency is higher than when using technologies based on combustion.
- The gas is well suited for cogeneration units, especially small-scale gasifiers.

Small-scale biomass gasification is found worldwide, especially in India to supply electricity in rural areas. In Europe, small-scale gasification is becoming available alongside co-generation units. Gasifier designs, resulting in practically tar-free gas, have hit the European and American market in recent years. A few large-scale biomass gasification plants have come online during the same period. Integrated gasification combined cycle, in which the gas is first used to run a gas turbine and the exhaust from the gas turbine is used for steam generation for running a steam turbine system has also been demonstrated.

INTRODUCTION

Thermochemical gasification is a partial oxidation process whereby a carbon-rich material such as biomass (or coal) is broken down into a gas consisting of carbon monoxide (CO) and hydrogen (H_2) plus carbon dioxide (CO_2), methane (CH_4) and other gaseous hydrocarbons along with contaminants, such as tars, char, ash etc. This mix of gases is known as 'producer gas' or 'syngas' (synthesis gas) and the precise characteristics of the gas will depend on the feedstock properties, gasification parameters – such as temperature – and the oxidizer used. Gasification using air results in relatively low operating temperatures, higher amount of tar and about 50% nitrogen in the gas – this gas can be burned directly for heat or used for running engines after removing the tar. When oxygen and steam are used to produce a gas consisting of CO and H_2, it is called syngas.

Gasification is not a new technology. It was originally developed in the 1800s and is the process that was used to make town gas for lighting and cooking. From well before 1900, motors running on what was then called wood gas, produced from gasifying dry wood, often powered pumps for mines and for irrigation. Small-scale gasifiers using charcoal were also used to power internal combustion engines in vehicles during the transport fuel shortages experienced by many countries during the Second World War.

Photo: Acumen

Figure 1. Company Husk power systems is creating change in rural India by providing electricity through bioenergy. In Bihar, more than 70 percent of the population has no electricity but now 200 000 have been provided with electricity.

Today, biomass gasification can be performed in small, medium and large-scale gasification units.

In this factsheet, capacity refers to the output capacity of the plant in terms of heat (MW_{th}) and/or the electrical capacity of the gas-powered electricity generation system (MW_e).

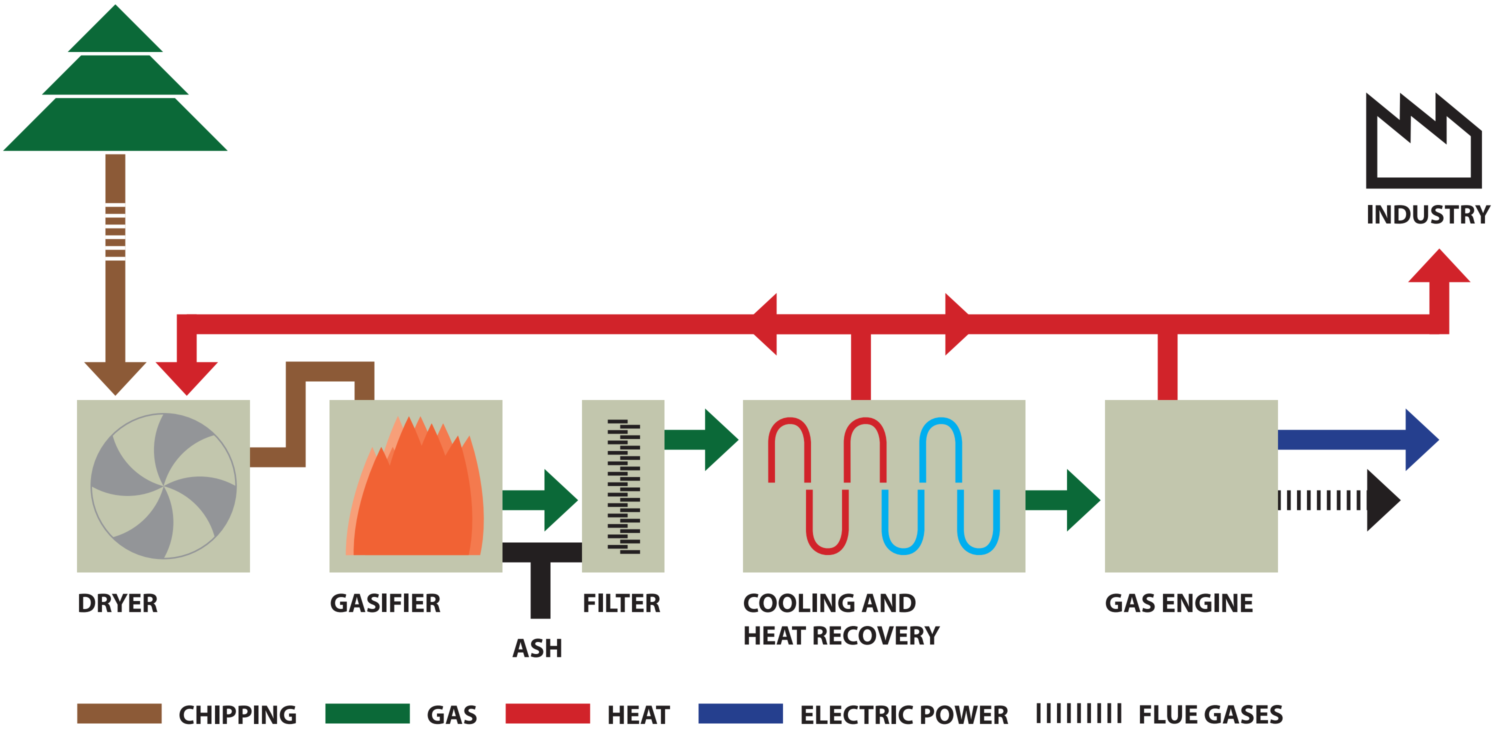

Figure 2. A typical set up of a small-scale gasification plant in Europe. Picture taken from Energy Agency for Southeast Sweden, who manage a demonstration project with a small-scale gasifier at a local dairy. Photo: Energikontorsydost

THE BASICS OF GASIFICATION

The gasification process combines several steps: pre-treatment of the feedstock, the gasification itself, the gas cleaning and the utilization of the gas in a gas engine or any other device depending upon the intended purpose. In many cases, pre-treatment of the feedstock is performed to increase the gas output.

The pre-treatment of biomass is important to achieve a high performance of the gasifier. Some small gasifiers use standardized biomass chips with low moisture content or pellets. Milling of the biomass is only needed for the entrained flow technology (will be discussed later).

In the gasification process, the biomass and the gasification media (air, oxygen, steam or a mixture of these) are injected into the gasifier. The oxygen or air combust part of the biomass fuel in order to heat the incoming fuel to the process temperature and to give the reaction heat required such that the rate of flow controls the gasifier temperature.

The partial combustion can take place directly in the gasifier, which is the case in most applications, or indirectly in an adjacent combustor and from which heat is transferred to the gasifier by a circulating medium, most commonly sand. The indirect combustion permits the generation of a N2 free gas with a complete conversion of biomass.

The efficiency is higher in gasification processes as they can be run at a higher temperature than combustion. 70 -80% of the energy contained in the feedstock is converted to the energy content of the producer gas, the rest being heat and losses (1). In some cases cold gas efficiency (CGE[1]) will be 40-50% but the low efficiency is compensated by low maintenance costs.

When air is used as the gasification medium, the nitrogen in the air dilutes the produced gas, and therefore it results in a fuel gas with low heating value (4-7 MJ/Nm3, significantly lower than natural gas at approx. 40 MJ/Nm^3) (2). Biomass gasification using air is suitable for the generation of power and heat from combusting the fuel gas, but due to the high levels of nitrogen (typically around 50 % by vol.) and low levels of hydrogen it is not suitable for the production of liquid biofuels or biochemicals.

To avoid the dilution by produced nitrogen, oxygen and steam are used to produce a gas with a medium heating value (8-12MJ/Nm3) (2) and with combustion properties (flame temperature etc.) close to the properties of fossil fuels. However, the production of oxygen is an energy-intensive process and so decreases the overall efficiency while increasing the operational costs. Because of this it is only considered for large capacity installations for syngas, and not for fuel gas.

Depending on the end use of the gas and the capacity of the installation, the gasification process can be operated at atmospheric pressure or at elevated pressure up to 2.5 MPa. Gas cleaning is important, especially removal of tar particles that might damage the gas engine.

TABLE 1: OVERVIEW OF THE 4 STEPS OF PROCESSES INVOLVED IN BIOMASS GASIFICATION

Step 1	Step 2	Step 3	Step 4
Pre-treatment of biomass	Gasification	Gas cleaning	Utilization Heat/Power/Fuel
Treatments as drying, standardizing of particle size, grinding etc.	Technologies as - Fixed bed - Fluidized bed - Entrained flow	Reduction of tar content, of NOx and SOx and other particles	Technologies as burner, gas engine, gas turbine etc.

(1)

[1] Cold Gas Efficiency (CGE, in %): Chemical energy contained in the product gas with respect to the energy contained in the initial solid fuel. (1)

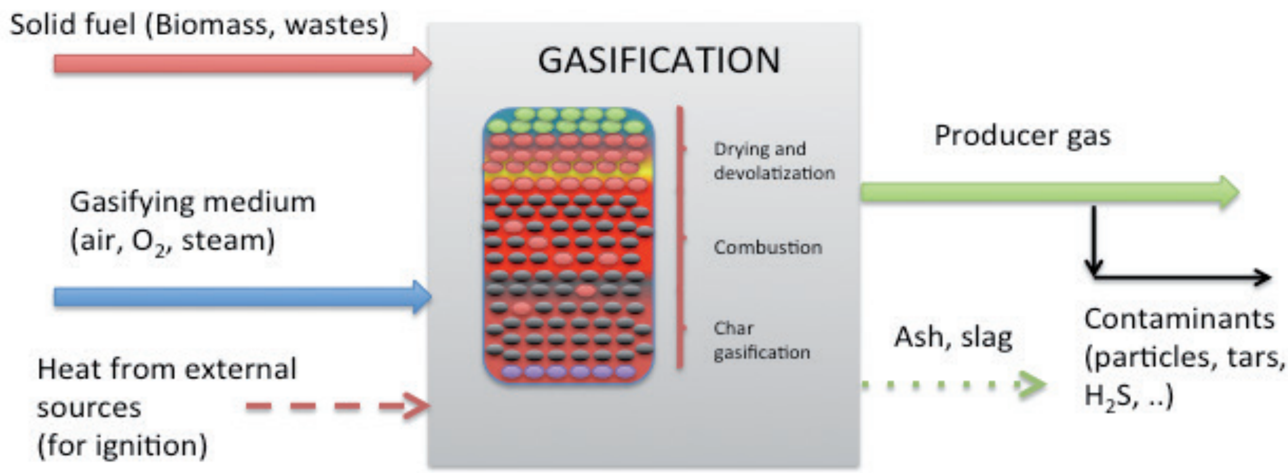

Figure 3. Set up of a principal figure of the gasification process includes four stages, each occurring in one of the four separate zones within the gasifier: drying, pyrolysis, oxidation and reduction zone. Figure modified from (1)

THE TECHNOLOGIES OF GASIFICATION

The various gasification processes are based on the type of reactor, contact of fuel and gasification media along with physical properties. There are three main types of technologies: fixed bed, fluidized bed and entrained flow.

Fixed bed

The fixed bed process includes updraft, downdraft and cross draft gasifiers. Most of the fixed bed reactors are small - scale and the common application is for heat applications or small-scale power generation. In a downdraft gasifier type, sized fuel is fed to the top of the cylindrical reactor together with the air. As they move down, they undergo pyrolysis, which produces a so-called pyrolysis gas. The gases move downward along with the fuel. As the fuel reaches the bottom, it is converted to charcoal and reacts with air. The pyrolysis gases along with the conversion of charcoal in air generates a combustible gas. The gas is then either redirected horizontally or upward to some type of filtering system to separate the gas from suspended particles and possibly tar. At the bottom, there is typically a moving grid or other device to control the movement of the bed and to extract ash from the gasifier by gravity. The size of such gasifiers is limited in capacity to the range 0.05 – 1 MWth.

In comparison, the updraft gasifier (and also the cross draft intended for charcoal) has a capacity range of 1 – 10 MWth.

The fuel is fed from the top while the air is added at the bottom. However, in this case, the gas flow is counter current relative to the fuel. The hot gases meet the colder fuel and cause pyrolysis at lower temperatures. This internal heat exchange makes the process very energy-efficient. However, the tar content of the gas is very high compared to all other gasifiers, as the pyrolysis products have never been exposed to elevated temperatures. Therefore, the gas is typically used as a fuel in a close-coupled burner and could be a substitute for natural gas (3).

Fluidized bed gasification

The bubbling fluidized bed (BFB) or circulating fluidized bed (CFB) technologies can be operated at capacities between 10 and 150 MWth at atmospheric pressure, and up to 150-200 MWth, if pressurized. The fuel can be a similar size as wood chips.

In a BFB, some type of sand can be used as the bed material. The bed material is fluidized by supplying the gasification medium, which is air or oxygen and steam, at the bottom of the reactor whereby the bed material becomes suspended in the gas stream.

In a CFB, the relatively dense suspension of bed material is carried upwards in the shaft and into a set of cyclones. Here, the bed material is separated from the gas and returned as a moving bed to the bottom of the gasifier.

The BFB provides good mixing of the solid material and enables a long residence time for large fuel particles at the bottom of the gasifier where the solids meet the oxygen. In addition, the bed material present and the refractory lining used as heat insulation inside the reactor, once heated, store a large energy content relative to the

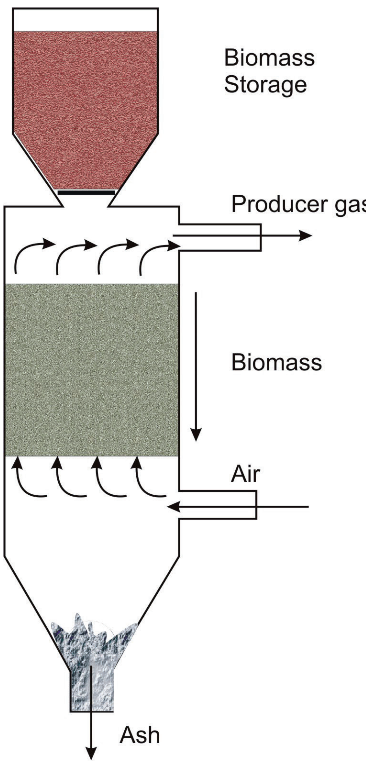

Figure 4. Schematic of a small-scale updraft gasifier. Photo: Jan Brandin (9)

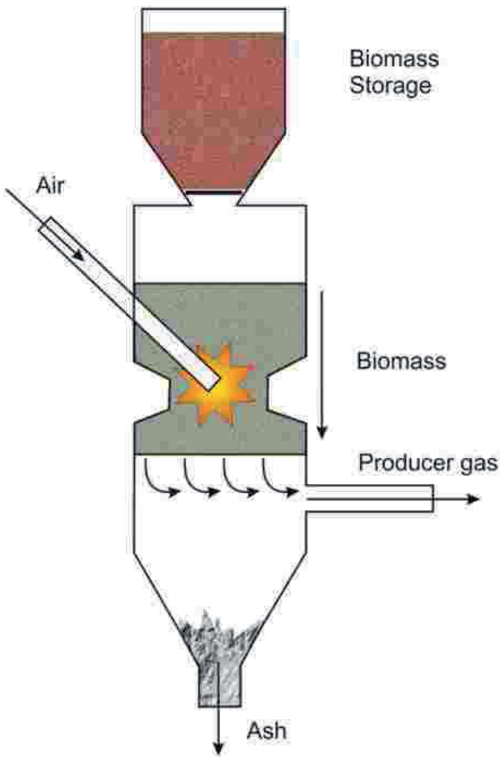

Figure 5. Schematic of a downdraft gasifier. Photo: Jan Brandin (9)

TABLE 2: COMPARISON OF DIFFERENT BIOMASS GASIFICATION TECHNOLOGIES

Technology		Capacity (MWth)	Pros	Cons
Fixed bed	Down draft	< 1	Simple configuration Feedstock flexibility	Require high control. Low tar.
	Updraft	1 – 10		Updraft high tar
Fluidized bed		10 – 200	Moderate oxygen requirement Uniform temperature	High tar
Entrained flow		2 - 100 > 100 (few)	Uniform temperature High conversion efficiency	Requires grinding or small feedstock fractions

(1) (8)

TABLE 3. REQUIREMENTS FOR DIFFERENT GASIFICATION TECHNOLOGIES

Type of gasifier	Typical particle size (Ø)	Others
Fixed bed/moving	1 – 10cm	Stable particle
Fluidised bed	Smaller than 8cm for BFB and smaller than 4 cm for CFB,	Reduction of tar content, of NOx and SOx and other particles
Entrained-flow	Pulverized fuel – 50 µm - 1000 µm Droplets – 100 µm	Low moisture content required

(1) (8)

biomass feed, and act as a thermal 'fly-wheel' that helps to stabilize the operation of the reactor. However, BFBs are sensitive to agglomeration of the bed material, and the maximum temperature is limited by a combination of the type of bed material and the ash components of the fuel. Typically, the temperature is limited to below 950°C, but in many cases even lower temperatures are used.

Due to the significantly lower temperatures of BFBs, as compared to that of CFB, the yields of tar and gaseous hydrocarbons are much higher while a slightly lower carbon conversion is achieved. However, by using secondary catalytic treatment or other cleaning downstream of the gasifier the conversion of the tar and gaseous hydrocarbons can increase the syngas production (3)

Entrained flow gasification

At very high capacities, > 150 MWth, entrained flow (EF) gasification at pressures between 2 - 8 MPa is a well-established technique, in particular for non-biomass fuels. The technique is based on feeding of fine particles or droplets (typically 0.1 mm) in a burner arrangement where they become entrained in the gasification medium, typically oxygen and steam (the use of air would ruin the energy efficiency, apart from also making the gas unsuitable for synthesis purposes from nitrogen dilution). By reactions started at the burner exit, a high temperature flame (>1300-1500°C, the use of air would ruin the en-

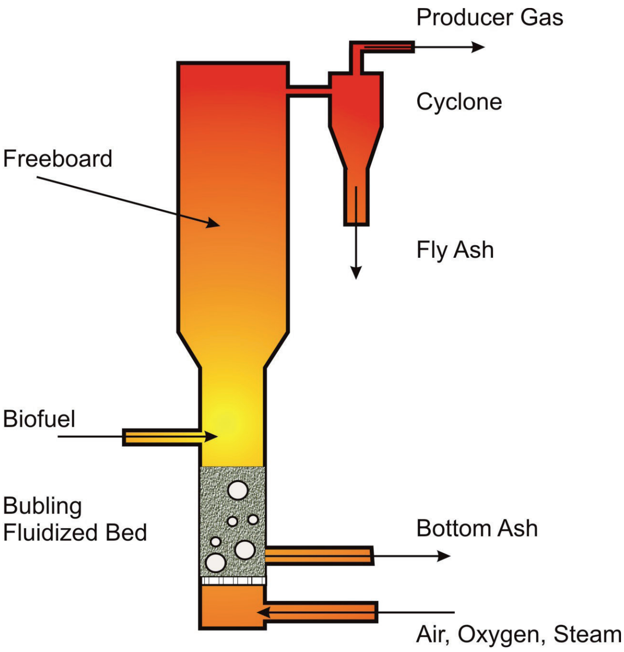

Figure 6. Schematic of a bubbling fluidized-bed gasifier.

Photo: Jan Brandin (9)

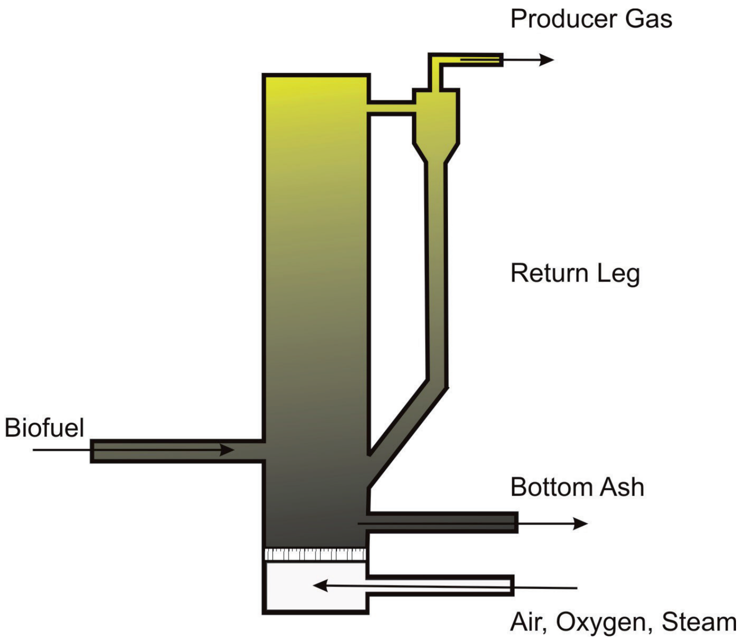

Figure 7. Schematic of a Circulating fluidized-bed gasifier.

Photo: Jan Brandin (9)

ergy efficiency) is established such that rapid conversion of the small fuel particles is ensured within a few seconds. The high temperature also results in that low yields of tar and other gaseous hydrocarbons such as methane are achieved. At this high temperature, the ash components of the fuel are in a molten state, and the lower part of the reactor involves radiant cooling or a quenching step to solidify and remove the molten ash.

Various types of entrained flow gasifiers are also used at smaller capacities, <25 MWth, at close to atmospheric pressure. Using air as the gasification medium, the resulting low heating value gas is mainly suitable for power and heat generation applications. Such gasifiers operate well below the ash melting point, which simplifies the gasifier design but also means that tar remains in the gas for removal in a downstream gas cleaning system. However, at this lower operating temperature, the gasifier can be designed to retain fuel particles in the gasifier for longer time than the gas, thereby allowing the use of somewhat larger fuel particles (magnitude 1 mm).

There are also examples of entrained flow gasifier at this small scale where the gasification medium is superheated steam, and indirect heating is used to provide the reaction energy. This avoids nitrogen dilution to give a medium heating value gas that can more easily substitute fossil fuels in more demanding industrial applications, and as a synthesis gas.

A major challenge is the pre-treatment required for biomass. Apart from the fuel drying, common to all gasifiers, it requires grinding the fuel to the very small particles required, which is associated with a high consumption of electrical energy (as much as 0.08 MWe/MWth produced for achieving 100μm particles, i.e. some 1.5 % of the energy content, and 5 % if expressed as an equivalent in electric power). To reduce the power consumption for grinding biomass, fuel preparation technologies, such as torrefaction and pyrolysis, are currently under investigation. (In one case pre-treatment by pyrolysis is also used to avoid tar formation in the gasifier which is fed with the charcoal only). But both torrefaction and pyrolysis have not yet been implemented on a large scale and cause losses of part of the fuel mass and energy that partially off-sets the gains form grinding. (3). To minimize and recover from such losses, a high degree of process integration is important.

However, for small capacity applications, there are also advantages in terms

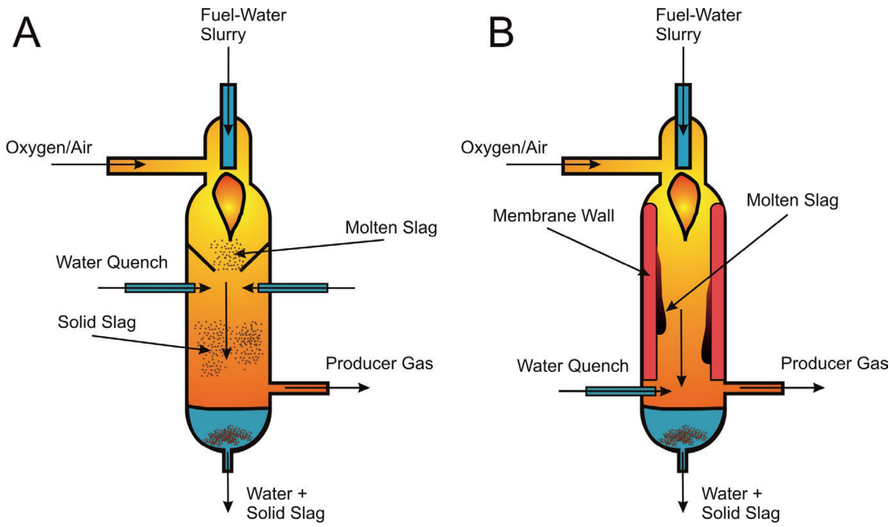

Figure 8. Schematic of two entrained-flow gasifiers operating under slagging conditions.

Photo: Jan Brandin (9)

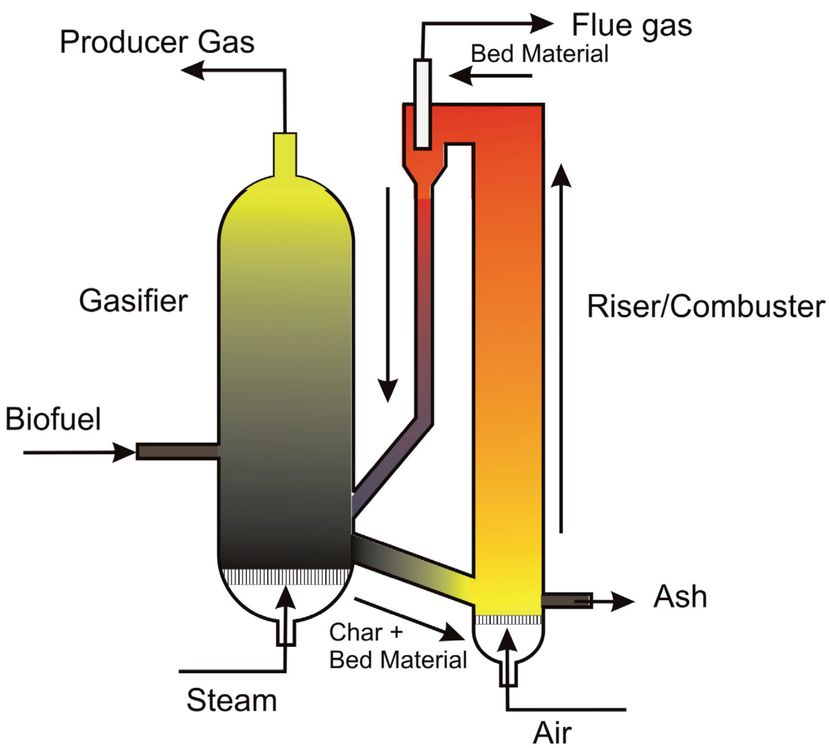

Figure 9. Schematic of use of multiple beds for indirect heating of the gasifier.

Photo: Jan Brandin (9)

TABLE 4. FEEDSTOCK PROPERTIES INFLUENCING THE GASIFICATION PROCESS

	Ash content	Ash melting point	Other components
Woody biomass	Lower (depending on bark content)	>1000°C	Normally low
Agricultural biomass (herbaceous biomass)	Higher	< 700°C	Higher in Cl, S, K, Na

(1)

Photo: Burkhardt GmbH

Figure 10. The central element of the plant in Haslach im Kinzigtal, Germany is the biomass gasifier (270kWth/190kWe). The plant is run by Bioenergie Schnellingen. In contrast to what is described in the chapter about Fluidized bed gasification, the plant constructor Burkhardt has turned the process upside down: The fuel is fed into the reactor from below. The reactor is served by high quality pellets from the region and can serve 400 households including local heating for window construction company, paint shop , gardening, a hotel with spa and several single houses with heat and electricity is fed into the grid. In addition this plant also has a natural gas CHP system (248kW_{th}/210kW_{e}).

pre-treatment as some gasifiers can accept locally derived fuel feedstocks as husks and saw dust with only a minimum of pre-treatment. Thereby the pre-treatment methods mentioned above that, for logistic and process reasons are required for the fuel supply of large capacity gasifiers, can be avoided (2).

THE FEEDSTOCK

The physical and thermochemical properties of the feedstock influence the quality of the producer gas, and therefore play a decisive role on the selection of the gasification technology. Biomass has special characteristics such as, for example: a complex molecular make-up and moisture content which can affect the whole conversion process (pre-treatment, gasification, and the gas cleaning system). Also the availability of the feedstock plays an important role when technology is selected, as small scale is easer to design for feedstock availability than is large scale.

Gasifier feedstock should be relatively dry, < 30 % moisture content to give a reasonable gas heating value, but preferably even drier feed is used (down to 10% for pellets). In many cases, if air-drying is not sufficient, there is low temperature waste heat that can be used. The fuel material needs to be sized for the gasifier. The specific needs of the EF gasifier in terms of milling has been discussed above, while FB and DFB (Dual Fluidized Bed) gasifiers can accept more or less the same fuel qualities that are traded (chips, forest residues, pellet, chopped or crushed agricultural wastes etc.). The main limitation is significantly oversize materials or excessive

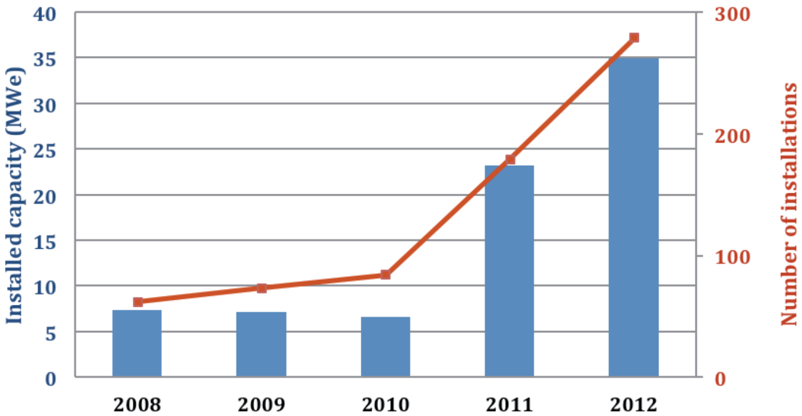

Figure 11. Development of installations of gasifiers in Germany until 2012.
Source: Fördergesellschaft Erneuerbare Energien e.V. (www.fee-ev.de)

Photo: Spanner RE² GmbH.

Figure 12. Woodchips cogeneration plant to produce electricity and heat. This plant includes 10 x 45 KW biomass gasifier & CHP installed in the city of Jaunjelgava, Latvia. Ten independent units generate 450 kW of electrical power and 1.08 MW of thermal power. The plants in Jaunjelgava provide a school, a kindergarten and several blocks of flats with heat at 2 ct/kWh. The electricity produced is fed into the national grid at 14 ct/kWh. The total investment was 4700 €/kWel. The charcoal which accumulates during gasification is collected in big bags and sold to Poland.

fines, and these should be screened out. Fixed bed gasifiers are best operated on lumpy materials to give a uniform bed and low amounts of fines. However, in practice various fine agricultural wastes are often used too.

But fuel handling upstream of the gasifier is also important and sets more strict limitations on the feed, while the physical size of the equipment makes larger installations more tolerant of feedstock size than smaller ones. Ash properties of the feedstock are important for all gasifiers, as at some point air and high temperature meets the fuel residues, and melting or agglomeration causes loss of bed fluidity or of porosity.

In the biomass feedstock, there are important differences between woody biomass and biomass from agriculture (straw, rice husk, miscanthus). Due to its lower ash melting temperatures herbaceous biomass is better suited for larger gasification units.

GLOBAL USE

The annual biomass gasification capacity can be estimated to be around 15 PJ (4). Biomass gasification has been used for decades in small units for cooking, heating and for vehicles. During the last several years, new developments have come to market. Nowadays, modern small and medium-scale biomass gasification is mainly used for efficient electricity and heat generation from biomass with a relatively high output of electricity.

Clean gas units practically free from tar have been developed in USA and Europe. Operation of some of these units is fully automatic (Figures 10, 12). Micro-gasification, particularly gasifier stoves, are now commercially available in a number of countries, including India and China. Integrated gasification combined cycle (IGCC) plants, have been demonstrated to produce electricity with efficiencies above 40% (5).

Other developments focus on large-scale solutions that deliver a syngas as basis for the generation of different chemicals, or synthesized 'drop-in' fuels or for injection into natural gas grids. Worldwide, several demonstration projects are under construction or in operation. The availability of feedstock at reasonable prices is one of the pre-requisites for this kind of large-scale gasification. Also the investment cost is an important parameter.

Biomass gasification in small units is of particular interest for the improvement of electricity supply in rural areas of Asia and Africa.

In China, biomass gasification power plants of different types and scales are in use, including simple gas engine-based power generation systems with capacity from several kW to 3 MW and integrated gasification combined-cycle systems with capacity of more than 5 MW. In recent years, due to the rising cost of biomass material, transportation, manpower, etc., the final cost of biomass power generation has increased The government of China has also supported the technology, and has a target of 30 GW (electric) of bioenergy supply capacity by 2020 (6).

Also in India and many other Asian countries, the gasification of residues of agriculture and forestry is spreading mainly to supply electricity to rural regions. Producing a low tar gas or removing the tar effectively from the raw gas is quite challenging in this case; many gasifier engine systems in India appear to be out of operation because of problems associated with tar.

India has supported the technology to make it possible to electrify areas with no access to grid electricity. According to Indian government statistics, around 150 MW (electric) of biomass gasifiers were in use in 2011 (7).

In Cambodia, many industries (like garment factories) use wood gasifiers to generate electricity to meet their own needs and for sale, as grid power is unreliable. In Africa and Latin America, the interest in biomass gasification is growing but the use of this technology so far is quite limited. In Europe development is mostly in electricity, such as in Germany, where more than 100 power plants based on biogasification units are in operation, as illustrated in Figure 11. The biggest BioSNG in Europe is probably GoBiGas, 20 MW, in Gothenburg, Sweden (Figure 13).

Photo: Göteborg Energi AB

Figure 13. GoBiGas (Gothenburg Biomass Gasification) is a Göteborg Energi AB initiative and the plant is the first in the world to combine large-scale gasification with methanation. The capacity of the produced gas is to supply about 15,000 cars or 400 buses a year with biofuels.

POSITION OF WBA

The gasification of biomass, especially in the form of residues from agriculture and forestry is an important technology with a significant future in industrialized countries as well as in developing countries. The WBA sees a big potential for small and medium-scale biomass gasifiers all over the world for cogeneration, and for improving electricity supply in rural areas. In regions with biomass-fuelled district heating systems small-scale biomass gasification is an interesting technology for its ability to combine heat and electricity generation in an efficient way. For these applications, specific feed-in-tariffs for the winter period are proposed to make biomass gasifiers profitable.

In the period from November to February in the higher latitude countries of the Northern Hemisphere, renewable electricity generation from hydro and solar is low – measurements in central Europe deliver only 13% of the annual solar electricity generation for these four months. Therefore, production of electricity from biomass is of particular significance during this part of the year. Medium and large-scale gasification offers a high versatility in output of products such as syngas for biofuels, chemicals, and synthetic natural gas (BioSNG) for gas grids. But it will remain restricted to regions with an abundance of relatively cheap biomass feedstock. Biomass gasification in rural areas makes use of locally available feedstock, creates jobs and reduces CO_2 emissions as compared to use of diesel engines. The reliable supply of electricity is a prerequisite for a better life of the rural population in their homes and enables the extension of business activities of rural companies.

The WBA strongly supports the further development and deployment of thermal biomass gasification. ■

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World Bioenergy Association, Holländargatan 17, SE 111 60 Stockholm, Sweden
Tel. + 46 (0)8 441 70 80, info@worldbioenergy.org, www.worldbioenergy.org