Biomass Conversion – Reality and Outlook

Miro R. Susta

IMTE AG Power Consulting Engineers
5423 Freienwil, Switzerland
++41-56-221 85 09

imte@powergolflink.com ** www.powergolflink.com

ABSTRACT

Rapid rate at which fossil and residual fuels are releasing CO_2 into the atmosphere has raised international concern and has spurred intensive efforts to develop alternative, renewable, sources of primary energy.

There are a number of ways to reduce the emission of green house gases like large application of wind energy or solar energy as well as storage of CO_2 in the deep see or underground.

Another way is the utilisation of biomass. Although biomass contains carbon and the generation of energy out of this fuel releases CO_2, this CO_2 is also taken out of the atmosphere during growth of the plant.

Therefore we call biomass a green house gas emission neutral energy source. In contrast to the carbon in fossil fuels the carbon in biomass has a cycle period from plant to the atmosphere and back of between one and some tens of years.

The promotion of biomass energy and more efficient utilization of local sustainable energy resources is part of strategy on fuel diversification in many countries worldwide.

Almost all sub-tropical and tropical countries and areas in Europe, Asia, Africa, Australia and America have a great comparative advantage due to the intensity and regular availability of solar energy, which may be exploited through plant photosynthesis.

The solar energy stored in chemical form in plant and animal materials is among the most precious and most promising alternative fuels not only for power generation but also for other industrial and domestic applications.

Biomass absorbs the same amount of CO_2 in growing that it releases when burned as a fuel in any form. Biomass contribution to global warming is zero. In addition, biomass fuels contain negligible amount of sulphur, so their contribution to acid rain is minimal.

The earth receives annually 3 millions of Exajoule[‡] (EJ) from the sun.

Part of this energy comes availably as hydropower at 90 EJ, as wind 630 EJ and via biosynthesis 1250 EJ. This has to be compared to an annual consumption of energy worldwide, which amounts to 400 EJ.

Currently, biomass is the fourth largest energy resource after coal, natural gas and oil.

However, the technical biomass potential is only that part of the 1250 EJ, which with present day state of the art technology, can be made available. This technical potential is evaluated at 150 - 200 EJ, but can increase rapidly if technology progresses.

Over millions of years, natural processes in the earth transformed organic matter into today's fossil fuels: oil, natural gas and coal.

In contrast, biomass fuels come from organic matter in trees, agricultural crops and other living plant material. Major biomass energy resources for power generation include:

- The Forest Residue PRODUCTION OF → Heat (Direct Combustion=DC) & Syngas
- Free Field Residue PRODUCTION OF → Heat (DC) & Syngas
- Waste from Wood Processing Industry PRODUCTION OF → Heat (DC) & Syngas
- Urban Wood, Paper & Cardboard Waste PRODUCTION OF → Heat (DC) & Syngas
- Waste from Agricultural Products Processing Industry PRODUCTION OF → Biogas & Syngas
- Organic Components in Town Waste PRODUCTION OF → Syngas & Biogas
- Solid & Liquid Animal Manure PRODUCTION OF → Syngas & Biogas
- Agricultural Plant Waste PRODUCTION OF → Heat (DC), Biogas, Syngas, Methanol & Ethanol
- Waste Waters PRODUCTION OF → Biogas
- Landfills PRODUCTION OF → Biogas (Landfill gas)

Unlike any other energy resource, using biomass to produce energy is often a way to dispose of biomass waste materials that otherwise would create environmental risks.

We distinguish the following three major biomass conversion technologies:

- Direct Combustion PRODUCT→ Heat (Hot Water, Hot Air, Steam);
- Thermo-Chemical Conversion PRODUCT→ Pyrolysis, Charcoal, Syngas;
- Bio-Chemical Conversion PRODUCT→ Methanol, Ethanol, Biogas.

[‡] **1EJ = 10^{18}J**

There are a number of challenges that inhibit the development of biomass energy. In this regard, formulation of sustainable energy policy and strategies in addressing these challenges is indeed a pre-requisite for the development and promotion of biomass energy.

Major available biomass conversion technologies and their commercial implications are discussed in this paper.

INTRODUCTION

With oil and gas prices soaring amid deepening instability in the Middle East, renewable energy is emerging as a bright spot in the global energy economy-and is poised for a worldwide takeoff.

The availability of crude oil, including the proven reserves is up to 8500 EJ with a yearly consumption level of 150 EJ, so that we can soon expect that crude oil prices will further increase and have severe negative influence on the global economic stability.

In fact we can say that there is by far sufficient of energy from the sun and related conversion processes to fulfil all our needs in energy. However disclosing this wealthy recourse is the major problem due to which we so much depend, and will be depending, on fossil fuels now and in the coming decades.

At the present, new renewable energies[§]-including wind, solar, geothermal, ocean current & wave as well as modern biomass based energy-supply enough electricity for more than 300 million homes worldwide.

In 2003, an estimated 20 billions USD, about one-sixth of total global investment in power generation equipment, was invested in renewable energies. Within the next decade, this is expected to approach 85 billions USD annually.

Renewable energies have proved they can meet the energy needs of industrial and developing countries alike, and are offering real solutions to a world facing accelerating global energy demand and rising concerns about energy supplies and environmental impacts.

Around the world, a growing number of nations have recognized the economic and environmental benefits of renewable energy, and are enacting tax breaks and other policy measures to partially offset the advantages enjoyed by fossil fuels.

[§] **Excluding classic hydro power**

- In Austria, there has been an increase in the use of biomass for district heating by a factor of six, and in Sweden by factor of eight during the last ten years.
- In the USA, more than 8,000 MWe of installed generating capacity is based on the use of biomass.
- In France, 5% of heat used for space heating is produced from biomass.
- In Finland, bio-energy already contributes about 18% of total energy production and the aim is to further increase this to 28% in 2025.
- In Brazil ethanol is produced on a large scale as a fuel for automobiles. The total quantity of ethanol produced for haulage purposes is already 15 to 17 million tons per year.
- A new EU Directive will stimulate a similar development in Europe. As a result, the production of bio-oil and possibly methanol will increase significantly.

Among other nations where policy changes may allow dynamic new renewable energy markets to emerge in the next five years are China, India, Malaysia, Thailand and some of the African countries.

Especially biomass based renewable energy will play major role in the future power generation worldwide.

Under ordinary circumstances, virgin biomass is harvested for feed, food, fiber, and materials of construction or is left in the growth areas where natural decomposition occurs.

The decomposing biomass or the waste products from the harvesting and processing of biomass, if disposed of on or in land, can in theory be partially recovered after a long period of time as fossil fuels.

Alternatively, virgin biomass and any waste biomass that results from the processing or consumption of virgin biomass can be transformed into valuable energy or fuels.

Virgin biomass crops that have been used for energy production include: sugar cane, corn, sugar beets, grains, elephant grass, fast grooving wood and many others.

There are two main factors which determine whether a crop is suitable for energy use. Good energy crops have a very high yield of dry material per unit of land (dry tonnes/hectare).

A high yield reduces land requirements and lowers the cost of producing energy from biomass. Similarly, the amount of energy which can be produced from a biomass crop must be much less than the amount of energy required growing the crop.

Once more it shall be emphasized, that biomass as the solar energy stored in chemical form in plant and animal materials is among the most precious and most promising alternative fuels not only for power generation but also for other industrial and domestic applications on earth.

It provides not only food but also energy, building materials, paper, fabrics, medicines and chemicals. Biomass has been used for energy purposes ever since man discovered fire.

CO_2 from the atmosphere and water from the earth are combined in the photosynthetic process to produce carbohydrates that form the building blocks of biomass.

The solar energy that drives photosynthesis is stored in the chemical bonds of the structural components of biomass. If biomass is burnt efficiently the oxygen from the atmosphere together with the carbon contained in plants produce CO_2 and water.

The process is cyclic because the carbon dioxide is then available to produce new biomass (Figure 1).

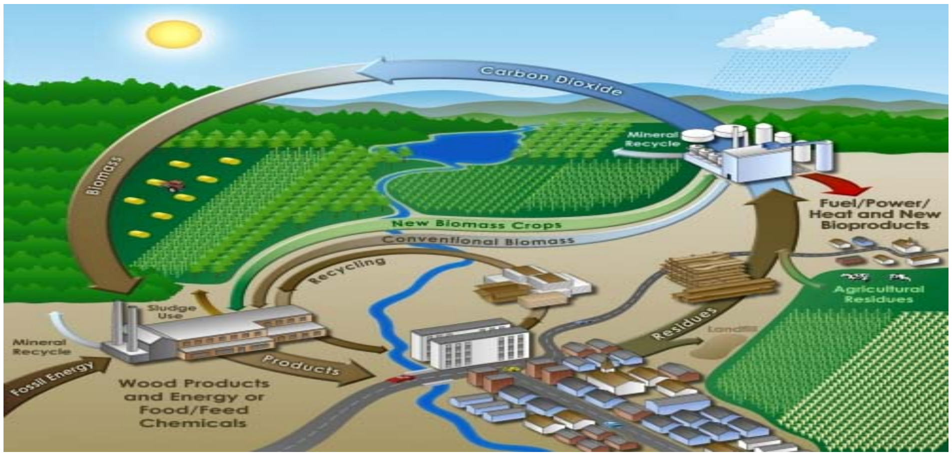

FIGURE 1
BIOCYCLE

Fossil fuels are not renewable. The fossil crude oil, natural gas and coal we use today are gone forever.

Hundreds of millions of people, many of them in developing countries, are completely reliant upon biomass, mainly wood, for fuel – a fact that is not likely to change in the next several decades. Biomass provides roughly 30% of the total energy supply in developing countries, and wood accounts for more than half of this—about 15% of the energy supply in the developing world. However, in many individual developing nations, dependence on wood is much higher. World production of biomass is estimated at 146 billion metric tons a year, mostly from wild plant growth.

Some farm crops and trees can produce up to 50 metric tons per hectare of biomass a year. Types of algae and grasses may produce even more than 100 metric tons per year.

In some countries, like Nepal in Asia, and Uganda, Rwanda, and Tanzania in Sub-Saharan Africa, wood-fuels provide 80% or more of total energy requirements.

Following diagram (Figure 2) shows biomass energy consumption in selected Asian countries.

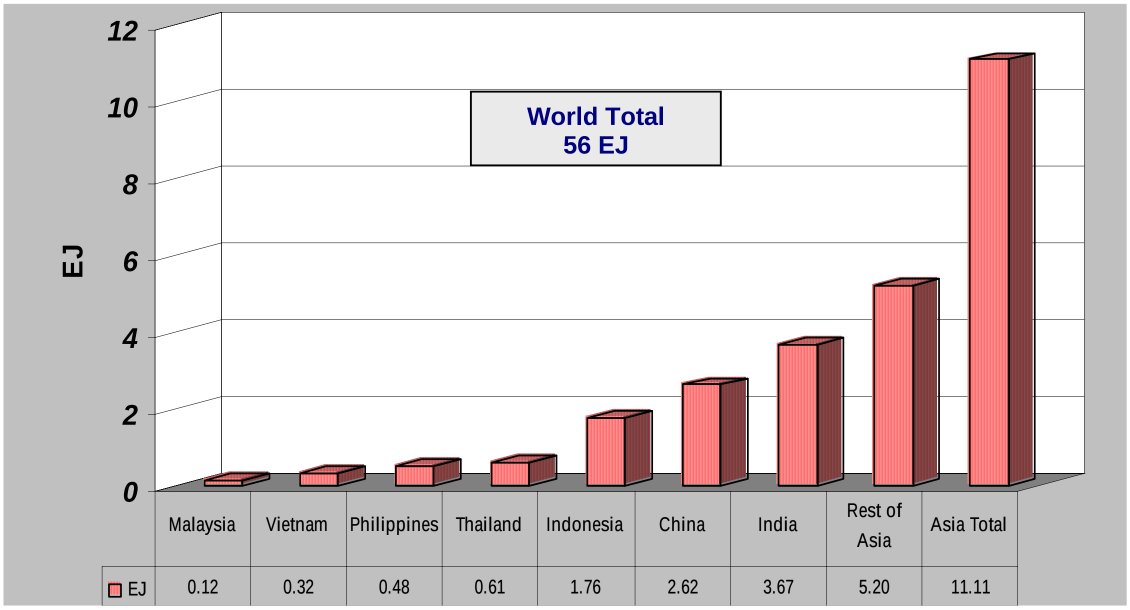

FIGURE 2
BIOMASS CONSUMPTION IN SELECTED ASIAN COUNTRIES

Virtually all crops, whether grown for food, animal feed, fibre or any other purpose, result in some form of organic residues after their primary use has been fulfilled.

Biomass conversion technologies include a variety of **THERMAL**, **THERMOCHEMICAL** and **BIOCHEMICAL** technologies to obtain **PROCESS HEAT ENERGY** or **GASEOUS** and **LIQUID FUELS**.

DIRECT COMBUSTION

Direct combustion or co-firing is the simplest way to convert biomass into useful thermal energy. The heat energy which is produced during this process can be used to provide hot water, hot air and/or process steam for domestic applications, industrial processes or for electric power generation.

Co-firing is mixing of biomass with the pulverised coal in the boiler. In this way a part of the coal used is replaced by biomass, and the proportionate part of the heating value of the biomass used can be considered as renewable energy.

However, the biomass should be given such properties that it can be carried along with the coal without any difficulty.

It has to be ground into very small particles and in the process acquire flow properties that are the same as those of coal.

The fibrous structure of biomass makes this grinding more difficult, as a result of which much effort has been invested in development of the grinding technology.

Direct combustion, is the straightest and oldest process for converting biomass into usable energy.

Since prehistorical inhabitants of this planet learnt how to make fire, they converted biomass to useful energy by burning wood in a fireplace or woodstove. Direct biomass burning has been a source of energy for meeting human needs until the present time.

In the developing world, many types of biomass such as dung and agricultural wastes are burned for cooking and heating.

Direct combustion is a thermochemical conversion process utilizing the following major feedstock:

- Wood
- Agricultural waste
- Municipal solid waste

Despite its apparent simplicity, direct combustion is a complex process from a technological point of view. High reaction rates and high heat release and many reactants and reaction schemes are involved.

In order to analyze the combustion process a division is made between the place where the biomass fuel is burned (the furnace) and the place where the heat from the flue gas is exchanged for a process medium or energy carrier (the heat exchanger). The basic process flow diagram for direct combustion is shown in the following picture (Figure 3).

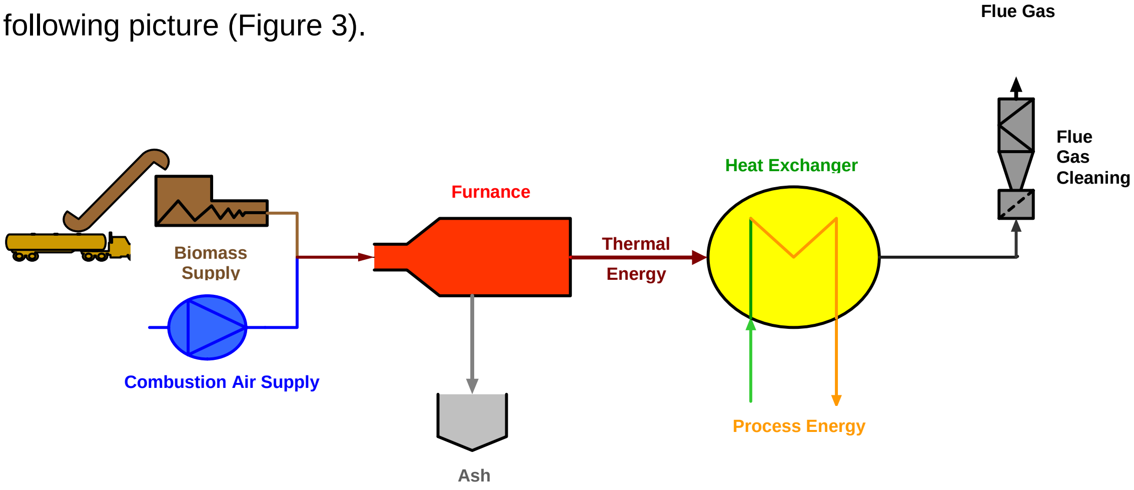

FIGURE 3
PRINCIPAL SCHEME OF DIRECT COMBUSTION SYSTEM

Proper designed industrial biomass combustion facilities can burn all types of biomass fuel. In combustion process, volatile hydrocarbons (C_xH_y) are formed and burned in a hot combustion zone. Combustion technologies convert biomass fuels into several forms of useful energy for commercial and/or industrial uses.

In a furnace, the biomass fuel is converted via combustion process into heat energy. The heat energy is released in form of hot gases to heat exchanger that switches thermal energy from the hot gases to the process medium (steam, hot water or hot air).

The efficiency of the furnace is defined as follows:

$$\eta_{\text{COMBUSTION}} = \frac{\text{CHEMICAL ENERGY AVAILABLE IN FURNACE EXHAUST GAS}}{\text{CHEMICAL ENERGY CONTAINED IN BIOMASS}}$$

Depending on the **L**ow **H**eating **V**alue (LHV) of received biomass fuel, typical combustion efficiencies varies in the range of 65% in poorly designed furnaces up to 99% in high sophisticated, well maintained and perfectly insulated combustion systems.

In single statement, the combustion efficiency is mainly determined by the completeness of the combustion process (i.e. the extent to which the combustible biomass particles are burned) and the heat losses from the furnace.

Biomass Fue
Supply

Direct combustion systems are of either fixed-bed or fluidized-bed systems. Fixed-bed systems are basically distinguished by types of grates and the way the biomass fuel is supplied to or transported through the furnace.

In stationary or travelling grate combustor, a manual or automatic feeder distributes the fuel onto a grate, where the fuel burns. Combustion air enters from below the grate. In the stationary grate design, ashes fall into a pit for collection.

In contrast, a travelling grate system has a moving grate that drops the ash into a hopper. Very important factor is also acceptable maximum moisture content in supplied biomass fuel. In the following table a comparison between individual systems is made (Table 1).

System	Fuel size mm	Max. Moisture Content in %	Fuel Supply	Ash Removal
Static Grate	∅ 100 x 300	50	Manual/automatic	Manual/automatic
Underscrew	< 40x 30 x 15 >20 x 20 x 10	40	Automatic	Manual/automatic
Through Screw	< ∅ 50 x 100	40	Automatic	Automatic
Inclined Grate	< 300 x 100 x 50	50	Automatic	Automatic
Sloping (moving) Bed	< 300 x 100 x 50	50	Automatic	Automatic
Suspension Burning	< 5 x 5 x 5	20	Automatic	Manual/automatic
Spreader-stocker	< 40 x 40 x 40	50	Automatic	Manual/automatic

TABLE 1
FIXED BED COMBUSTION SYSTEMS

Fluidized-**B**ed **C**ombustor (FBC) burns biomass fuel in a hot bed of granular, non-combustible material, such as sand, limestone, or other.

Injection of air into the bed creates turbulence resembling a boiling liquid. The turbulence distributes and suspends the fuel.

This design increases heat transfer and allows for operating temperatures below 970°C, with reduced NOx emissions.

Depending on the air velocity, a bubbling fluidized bed or circulating fluidized bed is created. The most important advantages (comparing to fixed bed systems) of fluidized-bed combustion system are:

- Flexibility to changes in biomass fuel properties, sizes and shapes;
- Acceptance of biomass fuel moisture content up to 60%;

- Handling high-ash fuels and agricultural biomass residue (>50%);
- Compact construction with high heat exchange and reaction rates;
- Low NOx emissions;
- Low air excess factor, below 1.2 to 1.4, resulting in low heat losses from flue gas.

Additional factor that determines the system efficiency is the efficiency of the heat exchanger, which is defined as follows:

$$\eta_{\text{Heat Exchanger}} = \frac{\text{Available Process Thermal Energy}}{\text{Chemical Energy Available in Furnace Exhaust Gas}}$$

Typical heat exchanger efficiencies based on biomass LHV range between 60% and 95%, mainly depending on design and kind of operation and maintenance. The main losses are in the hot flue gas exiting from the stack.

In the industrial practice, the furnace and heat exchanger form together biomass-fired boiler unit.

The boiler is a more adaptable direct combustion technology because the boiler transfers the heat of combustion directly into the process medium. Overall boiler efficiency is defined as follows:

$$\eta_{\text{Boiler}} = \eta_{\text{Combustion}} \text{ x } \eta_{\text{Heat Exchanger}}$$

Overall boiler efficiency varies between 50% and 94%.

Very common and most efficient are biomass systems with direct combustion for electrical power generation and co-generation. Such system can achieve an overall efficiency between 30% (simple power generation systems) and 85% (high sophisticated co-generation systems).

Two following cycles are possible for combining electric power generation with heat and process steam production.

Steam can be used in process first and then re-routed through a steam turbine to generate electric power. This arrangement is called a bottoming cycle.

In the alternate cycle, steam from the boiler passes first through a steam turbine to produce electric power.

The back-pressure (or extracted) steam from the steam turbine is then used for processes or for heating (or cooling) purposes. This arrangement is called a topping cycle, which is the more common cycle.

Typical flow diagram of biomass fired (mixture of wood chips and hay) 11MW power plant with fluidized-bed boiler system, designed by SIEMENS AG is shown in the following picture (Figure 4).

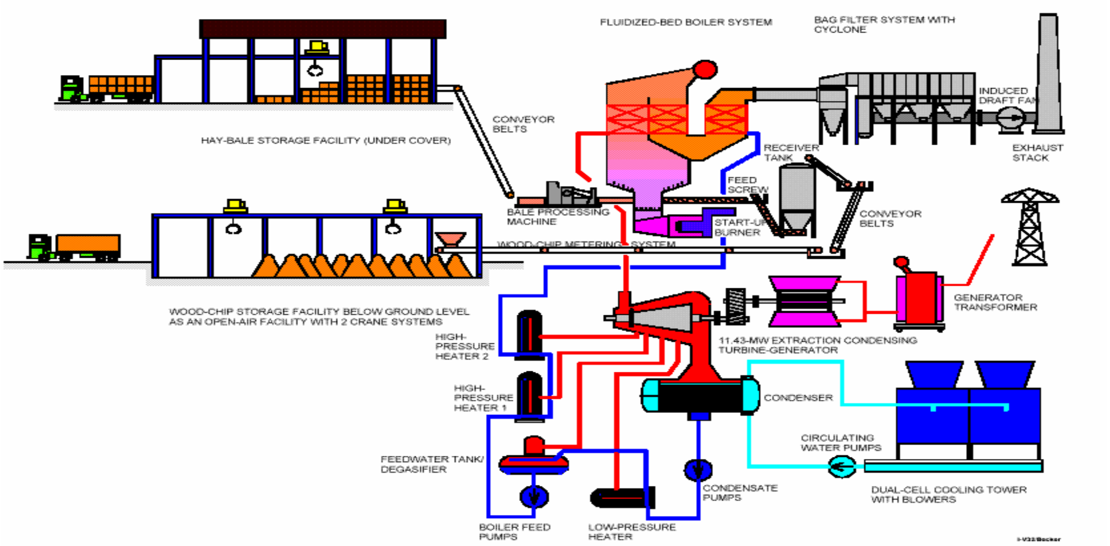

Figure 4

Typical Scheme of Biomass Fired Power Generation Plant

(Courtesy of SIEMENS)

Most efficient co-generation system based on above steam cycle can be designed in such way that instead of condensing steam turbine a back-pressure steam turbine will be used, delivering steam at required process conditions.

Another possibility is a combination of condensing steam turbine with controlled steam extraction facilities. This alternative offers maximum flexibility, i.e. during low process steam demand period maximum electric power can be generated.

Up to the present time, many biomass fired co-generation power plants have been built worldwide, replacing low efficient heat-only boilers.

Biomass Gasification Systems

Gasification, production of combustible gas (syngas) from carbon containing materials, is already an old technology. The first record of its commercial application origins from so called dry distillation (or pyrolysis – heating of feedstock on absence of O_2, resulting in thermal decomposition of fuel into volatile gases and solid carbon) origins from year 1812 (Gas Company in London).

The first commercial gasifier for continuous air-blown gasification of solid fuels was installed in 1839. Later, gas industry producing gas from coal and biomass was established. The first attempt to use produced gas to fire the internal combustion engine was carried out in 1881.

In 1920's gasification systems were being implemented to operate lorries and tractors. Biomass gasification was reintroduced during the 2nd World War as the consequence of unavailability of fuel oil. More than a million of gasifier-powered vehicles were in operation during that time in Europe. They ran on wood or charcoal. After the end of the war gasifier systems were substituted with engines driven by liquid fuels again.

It was not before the 1970s energy crisis when gasification wan its come-back for the third time through its history.

Gasification is a form of pyrolyses and is the complete thermal breakdown of biomass into a combustible gas, volatiles and ash in an enclosed reactor or gasifier. The produced syngas can be used either for process heat production or for electric power generation or combination of both.

Biomass gasification is normally practised at a relatively small scale, but systems exist up to 50 MWe. High system efficiencies (up to 50%) are achievable using combined cycle gas turbine (CCGT) systems.

A wide range of biomass materials (wood, charcoal, coconut shells, rice husk, and palm oil waste, straw) can be used to fuel gasifiers. Typically 1kg of air dried biomass gives 3-3.5 kWh heat, or 0.7-0.9 kWh electricity plus 1.4 kWh heat.

Major feedstock for gasification is:

- Wood
- Agricultural waste
- Municipal solid waste

Chemical process of gasification means the thermal decomposition of hydrocarbons from biomass in a reducing (oxygen-deficient) atmosphere.

The process usually takes place at about 850ºC. Because the injected air prevents the ash from melting, steam injection is not always required. A biomass gasifier can operate under atmospheric pressure or super-atmospheric pressure.

If the syngas is generated for combustion in the gas turbine the pressure of gasification is always super-atmospheric and if required by GT design, an additional syngas compressor may be employed (Figure 4). The resulting gas product, the syngas, contains methane (CH_4), hydrogen (H_2) and carbon monoxide (CO) as the main constituents.

By-products are liquids and tars, charcoal and mineral matter (ash or slag).

Reducing atmosphere of the gasification stage means that only 20% to 40% of stochiometric amount of oxygen (O_2) related to a complete combustion enters the reaction.

This is enough to cover the heat energy necessary for a complete gasification. Say in other words, the system is autothermic. It creates sensible heat necessary to complete gasification from its own internal resources. Prevailing chemical reactions are listed in Table 2, where the following main three gasification stages are described.

Stage I ⇨ Gasification process starts as autothermal heating of the reaction mixture. The necessary heat for this process is covered by the initial oxidation exothermic reactions by combustion of a part of the fuel (refer to Table 2).

Stage II ⇨ In the second – pyrolysis stage-, combustion gases are pyrolyzed by being passed through a bed of fuel at high temperature.

Heavier biomass molecules distillate into medium weight organic molecules and CO_2 through pyrolysis reactions. In this stage, tar and char are also produced.

Stage III⇨ Initial products of combustion, carbon dioxide (CO_2) and (H_2O) are reconverted by reduction reaction to carbon monoxide (CO), hydrogen (H_2) and methane (CH_4).

Stage III gasification reactions, which are most important for the final quality (heating value) of syngas, take place in the reduction zone of the gasifier. Heat consumption prevails in this stage and the gas temperature will therefore decrease.

Tar is mainly gasified, while char, depending upon the technology used, can be significantly "burned", reducing the concentration of particulates in the product.

Gasification Stage	Reaction formula	(Reaction number) / Reaction type	Reaction heat kJ/kmol
Stage I Oxidation and other exothermic reactions	$C+½O_2 \rightarrow CO$	(1) Partial oxidation	+110,700
	$CO+½ O_2 \rightarrow CO_2$	(2) CO oxidation	+283,000
	$C+O_2 \rightarrow CO_2$	(3) Total oxidation	+393,790
	$C_6 H_{10} O_5 \rightarrow xCO_2+yH_2O$	(4) Total oxidation	>>0
	$H_2+½O_2 \rightarrow$ H2O	(5) Hydrogen oxidation	+241,820
	$CO+H_2O \rightarrow CO_2+H_2$	(6) Water-gas shift	+ 41,170
	$CO+3H_2 \rightarrow CH_4+H_2O$	(7) Methanation	+206,300
Stage II Pyrolysis	$C_6H_{10}O_5 \rightarrow$ CxHz+ CO	(8) Pyrolysis	<0
	$C_6H_{10}O_5 \rightarrow C_nH_mO_y$	(9) Pyrolysis	<0
Stage III Gasification (Reduction)	$C+H_2O \rightarrow CO+H_2$	(10) Steam gasification	-131,400
	$C+CO_2 \rightarrow 2CO$	(11) Boudouard reaction	-172,580
	$CO_2+H_2 \rightarrow CO+H_2O$	(12) Reverse water shift	- 41,170
	$C+2H_2 \rightarrow CH_4$	(13) Hydrogenation	+ 74,900

TABLE 2

THREE MAIN SUCCESSIVE STAGES OF BIOMASS GASIFICATION.

SOURCE: J.B. JONES & G.A. HAWKINS: ENGINEERING THERMODYNAMICS, 1986, P. 456

Summarizing, the gasification is accompanied by chemical reactions that proceed at high temperature with gasifying agent and (occasionally) with steam as moderating agent.

In general, the gasifying agent can be air, oxygen (O_2) or oxygen-enriched air. For biomass gasification, air is normally used as oxidant (oxygen as the oxidant agent is preferred in high-capacity fossil fuel gasification systems).

The net product of air gasification can be found by summing up the partial reactions, as follows:

CARBOHYDRATE MATTER $(C_6H_{10}O_5)+O_2 \rightarrow C_XH_Y+C_LH_MO_N+CO+H_2+$**HEAT**

Reactions labelled in Table 2 with positive value of reaction heat are exothermic (chemical energy is converted to sensible heat). Reactions with the negative sign are on contrary endothermic (heat is consumed in favour of chemical energy).

Gasifiers are designed according to the origin and quality of fuel and the method in which the fuel is brought to contact with the oxidant. According to the syngas end use, the gasifier types can be divided into:

- heat gasifiers - used for fuelling external burners in boilers or dryers; and
- power gasifiers - coupled to gas turbine or internal combustion engine for power generation

Additionally, apart from being categorized according to heat or power generation purposes, gasifiers can be classified as:

- Entrained bed
- Fluidised bed
- Fixed bed

Entrained **B**ed **G**asifiers (EBG) are high-capacity design apparates. They require perfect atomisation of feedststock (0.1mm) and therefore are not suitable for biomass gasification.

Fluidised **B**ed **G**asifiers (FBG) can be divided into **B**ubbling (BFBG) and **C**irculating (CFBG) gasifiers. BFBG give a good temperature control and high conversion rates, good scale-up-potential, possibility of in-bed catalytic processing.

FB Gasifiers are not sensitive to particle size and to fluctuations in feed quantity and moisture. Syngas generated by BFGB has low tar content, only drawback is high content of particulates. CFBG are suitable for fuel capacity higher than 10 MWth. Compared to BFBG, they have the additional advantage of giving high syngas quality.

Fixed **B**ed **G**asifiers (FBG) are the most suitable for biomass gasification. Three possible designs of fixed bed gasifiers exist, namely:

- Down-draft (or co-current)
- Updraft (or counter-current)
- Crossdraft (or cross current)
- Open core (open current)

All FBG have strict fuel requirements to size, moisture and ash content. The typical characteristics of some biomass fuels can be summarised as presented in the Table 3.

Biomass Fuel	Moisture % wet	Ash % dry	Volatile Matter % dry	Bulk density kg/m^3	Average HHV MJ/kg dry
Charcoal	2-10	2-5	5-30	200-300	30
Wood	20-40	0.1-1.0	70-80	600-800	20
Rice Husks	3-5	15-25	60	100	15
Coconut Shells	25	0.8	79	not available	20

TABLE 3
TYPICAL CHARACTERISTICS OF BIOMASS FUELS FOR GASIFICATION

A generalised overview of the most important fuel requirements for different type of FBGs, are presented in Table 4.

Gasifier Type	Updraft	Downdraft	Open Core	Cross draft
Fuel	Wood	Wood	Rice Husks	Charcoal
Size, mm	20-100	5-100	1-3	40-80
Moisture, %	<25	<60	<12	<7
Ash, %	<6	<25	Approx. 20	<6

TABLE 4
FUEL REQUIREMENTS FOR DIFFERENT GASIFIER TYPES

The produced syngas can be utilized not only as the fuel for power generation but also as the feedstock for chemical industry. Final products of synthesis can be various chemicals, hydrogen, ammonia and methanol.

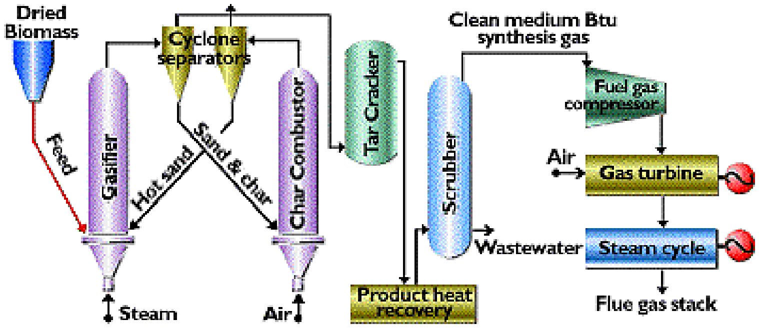

FIGURE 4

PRINCIPLE SCHEME OF BIOMASS GASIFICATION FOR POWER GENERATION

Gasification process is versatile in the feedstock choice as well as the end-product spectrum following from further processing of syngas. A typical diagram of a biomass gasification process combined with power and heat generation is shown in Figure 5. In this example, biomass (bagasse) is first dried and than injected in to the gasifier. The resulting syngas is purified in the **H**ot **G**as **C**lean-up (HGC) system. The purified biogas is then utilized in the conventional co-generation power plant, to produce electricity and steam.

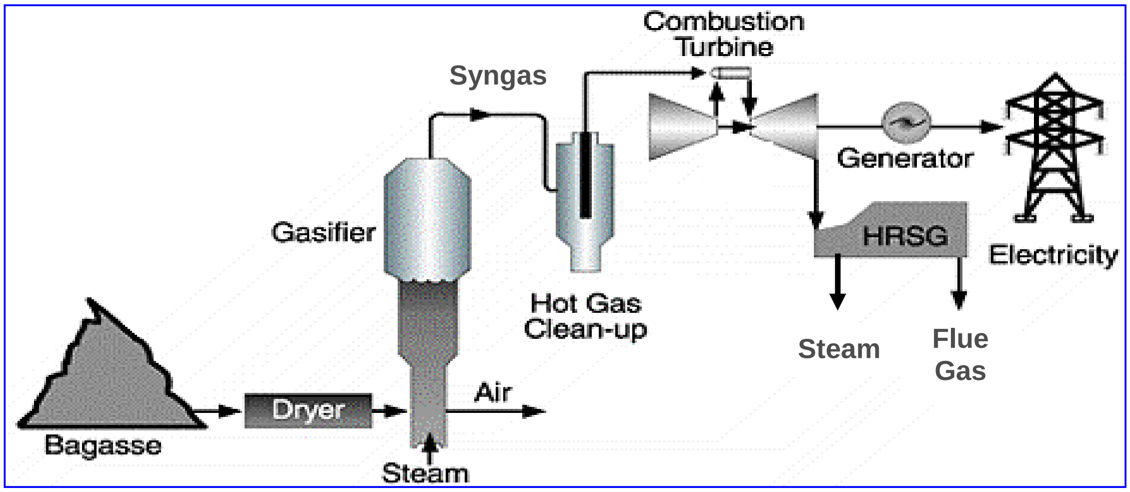

FIGURE 5

A SIMPLIFIED FLOWSHEET FOR THE BAGASSE GASIFICATION PROCESS INTEGRATED WITH CCGT

It has to be stated, that present well advanced integrated biomass gasification and combined heat and electric power generation concepts are promising but still not commercially fully demonstrated.

The main difficulties are the requirements set by gas turbine manufacturers in adapting gas turbines to medium-low BTU gases and to fulfil the gas quality specifications applicable for syngas utilization in highly fuel sensitive gas turbines.

ANAEROBIC DIGESTION – BIOGAS & LANDFILL GAS

As per records, biogas was first discovered by Alessandro Volta in 1776 and Humphery Davy was the first to pronounce the presence of combustible gas, *Methane* (CH_4), in the Farmyard Manure in as early as 1800.

Anaerobic digestion is a biological process that produces a gas principally composed of methane (CH_4) and carbon dioxide (CO_2) otherwise known as biogas. The biogas is produced from the following major organic wastes:

- Solid & liquid animal manure
- Agricultural plant waste
- Waste from agricultural products processing industry
- Organic components in town waste
- Waste waters
- Landfills

Biogas occurs naturally, hence its name, amongst others in swamps and lakes when conditions are right. Anaerobic digestion can be used to produce valuable energy from waste streams of natural materials or to lower the pollution potential of a waste stream.

The biogas-production will normally be in the range of 0.3 - 0.45 m^3 of biogas per kg of solid substances for a well functioning process with a typical retention time of 20-30 days. The lower heating value of biogas is about 22 MJ/m^3.

Biogas plant has a self-consumption of energy to keep the sludge warm. This is typically 20% of the energy production for a well designed biogas plant.

For example if the biogas is used for power and co-generation, the available electricity will be 30-40% of the energy in the biogas, the heat will be 40-50% and the remaining 20% will be said self-consumption. Flow diagram of typical anaerobic digestion process for biogas production from sisal waste in Tanzania is shown in Figure 6.

Anaerobic digestion is a complex biochemical reaction carried out in a number of steps by several types of micro-organisms that require little or no oxygen to live.

During the process a biogas, principally composed of approximately 65% methane (CH_4) and about 30% carbon dioxide (CO_2), is produced.

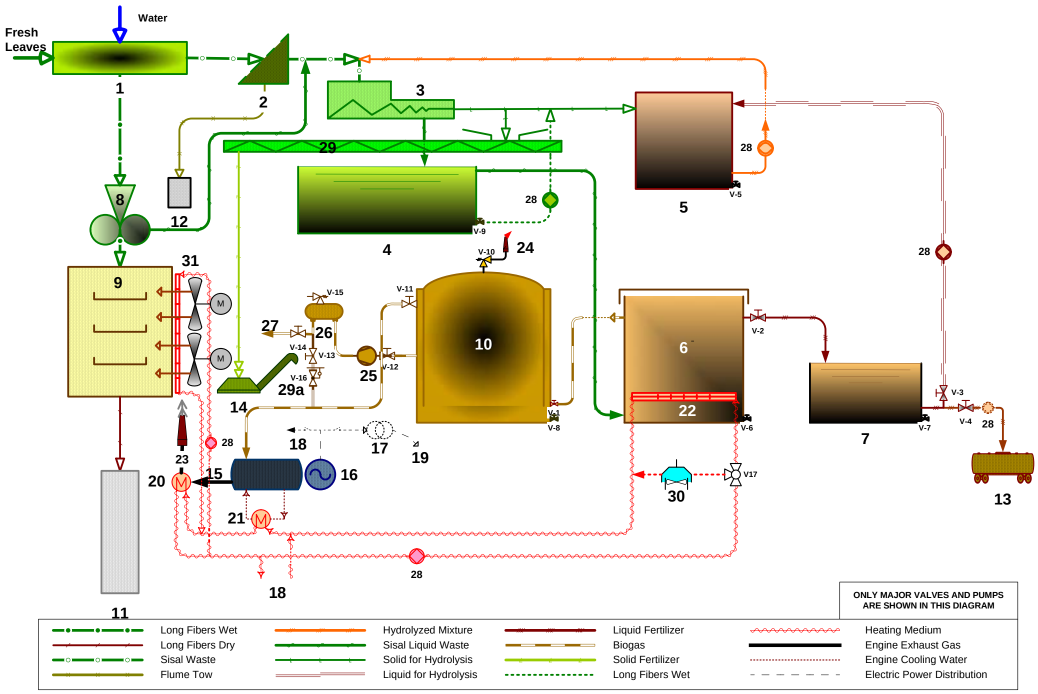

FIGURE 6

TYPICAL BIOGAS PRODUCTION FLOW DIAGRAM

The amount of biogas produced varies with the amount of organic waste fed to the digester and temperature influences the rate of decomposition. Several different types of bacteria work in stages together, to break down complex organic wastes, resulting in the production of biogas.

Controlled anaerobic digestion requires an airtight chamber, called a digester. To promote bacterial activity, the digester must maintain a temperature of at least 20°C (ideal 25°C - 35°C). Higher digester temperatures, above 50°C - 65°C, shorten processing time, allowing the digester to handle a larger volume of organic waste.

A mixture of CH_4 with CO_2 is making up more than 90% of the total biogas composition. The remaining gases are usually smaller amounts of H_2S, N, H_2, methylmercaptans and O. The biogas energy content depends on the amount of CH_4 it contains. Biogas CH_4 content varies from about 55% to 80%. Typical biogas, with a CH_4 concentration of 65%, contains about 22 MJ/Nm^3 of energy which is equivalent to 0.55 kg of light diesel oil.

The process of biological anaerobic digestion occurs in a sequence of steps involving distinct types of bacteria as illustrated in Figure 7.

The acetogenic bacteria grow in close association with the methanogenic bacteria during the last stage of the process.

The reason for this is that the conversion of the fermentation products by the acetogens is thermodynamically only possible if the hydrogen concentration is kept sufficiently low. This process only takes place under strict absence of oxygen.

Digester residence time has to be well balanced and optimized. The longer a substrate is kept under proper reaction conditions the more complete its degradation will become.

But the reaction rate will decrease with increasing residence time. Longer residence time requires automatically larger reactor for a given amount of substrate to be treated.

Shorter residence leads to a higher production rate per reactor volume unit, but a lower overall degradation.

Acidity (pH-value) is other very important factor for bacteria digestion process. It is important to balance the acidity in reactor in such way that the bacteria become most productive.

Unfortunately, for the different groups of bacteria the optimum acidity is not the same. The complexity of the entire system is increased by the fact that the intermediate products of the digestion have a tendency to lower the acidity, making the later steps in the process more difficult.

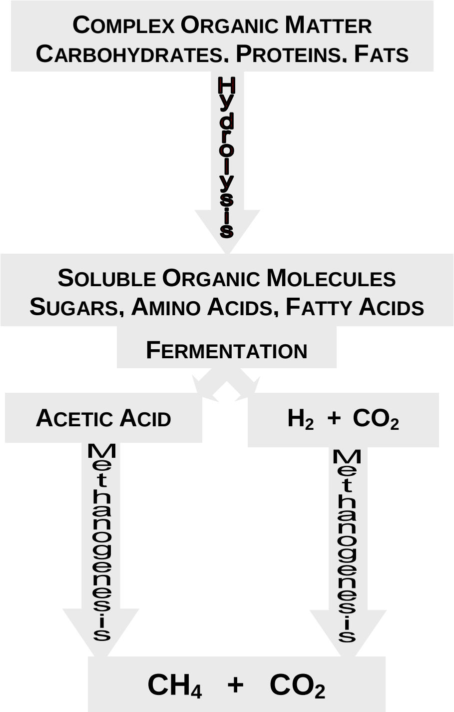

Figure 7

Sequential steps of biogas production

Comparison of various anaerobic digestion process parameters is shown in the Table 5.

Digestion Process	**Description**	**Advantages**	**Disadvantages**
Dry	**Dry solids content of > 25-30%**	**Compact, lower energy input, better biogas quality (<80% CH_4), maintenance friendly**	**Restricted mixing possibilities**
Wet	**Dry solids content of < 15%**	**Better mixing possibilities**	**Higher energy input, lager reactor**
Mesophilic	**Digestion temperature between 25°C and 35°C**	**Longer process time, slower rate**	**Low energy input**
Thermophilic	**Digestion temperature between 50°C and 70°C**	**Shorter process time, higher degradation, faster rate**	**Higher energy input**
Batch	**Substrate in closed reactor during whole degradation period**	**Suitable for small plants with seasonal substrate supply**	**Unstable biogas production**
Continuous	**Reactor is filled continuously with fresh material**	**Constant biomass production through continuous feeding**	

TABLE 5
ANAEROBIC DIGESTION PROCESS PARAMETERS

The combustion of biogas can supply useful energy in the form of steam, hot water or hot air. After filtering and drying, biogas is suitable as fuel for an internal combustion engine.

Future applications of biogas may include electric power production from gas turbines or fuel cells.

Biogas can substitute for natural gas or propane in space heaters, refrigeration equipment, cooking stoves or other equipment. Compressed biogas can be used as an alternative transportation fuel.

The same anaerobic digestion process that produces biogas occurs naturally underground in landfills.

Most landfill gas results from the decomposition of cellulose contained in municipal and industrial solid waste.

Unlike above motioned anaerobic digesters, which control the anaerobic digestion process, the digestion occurring in landfills is an uncontrolled process of biomass decay.

The efficiency of the process depends on the waste composition and moisture content of the landfill, cover material, temperature and other factors.

The biogas released from landfills, commonly called "landfill gas," is typically 50% CH_4 and 45% CO_2. Remaining 5% are usually other gases like H_2S, N, H_2 and O.

In theory, the lifetime yield of a good site should lay in the range 150-300 m^3 of gas per tonne of wastes.

This offers a total energy of 5-6 GJ per tonne of waste, but in practice yields are much less. Capturing landfill gas before it escapes to the atmosphere allows for conversion to useful energy.

The gas is collected by an array of interconnected perforated pipes (wells) buried at depths up to 20 metres in the waste. In new sites this pipe system is constructed before the wastes start to arrive, and in a large well-established landfill there can be several miles of pipes, with as much as 1000 m^3 an hour of gas being pumped out.

A landfill must be at least 12m deep and have at least one million tons of waste in place for landfill gas collection and power production to be technically feasible.

Combination of landfill gas capturing with power generation, landfill gas to energy system, is shown in Figure 8.

A piping system (Manifold) connects the wells and collects the gas. De-watering system with integrated dryers removes moisture from the gas, and filters remove impurities.

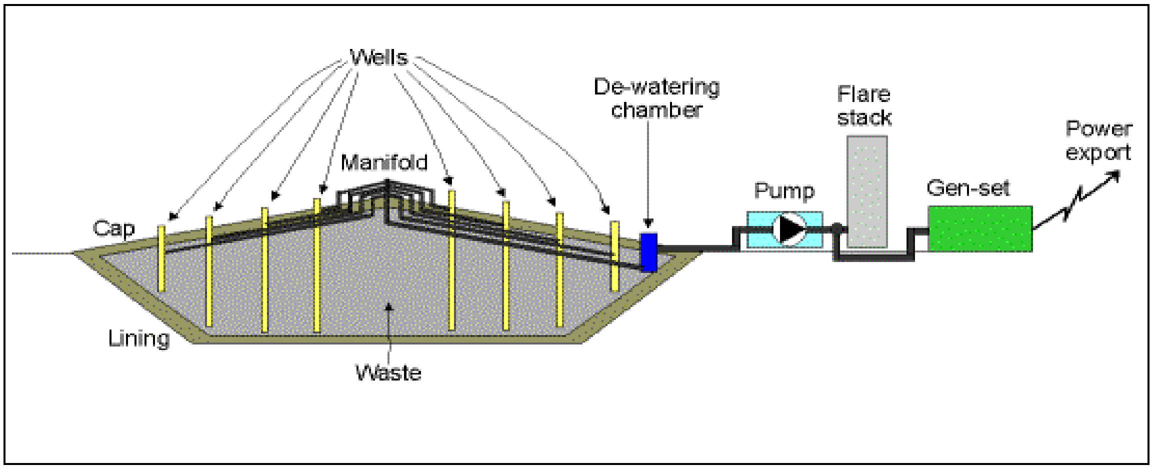

FIGURE 8
POWER GENERATION FROM LANDFILL GAS

The landfill gas typically fuels a boiler to produce heat (steam, hot water, etc.) or gas turbine to produce electricity.

The excess gas can be flared in emergency flare stack.

Further gas cleanup improves biogas to pipeline quality, the equivalent of natural gas. Reforming the gas to hydrogen would make possible the production of electricity using fuel cell technology.

BIOETHANOL

Starch content of Biomass feedstocks like corn, potatoes, beets, sugarcane, wheat, barley, and similar can be converted by fermentation process into alcohol (bioethanol).

Fermentation is the biochemical process that converts sugars into bioethanol. In contrast to biogas production, fermentation takes place in the presence of air and is, therefore, a process of aerobic digestion.

Bioethanol, CH_3CH_2OH, producers use specific types of enzymes to convert starch crops such as corn, wheat and barley to fermentable sugars. Some crops, such as sugar-cane and sugar beets, naturally contain fermentable sugars.

Bioethanol may also be used as a hydrogen source for fuel cells. Because ethanol is easier to transport and store than hydrogen, fuel reforming (using a chemical process to extract hydrogen from fuel) may be a practical way to provide hydrogen to fuel cells in vehicles or for remote stationary applications.

Latin America, dominated by Brazil, is the world’s largest production region of bioethanol.

Bioethanol fuels have also been aggressively pursued in a number of African countries currently producing sugar - Kenya, Malawi, South Africa and Zimbabwe. Others with great potential include Mauritius, Swaziland and Zambia.

In developing countries interest in bioethanol fuels has been mainly due to low sugar prices in the international market, and also for strategic reasons. In the industrialized countries, a major reason is increasing environmental concern, and also the possibility of solving some wider socio-economic problems, such as agricultural land use and food surpluses.

As the value of bioethanol is increasingly being recognized, more and more policies to support development and implementation of ethanol as a fuel are being introduced.

METHANOL

Methanol, CH_3OH (methyl alcohol or wood alcohol) is produced from the distillation of wood or selected agricultural residues. However, nearly all methanol produced today is made from natural gas, thus, will not be considered in this paper.

Methanol is a fatal poison. Small internal doses, continued inhalation of the vapour, or prolonged exposure of the skin to the liquid may cause blindness. As a result, commercial use of methanol has sometimes been prohibited.

In addition, there is a growing consensus that methanol does not have all the environmental benefits that are commonly sought for oxygenates and which can be fulfilled by ethanol.

COMMERCIAL ASPECTS

Direct combustion, gasification as well as anaerobic digestion systems are commercially available. Direct combustion most advanced concepts based on fluidized bed combustion are technically proven.

Even though that gasification systems are also commercially available, they are less reliable and need more supervision in comparison to direct combustion. The further development should be directed towards improving their performance and reliability.

Anaerobic digestion is very wide used common method for biogas generation, mainly from sewage, landfills and from waste produced in medium and large farms.

The economy of a biogas plant consists of large investments costs, some operation and maintenance costs, mostly free raw materials, and income from sale of biogas or electricity and heat.

Sometimes other values may be added e.g. for improved value of sludge as a fertilizer. A comparison between all three technologies is shown in the following Table 6.

Type	Technology	GT Power Output MWe	ST Power Output MWe	Fuel Input Ton/hour	Specific Costs US$/kW
FBC	**Fluidized Bed Combustion**	**0**	**5**	**5-10**	**2600**
FBG	**Fluidized Bed Gasification**	**3.3**	**1.7**	**4-8**	**2800**
ADB	**Anaerobic Digestion-Biogas**	**<1.0**	**<0.9**[1]	**2.5**[2]	**3000-4500**

[1] 0.9 MW_{th} (Net Available Heat Energy) [2] Assumptions: Biomass LHV=8 MJ/kg, 35% Power / 45% Heat Generation / 20% Internal Consumption

TABLE 6
COMPARISON BETWEEN GASIFICATION SYSTEMS

What can not be seen from the above comparison is the production of by-products like additional heat energy extracted from direct combustion and gasification process as well as fertilizer produced from anaerobic digestion process.

Depending on system design and optimization, both systems, combustion and gasification, can produce hot water or hot air for process, heating and also cooling purposes. Additional to 1.3 MW_{th} heat energy, typical 1 MWe aerobic digestion plant produces annually more than 20’000 tons of valuable fertilizer.

Due to biomass fuel relatively low energy content and low bulk density of the fuel, which prevents from economic point of view, transportation of fuel over long distances, FCB &FBG (Table 1) power plants shall be optimized to 5 – 10 MWe.

Lower size will improve the fuel supply logistics, but it will considerably increase total investment costs.

For example specific costs (US$/kW) for 1 MWe power plant will be approximately 30% higher than specific costs for 5 MWe power plant and this will be again around 20% higher than 10 MWe power plant.

Biomass fired power plant larger than 10 MWe is recommendable only for locations where the biomass fuel can be secured not only in sufficient quality and quantity but also during the whole expected operational time period.

Due to high ratio between fuel demand for power generation and size of anaerobic digestion equipment the biogas fired power plants are sized between couple of kW^s and 1 MW.

PROJECT RISK ASPECTS

In order to manage risks it must be understood what a project risk is. It is a combination of constraint and uncertainty. <u>Each project faces constraints, and also uncertainty</u>. So the project risk may be minimized either by eliminating constraints or by finding and reducing uncertainties.

Therefore it is important to review certain major risk factors, which may affect the commercial performance of any project, in this case biomass utilization project for power generation. Two following very important stages in the process of Project Risk Management shall not be overlooked -<u>Risk Assessment and Risk Control</u>.

Risk Assessment can take place at any time during the project, though the sooner the better. However, the Risk Control cannot be effective without a previous Risk Assessment.

The following (Table 8) does not purport to be a complete or exhaustive review of all risks facing the project investor, it is a summary of relevant risks and mitigating factors associated with the project.

RISK MATRIX			
RISK	**RISK FACTOR 5=MAX 0=MIN**	**BEARER OF RISK**	**MITIGATING FACTORS**
CONSTRUCTION PERIOD RISKS			
Completion Risk	2	Contractor-Investor	Turnkey contract – liquidated damages.
Construction Price Risk	1	Contractor-Investor	Turnkey Contract – Fixed price.
Permitting and Approvals	0	Contractor-Investor	To obtain the majority of permits and approvals.
OPERATING RISKS			
Project Performance	2	Operator- Investor	Contract warrantees-Liquidated damages.
Technology	2	Contractor- Investor	New technology risk.
Market Demand and Price	2	Investor – Utility	Long term Power Purchase Agreement (PPA) required.
Energy Dispatch	2	Investor - Utility	Long term PPA with capacity payments preferable.
Operating and Maintenance Costs	2	Operator- Investor	Support from major equipment supplier required.
Biomass Supply	3	Investor	Long term delivery agreement with biomass producers (BP) required.
Biomass Price	3	Investor	Long term price agreement with BP required.
Equipment Breakdown or Failure	1	Operator- Investor	Critical spare parts must be available on site + proper insurance coverage.
REGULATORY AND ENVIRONMENTAL RISKS			
Environmental	1	Investor	Environmental Impact Assessment that ensures compliance with all required environmental regulations must be performed. Operator shall regularly monitor the Project's environmental parameters to ensure compliance.
Emissions	1	Contractor – Investor	The Contract shall provide for guaranteed emission levels.
Waste Disposal	0	Operator - Investor	Shall be considered in project design.
ECONOMIC AND FINANCIAL RISK			
Inflation	2	Investor – Utility	PPA
Interest & Exch. Rate	2	Investor	Conservative assumptions & hedging.
Force Majeure	3	Investor - Utility - Operator	Subject to terms of PPA and biomass supply agreement.

TABLE 7
PROJECT RISK ASPECTS

Among others, biomass fuelled power generation projects are facing following two major long term risk components:

- **BIOMASS SUPPLY** → There is a risk that biomass supply could be impaired, thereby decreasing the output of the project and in addition, issues such as the logistic of biomass supply (low heating value = high quantity), the storage, treatment processes to convert it into usable fuel must be taken seriously into consideration.
- **BIOMASS PRICE** → There is a potential risk that increases in the biomass price can adversely affect project cash flow. Major concern is that the biomass has an affordable value at project beginning but there is no certainty how the price tag will look like in a few years.

However, other remaining project risk components, as listed in above Table 8, have to be seriously identified and analyzed.

During the project implementation, the project risks shall be monitored and all risk handling actions properly planned.

SUMMARY – CONCLUSIONS

Disposal of any kind of waste will become ever more constraining in the future, due to environmental regulations and legislations.

Modern biomass utilization technologies, mainly the gasification and anaerobic digestion, give the advantage of separating the toxious substances and providing clean gas for combustion.

Additionally, the internal combustion engines fuelled by syngas and/or biogas have the less emissions compared to petroleum derivates fuelled engines. Sulphur dioxide and NO_x are, normally, absent in syngas and biogas.

Plantation of electrical energy generation based on gasification and anaerobic digestion technologies is beneficial for world’s environment and its inhabitants.

In fact, the investment cost for rural electrification based on classical centralised power plants, is related to an erection of long electricity grids to connect the areas to be electrified to the power plants, far away.

Biomass technologies, such as biomass gasification and anaerobic digestion, that use locally available resources, would enable poor rural areas to access the electricity produced in a decentralised power plants.

Locally limited availability of biomass leads to the conclusion that small scale, modularized power plants with respectable efficiency will be preferred.

In order to increase the thermal efficiency of small systems, development works with steam cycles aims to downgrade large steam cycle (as already done for GT cycles) to ranges between 1 and 10 MWe.

The development of biomass utilization for heat and power generation is also important from a social and environmental perspective:

- The life cycle of biomass as a renewable material has a neutral effect on CO_2 and SO_2 emissions. Large-scale use of biomass for power generation also enables closure of the mineral and nitrogen cycles.
- Biomass can be used as a decentralised source of energy, where conversion to heat or electric power can take place close to production. This can lead to social stability at the regional level.
- Around 10 to 15 new jobs can be created per MW installed electrical power generation capacity. Translating this number to the situation in Europe, where 5% of energy demand must be derived from biomass, results in 160,000 new jobs.
- Large agricultural land and land areas with marginal production possibilities that are available worldwide, can be used for the production of biomass for energy production.

The growing interest in biomass utilization for power and heat generation in the late 1990's is the result of a combination of underlying factors, including:

- ✓ Rapid changes in the energy market worldwide, driven by privatisation, deregulation and decentralisation.
- ✓ Greater recognition of the current role and future potential contribution of biomass as a modern energy carrier.
- ✓ Its worldwide availability, versatility and sustainability.
- ✓ Better understanding of its global and local environmental benefits and perceived potential role in climate stabilisation.
- ✓ Growing concern with global climate change that may eventually drive a global policy on pollution abatement.
- ✓ Growing recognition among established international organizations & conventional institutions of the importance of biomass energy (UNO, UNIDO, WB, ADB, FARE, e.g).
- ✓ Expected increases in energy demand, combined with current rapid growth crude oil prices.

- ✓ Growing introducing of specific policies in support of renewable energies (also biomass) in many countries worldwide.
- ✓ Environmental pressures may increase the price of fossil fuels as the cheaper sources are depleted.
- ✓ Biomass utilization technology is evolving rapidly and the new technologies development time-span is being reduced.

A major challenge still remaining is how best to tackle the problems posed by the traditional uses of biomass based energy e.g. to improve low combustion efficiency and reduce health hazards.

There are a number of challenges that inhibit the development of biomass energy. In this regard, formulation of sustainable energy policy and strategies in addressing these challenges is indeed a pre-requisite for the development and promotion of biomass conversion energy.

For biomass based energy to have a future, it must provide people with what they want, e.g. reliable electrical power and proper environmentally acceptable fuels at an affordable price.

> *“The worst thing that can happen - will happen - is not energy depletion, economic collapse, limited nuclear war or conquest by a totalitarian government.... the one process that will take millions of years to correct is the loss of genetic and species diversity by the destruction of our natural habitats.*
>
> *This is the folly our descendants are least likely to forgive us. Humans would not survive more than a few months if all the insects and other land-dwelling arthropods were all to disappear ". E.O.Wilson, Professor at the Harvard University.*

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AUTHOR'S BIOGRAPHICAL SKETCH

Miro R. Susta, born in Bratislava, is graduate of Swiss Federal Institute of Technology in Zurich, ETHZ; Diploma (M.Sc.) degree in Power Plant Mechanical Engineering.

He is a Member of Swiss Engineers and Architects Association (SIA) and Member of American Society of Mechanical Engineers (ASME).

Mr. Susta has more than 28 years of professional experience in power plant design & engineering, field and factory testing, sales and marketing with Sulzer-Brown Boveri Turbomachinery AG, Brown Boveri AG, Motor Columbus Consulting Engineering AG, Asea Brown Boveri AG in Switzerland and NEI Parsons in England and Malaysia.

During his professional career, Mr. Susta accumulated a vast knowledge and experience not only in power plant design, engineering, marketing and management, but also in general power business not only in Europe but also in miscellaneous countries in Asia.

In year 1992, Mr. Susta joined Swiss consulting engineering company IMTE AG, which is specialized in thermal power generation consulting engineering activities.

With IMTE AG, he was involved in Lumut 1303MW CCGT, Sepang 710 MW CCGT and Tanjung Bin 2100MW Coal Fired Power Plant Project in Malaysia and Vembar 1800MW CCGT Power Plant Project in India.

Currently Mr. Susta is active in development of small biomass and biogas fired power plants in Malaysia and Tanzania.

From 1994 till 1997, Mr. Susta was external advisor to the President of Slovak Republic, HE Mr. Michal Kovac.