LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
DEPARTMENT OF ENERGY AND ENVIRONMENTAL TECHNOLOGY

MASTER'S THESIS

STATUS OF BIOMASS GASIFICATION

Examiners:
Professor, Ph.D. (Tech.) Esa K. Vakkilainen
Professor, Ph.D. (Tech.) Timo Hyppanen

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Marat Sagitov
Ruskonlahdenkatu 13-15 B11 room №3
53850 Lappeenranta
Finland
+358468483846
maratsagit@yandex.ru

ABSTRACT

Author: Marat Sagitov

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Examiners Professor Dr.Sc.(Tech.) Esa Vakkilainen
Professor Dr.Sc.(Tech.) Timo Hyppanen

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The problem concerning feasibility and cost-efficiency of today's gasification technologies has been subjected to a number of research works. However, the status of biomass gasification and the systems as well as equipment used for gasifying purposes are not certain. So further investigation and observation on the gasification ought to be made.

The paper is focused on an overview of currently exploited gasification methods as well as types of gasifiers. Several modern projects and research propositions are presented in the study. In addition, the gasification process is more prone to the challenges such as gas cleaning, conditioning process, biomass handling and gasifier refractory lining which are described in detail. Furthermore, full classification of different constructions with respect to gasifiers is considered.

In conclusion, the biomass gasification tends to reach possible opportunities for future expansion and development as it has been reported in EU policies and legislation.

TIIVISTELMA

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Professori TkT Timo Hyppanen

Hakusanat: kaasutus, kaasutin, biomassa

Kaasutuksen kannattavuus ja toteutustapa on ollut tarkea ja useiden tutkimuksien kohde. Biomassan kaasutuksen ja siina kaytettavien laitteiden nykytila on epavarma. Niinpa lisatutkimukselle ja tarkasteluille on edelleen tarvetta.

Tama tyo keskittyy nykyisin kaytettavien kaasutusprosessien ja laitteiden tarkasteluun. Tyossa kaydaan lapi useita uusimpia kaasutusprojekteja ja esitetaan niista tutkimustarpeita. Lisaksi kaasutusprosessissa pitaa saada hallintaan niille tyypillisia ongelmia kuten kaasun puhdistus, kaasun kasittely, biomassan kasittely ja kaasuttimen muuraus, joista esitetaan lisatietoa. Edelleen esitetaan kaasutusprosessien taydellinen luokittelu.

On huomattava etta biomassan kaasutusta tarvitaan jotta saadaan toteutettua EUn hahmotteleman ja saataman energiapolitiikan vaatima kasvu ja kehitys.

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LIST OF ABBREVIATIONS

BCL/FERCO	Battelle Columbus Laboratory/ Future Energy Resources Corporation
BGCC	Biomass gasification combined cycle
BFB	Bubbling Fluidized Bed
BFBG	Bubbling fluidized bed gasifier
BL	Black liquor
CFB	Circulating fluidized bed
CFBG	Circulating fluidized bed gasifier
CHP	Combined heat and power plant
ECU/MWth	European currency unit per Megawatts-thermal effect
EU	European unit
FAEE	Fatty acid ethyl ester
FAME	Fatty acid methyl ester
GTI	Gas technology institute
GWh/a	Giga watts hours annually
HRSG	Heat recovery steam generator
IGCC	Integrated Gasification Combined Cycle
MFV	Minimum fluidizing velocity
Mg/MJ	Milligrams per Mega Joules
mg/Nm3	Milligrams per Normal Cubic Meter (1 atm and 273.15K)
MJ/Nm3	Mega Joules per Normal Cubic Meter (1 atm and 273.15K)
MTCI	Manufacturing and Technology Conversion International
Mtoe	Mega tonnes of oil equivalent
MW	Megawatts
MWe	Megawatts - electrical effect
MWth	Mega Watts – thermal effect
NSPS	New Source Performance Standards
OP	Over Pressure (Atmospheric pressure = 0 bar OP)
ORNL	Oak Ridge National Laboratory
PIG	Products of incomplete gasification
Psi	Pounds per square inch
RDF	Refused derived fuels
R&D	Research and Development

REF	Recycled refused fuels
SNG	Synthetic or substitute natural gas
SRF	Solid recovered fuels
XRD	X-ray diffraction

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1 INTRODUCTION

The purpose of this study is to present recent information about biomass gasification status and to observe newest ideas about gasification process.

The intensity of agricultural processes has been established as quite high and accordingly the bigger energy amount is involved into the productivity growth and development of industry. The further industry growth was possible only with usage of the fossil fuels, but currently it occurs to be problematic to use those because of economic control methods e.g. policies and regulations. As a consequence fossil fuel usage for energy production purposes has been changed by alternative energy sources implementing such as solar, wind, geothermal etc. Even though energy produced from those methods has not been economically available and as a result biomass energy source implementation has solved the problem. Therefore wood or biomass gasification has been proven reliable and had been extensively used for transportation and on farm systems during World War II.

The definition of the biomass gasification can be described as "incomplete combustion of biomass resulting in production of combustible gases consisting of Carbon monoxide (CO), Hydrogen (H2) and traces of Methane (CH4)." The name of the gas produced during the gasification is producer gas. The reliability of gasification can be demonstrated by several applications such as internal combustion engine fuel, substitution for "furnace oil" in direct gasification processes and also as a feedstock to generate methanol, which in turn is suitable for heat engines as well as "chemical feedstock for industries". Another advantage of gasification as a process is that almost all biomass material might undergo gasification compare to ethanol or biogas production, where only selected biomass could be converted in a fuel. This benefit makes gasification more attractive. Moreover, when utilizing solid waste it is quite difficult to make an economical yield because of the rarity of the fuel on a farm. One option for wood waste is to utilize it by incineration in the boiler but in this case power generation is quite expensive due to equipment cost and low energy recovery level. As a result production of the producer gas by meaning of gasification proposes advantageous method of waste conversion into more readily usable fuel form. Thus the gasification might be very attractive.

However under present conditions, economic factors seem to provide the strongest argument of considering gasification. The biomass gasification can provide an economically viable system in many situations (the case in agricultural systems) where the price of petroleum fuels is high or where supplies are unreliable due to the lack of availability of the biomass feedstock.

There are many variations of the producer gas because of the affect of various processes and biomass feedstock which are outlined above.

Table 1 lists the composition of gas produced from various sources. Depending on the gasifier dimensions produced gas might have different fuel properties such as calorific value which is given approximately in the Table 1.

Table 1: Composition of Producer Gas from various fuels

Fuel	Gasification method	Volume Percentage					Calorific value MJ/m^3	Ref.
		CO	H_2	CH_4	CO_2	N_2		
Charcoal	Downdraft	28-31	5-10	1-2	1-2	55-60	4.60-5.65	12
Wood with 12-20% moisture content	Downdraft	17-22	16-20	2-3	10-15	55-50	5.00-5.86	12
Wheat straw pellets	Downdraft	14-17	17-19	-	11-14	-	4.50	15
Coconut husks	Downdraft	16-20	17-19.5	-	10-15	-	5.80	15
Coconut shells	Downdraft	19-24	10-15	-	11-15	-	7.20	15
Pressed Sugarcane	Downdraft	15-18	15-18	-	12-14	-	5.30	15
Charcoal	Updraft	30	19.7	-	3.6	46	5.98	16
Corn cobs	Downdraft	18.6	16.5	6.4	-	-	6.29	17
Rice hulls pelleted	Downdraft	16.1	9.6	0.95	-	-	3.25	17
Cotton stalks cubed	Downdraft	15.7	11.7	3.4	-	-	4.32	17

Nitrogen is promotional matter when dissolving produced gas, besides the content of noncombustible nitrogen in produced gas is about 50-60 per cent. For this reason it is better when oxygen is involved in the process in spite of air, however total cost of gasification process might be increased dramatically. But as the producer gas (methanol) possesses quite high heating value so that use of the oxygen during the process could be justified.

Production of 2.5 m^3 of producer gas requires supply of at least and 1.5 m3 of air needed for combustion. In comparison with gasification, consumption of the air is about 4.5 m3 in complete combustion process. Therefore gasification consumes 67 per cent of theoretical stoichiometric ratio less compare to regular incineration of biomass.

Direct Heat Systems

The producer gas is burnt directly inside the boiler or furnace in direct heat systems.

By meaning of direct gasification systems one can obtain a heating process which is more comfortable and suitable for control as well as higher frame temperature levels compare to direct biomass incineration. The other advantage of direct heat systems is less critical quality of producer gas in comparison to shaft power systems and the demand on cooling and cleaning equipment is quite low as well as versatility of the fuel is higher as fuel is concerned.

Drying on the farm and many others agricultural applications became more attractive for the direct heat systems, especially in U.S. Because of the Second World War the direct gasification systems were used quite seldom and thus the experience of their usage is very poor. An updraft or fluidized bed gasifiers types are accessible at the moment.

The capacity of such gasifiers varies around 0.25-25 GJ/hr. This range of capacities is too high when considering about agricultural drying applications but mostly these are for large kiln and furnace applications. The production of gas requires storage due to its unsteady and erratic properties changing from time to time. This approach could overcome the problem with uneven gas quality but currently no such systems with storage exist.

Energy content of producer gas is quite low (about 5 MJ/m^3) compare to natural gas (40-45 MJ/m3) for this reason, special burners are needed. The highest temperature applications can be around 1000-1200^0C as a consequence of the adiabatic flame temperature of producer gas (about 1400^0C).Nevertheless it has been observed that some manufacturers mislead their customers about using the gas for 1600^0C applications. “Most of the U.S. manufacturers producing direct heat systems have been summarized by Goss.”

The main applications of biomass gasifier are listed below:

a) Shaft power systems

b) Direct heat applications

c) Chemical production

The main agriculture applications of the shaft power systems are driving of farm machinery like tractors, harvesters etc. Many manufacturers provide agricultural on a farm machinery gasification systems. There is an attractive possibility to utilize producer gas in small scale electricity generation systems.

Apart from this another useful application of producer gas units is in irrigation systems. It tends to be the most attractive application in developing countries. As developing countries have installed a lots of irrigation systems working on solar energy there is no reason of implementation rejection of such systems based on producer gas.

It has been proven that the best applicable system in agriculture is direct heat system as a result of its simplicity. The same effect on agriculture has been made by grain drying, green house heating and running of absorption refrigeration and cooling systems. And of course among them one can find systems that can be combined together as well as other renewable energy systems like solar for thermal applications. Running of Stirling engines is quite novel and interesting application for direct heat (external combustion) systems. To work of such engines shows very high efficiencies and may prove to be a better alternative than internal combustion engine running on producer gas.

Another quite recent appearance is production of chemicals such as methanol and formic acid from producer gas. The usage of fossil fuels is becoming more and more difficult due to their depleted properties so that production of these chemicals by producer gas may prove to be an economically feasible proposition. Producer gas can be used to run a fuel cell plant which seems to be a profitable application compare to IC engine systems because of the energy density of such plant.

On the other hand any of these applications for producer gas can not be implemented without biomass feedstock thus the availability of biomass is crucial factor in this case. This factor makes biomass residues to be an attractive proposition for on farm

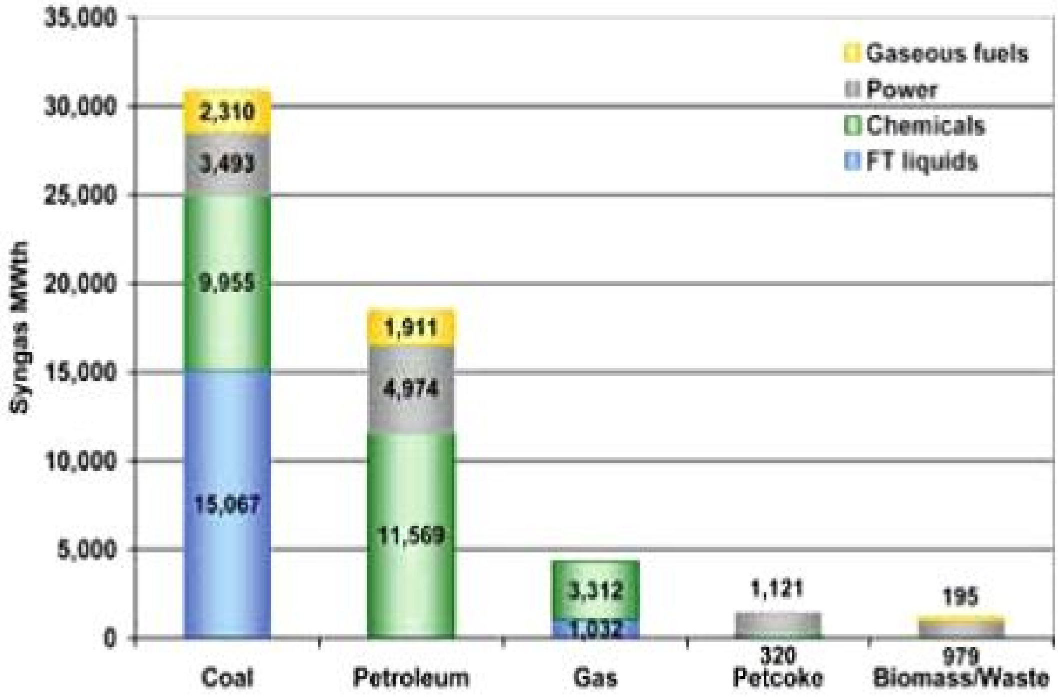

Figure 1: 2007 Operating world gasification capacities-by feedstock and product [3]

applications. After all, the fuel availability has to be critically assumed beforehand and especially when large scale application of gasification is getting to be done.

The relationship between gasification feedstock and product is demonstrated on the figure 1. One can see the allocation percentage of different kinds of feedstocks for gasification. In the first place coal is used to produce F-T liquids (49 percent) and chemicals (32 percent), for power generation (11 percent), and to produce gaseous fuels (8 percent). In contrast, petroleum is predominantly used to produce chemicals (63percent) but also produces power (27 percent) and gaseous fuels (10 percent). The share of natural gas (76 percent) is used to generate chemicals so that the rest of the energy is going to F-T liquids. Clearly petroleum coke and biomass/waste are used to provide power generation.

As a rule the availability of the fuel is not the only factor one should take into account when building a new plant. In other words it is also necessary to look at the land area required, for a gasifier to run on cotton stalks (biomass residue) as fuel. "On an average, quantity of stalks harvested is 1.5 tons/acre/yr. Thus a 100 kW gasifier running at 8 hours per day for 300 days/year will require about 213 acres of cotton plantation to produce the required cotton stalks." Hence the future applications of gasifiers have to be evaluated with compilation of all factors.

Of course it does not mean that one can not replace the biomass residue on wood when the availability of residues is not sufficient. “However such decisions can only be made at specific sites and for specific applications.”

In addition gasification systems could be implemented in such alternative energy source link as hybrid systems. To be more precise alternative energy systems would be great decision if combining with gasification systems, for example grain drying can have biomass gasifier/solar coupling.

An exception occurs in production of methanol or chemicals thus the gasification system is recommended to be used as separate one [6].

2 BIOMASS GASIFICATION

2.1 Market and opportunities

It has been observed that gasification occurs when “coal and other carbon feed stocks” converts into syngas or biogas, creating a diversity of fuel products in the worlds' economy. Gasification shows a huge potential for further research work as all industrialized countries have been using gasification as mean to produce electricity, chemicals, hydrogen, synthetic or substitute natural gas (SNG).

In addition, gasification tends to become the first in the range of global market, and it is considered as fast-growing and dynamical market. Together with market growth, production capacity growth is also noticeable, e.g. China has built a 21 gasification mills which in turn had an affect on production of feedstock and fertilizers by releasing nations reserve.

Currently “the world’s largest gasification plant” is building in Qatar, its production capacity is higher in 10-20 times compare to worlds’ plants capacities. The plant will be working on natural gas as a fuel.

The main direction of the work at many gasification plants in Japan, Brazil, and the Czech Republic as well as plants planned near-term for Italy and Poland is to generate power. However, new gasification mill in India will be focused on chemical production.

When considering about gasification capacity growth, it is investigated that the current situation in the United States do not show a high growth rate; however, there is still possibility to poise it by building of the new several gasification plants in the next 5 to 10 years .

Practically all of the gasification plants built during 2008-2010 period and it is 85 per cent of them, use coal as the primary feedstock .Many companies such as Shell (15 plants) and GE Energy (8 plants) continue to develop the new gasifiers thus providing 23 plants with new equipment, although only Shell gasifiers are projected for the 10 new plants planned during 2008 to 2010. [3]

As considered in the Combined Heat & Power Association, about 65 per cent of the fuel is wasted when producing electrical energy in the U.S. “The average efficiency of power generation has remained around 33% since 1960.” The efficiency can be increased to the level of 70 by substitution the old technologies to gasification combined cycle technologies.

Combined heat and power technologies have been practiced in the forest products industry for several decades, and this industry is currently the largest producer of energy from biomass in the world. The greatest opportunity occurs when combining the biomass gasification combined cycle with the renewable energy available through wood residuals and spent pulping liquors, and as a result the forest products industry affects on the National goals “of less dependence on foreign oil and reduced carbon emissions while at the same time increasing the industry’s global competitiveness [1].”

2.2 Gasification Reactions

The production of generator gas (producer gas) called gasification, is partial combustion of solid fuel (biomass) and takes place at temperatures of about 1000^{o}C. The reactor is called a gasifier.

The combustion products from complete combustion of biomass generally contain nitrogen, water vapor, carbon dioxide and surplus of oxygen. However in gasification where there is a surplus of solid fuel (incomplete combustion) the products of combustion are (Figure 1) combustible gases like Carbon monoxide (CO), Hydrogen (H_2) and traces of Methane and non useful products like tar and dust. The production of these gases is by reaction of water vapor and carbon dioxide through a glowing layer of charcoal. Thus the key to gasifier design is to create conditions such that a) biomass is reduced to charcoal and, b) charcoal is converted at suitable temperature to produce CO and H_2 [6].

The gasification process itself originates from the chemical reactions which might offer the way to understand the idea of whole process. Biomass gasification chemical reaction are quite complex. As shown in the scheme, biomass gasification takes place in two step reaction chain, where pyrolysis process occurs before the gasification process (Figure 2).

2.2.1 Process Zones

Four distinct processes take place in a gasifier as the fuel makes its way to gasification. They are:

a) Drying of fuel

b) Pyrolysis – a process in which tar and other volatiles are driven off

c) Combustion

d) Reduction

Though there is a considerable overlap of the processes, each can be assumed to occupy a separate zone where fundamentally different chemical and thermal reactions take place.

2.2.2 Pyrolysis zone

Wood pyrolysis is an intricate process that is still not completely understood. The products depend upon temperature, pressure, residence time and heat losses. However following general remarks can be made about them.

Up to the temperature of 200^0C only water is driven off. Between 200 to 280^0C carbon dioxide, acetic acid and water are given off. The real pyrolysis, which takes place between 280 to 500^0C, produces large quantities of tar and gases containing carbon dioxide. Besides light tars, some methyl alcohol is also formed. Between 500 to 700^0C the gas production is small and contains hydrogen.

Thus it is easy to see that updraft gasifier will produce much more tar than downdraft one. In downdraft gasifier the tars have to go through combustion and reduction zone and are partially broken down. Since majority of fuels like wood and biomass residue do have large quantities of tar, downdraft gasifier is preferred over others. Indeed majority of gasifiers, both in World War II and presently are of downdraft type.

Finally in the drying zone the main process is of drying of wood. Wood entering the gasifier has moisture content of 10-30%. Various experiments on different gasifiers in different conditions have shown that on an average the condensate formed is 6-10% of the weight of gasified wood. Some organic acids also come out during the drying process. These acids give rise to corrosion of gasifiers [6].

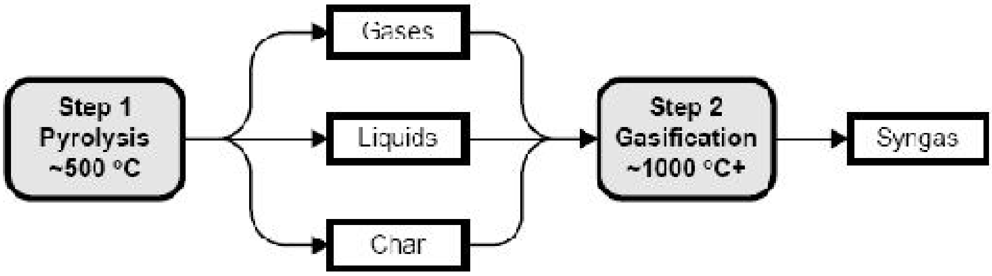

Figure 2: Gasification Steps

During step one the fuel is heated and pyrolysis process occurs, heating has an effect as decomposition of the biomass. This reaction, also known as devolatilization, is endothermic and produces 75 to 90% volatile materials in the form of gaseous and liquid hydrocarbons. "The remaining nonvolatile material, containing high carbon content, is referred to as char."

During gasification reaction the volatile hydrocarbons and char are converted to a syngas. The most important reactions have been involved during the two-step process which is divided into two groups: exothermic and endothermic reactions.

Exothermic Reactions:

1. Combustion {biomass volatiles/char} + $O_2 = CO_2$
2. Partial Oxidation { biomass volatiles/char} + O_2 = CO
3. Methane creation { biomass volatiles/char} + $H_2 + CH_4$
4. Water-gas Shift CO +$H_2O = CO_2 + H_2$
5. CO Methanation CO +$3H_2 = CH_4 + H_2O$

Endothermic Reactions:

6. Steam-Carbon reaction { biomass volatiles/char} + H_2O = CO + H_2
7. Bouduard reaction { biomass volatiles/char} + CO_2 = 2CO

Heat can be supplied directly or indirectly to satisfy the requirements of the endothermic reactions.

Gasification can be called "directly heated gasification" if the pyrolysis and gasification reactions occur in a single vessel. As one can see the part of biomass is burnt when getting an oxidant, air or oxygen to the fuel. (Reactions 1 & 2)

Thus, these reactions provide the heat required for the endothermic reactions. In order to increase the temperature of the reaction and to vaporize its products, pyrolysis requires from 5 to 15% of the heat as a supply from the combustion process. In direct heated gasification systems, an oxidant feed rate is responsible for the temperature inside the reactor. Generally when oxidation process uses air as the oxidant, heating value of the product gas decreases from 4 to 5 MJ/m3 (107-134 Btu/ft3) because of the nitrogen dilution. This method of gasification is used in the Gas Technology Institute (GTI) and the Syngas gasifiers.

Indirectly heated gasification technology is used in the BCL/FERCO gasifier. The main idea of its work is utilization of hot particles from bed (sand), where steam has been a matter to fluidize it. To separate solids (sand and char) from producer gas can be possible using a cyclone and later solids are transported to a second fluidized bed reactor. Stream of blown air is required in the second reactor as a second bed which is also working as a char combustor, creating a flue gas exhaust stream and a stream of hot particles. And finally flue gas is separated from the hot (sand) particles in order to transfer their heat energy to the gasifier (recirculation) to provide the heat required for pyrolysis. This approach is a good mean to achieve practically nitrogen free product gas as well as higher heating value of 15 MJ/m^3 (403 Btu/ft^3). One can notice that the combustion Reaction 1 is separated from the remaining gasification reactions in this case. “Reaction 2 is suppressed with almost all oxygen for the syngas originating in the feedstock or from steam (Reaction 6) [2].”

2.3 Detailed description of biomass gasification

The pressure is about the atmospheric one when indirect gasification system is used. On the contrary, direct gasification system is able to operate at both raised and atmospheric pressures.

It is considered that each gasifier type could be used in many practical applications. As mentioned in previous chapter, direct gasification produces syngas with a relatively low heating value (5.6-7.5 MJ/Nm^3) because of the diluent effect of the nitrogen in air. If gas turbine is used to generate energy with such a syngas from the direct gasification process, the fuel demand will be increased. "Consequently, in order to maintain the total (fuel + air) mass flow through the turbine within design limits, an air bleed is usually taken from the gas turbine compressor and used in the gasifier." The operational pressure of the direct gasifier is responsible for effects such as an insignificant pressure rising or pressure expansion up to atmospheric one. But the main reason of these pressure changes is bleed air so that it is connected quite closely to operational pressure [14].

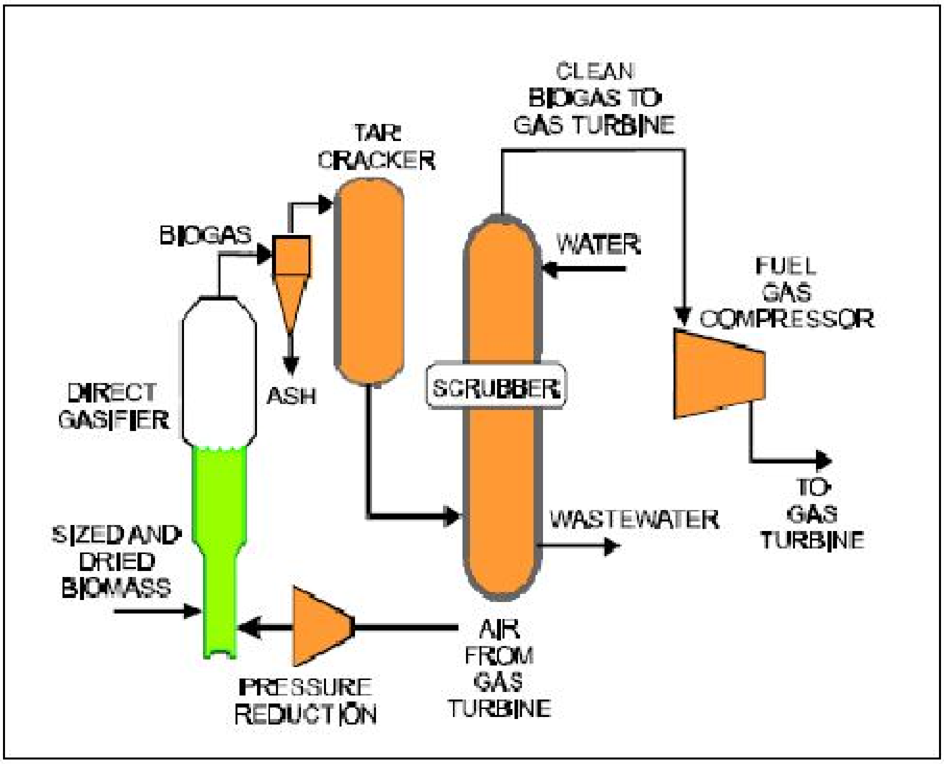

Figure 3: Low-pressure direct gasifier

The example of nitrogen diluent free syngas is indirect gasifier due to the separation of reactions taking place in different vessels. Therefore the product gas is of a medium heating value (13-18.7 MJ/Nm^3). This figure shows an advantage of indirect gasification since it is quite close to the natural gas heating value which is about 38 MJ/Nm^3. Owing to this, syngas from indirect gasifier can be used to drive a regular gas turbine without bleed air.

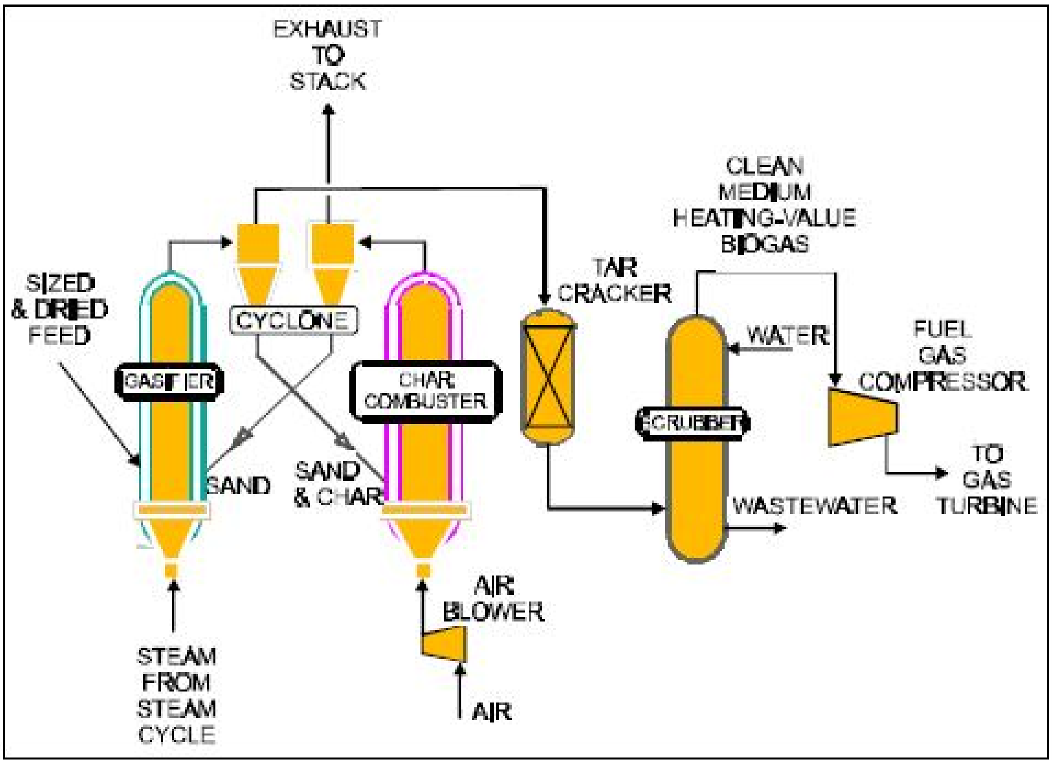

Figure 4: Indirect gasifier

“Gasifier operating pressure affects not only equipment cost and size, but also the interfaces to the rest of the power plant including the necessary cleanup systems.” Besides, gas turbine has to be supplied by high pressure gas thus in order to increase the pressure of syngas, which is quite low, compressor units have to be equipped. This promotes low temperature gas cleaning because the compression implies gas cooling before the entrance into compressor.

To recycle air in order to feed low pressure gasifier it has to be extracted from the gas turbine and reduced in pressure if direct gasification is considered or supplied independently (indirect gasifier). Pressurized cleaning of the syngas at high temperature is result of gasification process at high pressure. The temperature of gas input in the gas turbine combustor is quite high 538?C or 1,000?F. Thus gasification at high pressure provides efficient and effective flow and pressure drop control in combustor.

By condensing, cleaning and compressing producer gas the overall efficiency of indirect gasification is reduced up to 10 %. Another reason of efficiency drop is installation of new equipment for these processes. It has been estimated that electricity cost changes when applying high pressure gasification instead of low one.

One study has examined a 75 MW power plant which has an alfalfa stems feedstock for the gasification purpose. The final product is electricity energy to provide it to the Northern States Power Company while leaf, as a by-product of manufacture, has to be sold for animal feed. Another feedstock is wood biomass which can represent plant from the generic side of view. Addition processes such as alfalfa separation and leaf meal processing could effect on plant complexity, its cost and difficulty of economic analysis.

The pre-treatment of biomass feedstock is wood chips supply at the plant where it has to be screened and hogged in order to achieve a proper size consistency. Then obtained mass is dried in a rotary drum dryer. Next stage of the process is comparatively dry wood conveying to storage silos located near the gasifier building. After the storing process the weighing occurs and then transportation to a screw conveyor in order to feed the biomass into the fluidized bed gasifier. “A dolomite feed system is also provided to maintain the inventory of inert material in the bed.” The temperature of biomass gasification process is mostly ranging from 843?C (1550?F) to 954?C (1750?F). One of the gasifying medium is air which is primary going through the gas turbine and its compression section and then from the boost compressor line air is fed into the gasifier. Another gasifying medium is steam extracted from the steam cycle. The gasifier has a vessel form and intensive circulation of the fuel occurs inside the gasifier and gasifying medium resulting in a gasification chemical reactions and improvement in char cracking.

Producer gas is extracted from the gasifier for cooling or temperature reduction process so that gas is cooled up to approximately 538?C. Furthermore conditioning protects a fuel flow control valve and creates vapor-phase alkali species in the syngas by condensing on the fine particles exiting gasifier. These chemicals species in turn might cause turbine damage. To prevent turbine failure the concentration of combined particulate matter and alkali species must be reduced to the level when it is no longer dangerous in a Westinghouse hot ceramic candle filter unit.

The sulfur content of wood biomass is quite low hence it is not required to eliminate this matter before the gas turbine. “Hot cleanup of the fuel gas also minimizes waste water generation from this step of gas processing.” The fuel gas operates in a Westinghouse "ECONOPAC" 251B12 gas turbine to produce electric power and a high temperature exhaust stream. Exhaust stream is then can be recovered in heat recovery steam generator (HRSG). Lastly, produced steam at quite high parameters is used in steam turbine cycle generating electric power and heat for district heating application.

As mentioned earlier, this system generates 75 MW of total net electricity output. After all, it is considered that many gasifier architectures can be used for energy production goals. Combination of gasification unit with gas turbine and heat recovery boiler with steam cycle might be very profitable decision for some company. Moreover overall cycle efficiency is increased due to the thermal and chemical energy recovering from the fuel to the power generation units. “Combined cycles, with their high efficiency and low emission characteristics, are a prime choice for biomass gasification systems [15].”

2.4 Electricity production

The electricity supply system base on biomass fuel can no longer be neglected and it tends to progress in future. Pulp and paper manufacture and sugar cane industries require a system to recover its by-products and it has been considered that gasification cycle with gas turbine is applicable for this aim. Many pulp and paper facilities in U.S. which is approximately 70% of their power houses have to be replaced in the near future. It has been assumed that these units power is more than 30% of the world's capacity. Not only pulp and paper industry is involved but also sugarcane industry."Repowering these plants with modern, efficient, gas turbine technology will substantially improve efficiency, reduce emissions, and provide additional electrical power that can offset purchases or be exported to the surrounding area." Recent research has been aimed to select and study a diversity of options for plant rebuilding and established BGCC to be the most economically attractive one. Since the most part of sugar plants are located in the developing

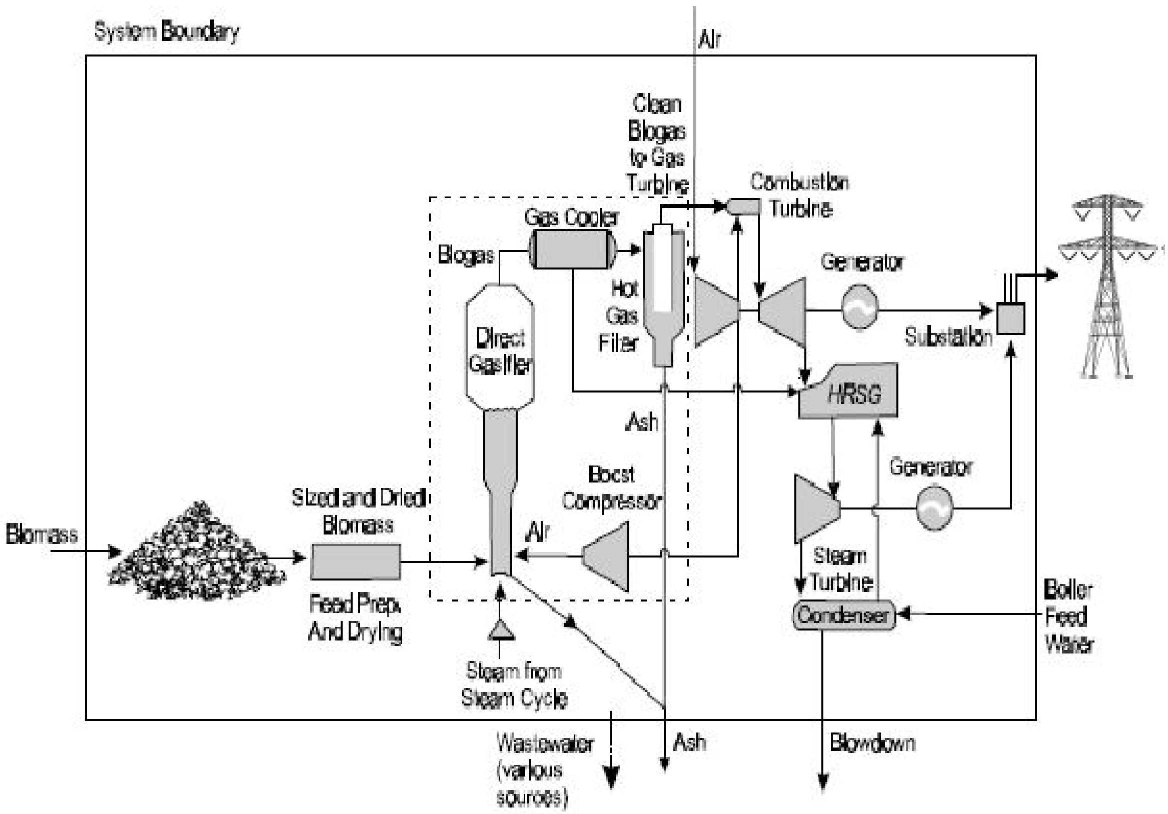

Figure 5: Biomass gasification combined cycle (BGCC) system schematic

countries where the demand for electricity energy is quite large, implementation of BGCC might result in power expansion in these countries and thus solve the problem [16].

In this case it is important to make a development not only in small scale turbine but also to involve cogeneration and industrial power markets.

The Overview of Biomass Technologies gives comprehensive look at power capacity generated by wood biomass usage which is roughly about 7 GW of energy in the U.S. This is to say that it is almost 50 % of all energy generation from biomass fuel. “In comparison, coal-fired electric units account for 297 GW of capacity, or about 43% of total generating capacity.” Back to the 1994, U.S. biomass demand was about 3 EJ which is approximately 3.2% of the 94 EJ of total primary energy consumption [17]. In addition electrical energy produced from biomass represents about 1% of the total U.S. demand. Taking into account efficiency of BGCC (about 35 to 40 %) compare to efficiency from regular biomass system (about 20 %) it is clear that BGCC would produce two times more electrical energy.

“Biomass-to-electricity systems based on gasification have a number of potential advantages.” For instance process efficiencies considerably transcend direct combustion systems that are currently usable. It has to be mentioned that efficiency of power plant based on coal as a fuel can be equal to biomass gasification cycle efficiency. Moreover it can be reached at a smaller scale of operation. The gasification based system, as well as other biomass based technologies, is a great help in climate change combating and reduction of CO_2 emissions per MW of power generated due to their high efficiency. Biomass, in comparison with coal, contains less sulfur. In general sulfur content of biomass is from 0.05 to 0.20 weight % sulfur on a dry basis and besides biomass heating value is quite high (about 29.8 MJ/kg). To sum up biomass sulfur content and NOx content can be estimated as tolerant for limit set in the current New Source Performance Standards (NSPS) which is in translation for sulfur would be twice higher than 51 to 214 mg SO_2 /MJ of sulfur in biomass(0.12 to 0.50 lb SO /MBtu)[18].

It is probable that future efficiency of gasification and fuel cell systems will be improved up to 50% including small scale operation. Furthermore the more developed gasifier systems the larger application and beneficial area for other industries such as chemical (syngas production) [19].

3 GASIFICATION PROCESSES AND EQUIPMENT

The conversion of an organically derived, carbonaceous feedstock into a gaseous product, synthesis gas or “syngas,” by being under the special conditions with partial oxidation is so called biomass gasification process. The main components of gasification are hydrogen (H_2) and carbon monoxide (CO), with lesser amounts of carbon dioxide (CO_2), water (H_2O), methane (CH_4), higher hydrocarbons (C_2+), and nitrogen (N_2). It has been evaluated that to provide gasification reactions, temperatures must be around 500-1400^{o}C, and atmospheric or elevated pressures up to 33 bar (480 psia). There are some options of the oxidants as follows: air, pure oxygen, steam or a mixture of these gases. Disadvantage of the air-based gasifiers is generation of a product gas with a relatively high content of nitrogen and low heating value between 4 and 6 MJ/m_3 (107-161 Btu/ft^3). In contrast, product gas of the oxygen and steam-based gasifiers contents a relatively high concentration of hydrogen and CO with a heating value between 10 and 20 MJ/m^3 (268-537 Btu/ft^3) [2].

3.1 Moving or Fixed bed gasifiers

"The moving bed (also called fixed bed) gasifiers have been in use for the longest time and therefore use the oldest technology." Quite simple and robust construction gives a big advantage to this technology. Since the bed is fixed, the design in normally very simple. However a disadvantage occurs when considering about expansion of the plant because the plant size is limited to about 10 – 15 tons of dry biomass per hour (t DS/h). Another problem is up-scaling limit because of the fixed bed technology. In other words the difficulties with uniform temperature distribution is a big disadvantage since it is quite problematic to achieve a large fuel bed – the larger the bed, the larger the temperature differences. As a result of this problem, many inhomogeneous processes suffering from process control difficulties and syngas quality. The observation of many different fixed bed gasifiers is presented on the table 2 below.

Table 2: Status of fixed bed gasifiers for power production (June 2004) [7]

Location	System, supplier	Power MW_e	Status
Harboore, Denmark	Babcock & Wilcox, Volund updraft, CHP with gascleaning and 2 gas engines	1.5	Commercial
Seco-Bois, Belgium	Xylowatt sa, downdraft CHP	0.6	Under commissioning
Gedinne, Belgium	Xylowatt sa, downdraft CHP, wood chips	0.6	Under commissioning
Greasted, Denmark	BioSynergi, open core, wood chips	0.075	Under commissioning
Viking gasifier, DTU, Denmark	2-stage developed at DTU used for long-term testing	0.017	Operational since June 2002, scaling-up foreseen
Austria	Grübl, wood gasifiers	0.05	Two in operation at farms
Londonderry, Northern Ireland	Rural Generation, downdraft on farm, runs partially on energy crops	0.1	In operation, 16.000 hrs operating
Blackwater Valley Museum, N-Ireland	Exus Energy, downdraft on farm, runs partially on energy crops	0.2	In operation, 1.000 hrs operating
Ballymena ECOS	Biomass Engineering, downdraft	0.075	In operation, 2.500 hrs
Spiez, Switzerland	Pyroforce gasifier	0.2	Operational since 2002
Bulle, Switzerland	Xylowatt, open-top	0.2	Operational since June
Beddington Zed, UK	Exus Energy, downdraft	0.13	Under commissioning
Legnano, Italy	CCT, downdraft and updraft	0.5	Under commissioning
Rossano, Italy	PRM, updraft, olive pits	4.5	Under commissioning

The power of all plants listed is not higher than 1.5 MW Denmark's power plant with updraft technology. And the minimum power value of the plant is Viking gasifier, Denmark. All advantages and disadvantages of this type of gasifiers are described detailed in the next chapter.

3.1.1 Updraft Gasifiers. Counter current or up-draft gasifiers

The most popular and suitable applications for updraft gasifiers are mostly heat applications at capacities below 10 MWt. This is result of relatively low temperatures of flue gas leaving gasifier so that the process efficiency is increased and that fact allows gasifying biomass with moisture content up till 50 %, in addition makes it possible to avoid drying of the feedstock. That brings a great heat economy and some other benefits. Furthermore, almost all size of the fuel are suitable for this type of gasifiers, thereby it diversifies biomass feedstock. But extensive generation of such by-product as tar is not the best side of up-draft gasifiers. On the other hand this problem is not perturbing the operational cycle for heat applications while the blocking of pipes does not occur. Even though it can be overcame if cleaning of pipes is carrying out. Finally, it makes this gasifier not a likely candidate for power applications due to quite high expenses connected with cleaning of the tar inside the tube. Taking into account this factor all manufacturers are working in this way to overcome these problems and become successful on the market.

The Bioneer Company has reached very impressive results in that field in the beginning of 1980 which could be possible only owing to one of the most successful fixed bed gasifiers in the market - counter-current gasifier (figure 6) based on the classical design. The aim of this gasifier is district heating applications. Accumulation of many experiences with Bioneer gasifier allows performing a data for this system, see Table 3.

Table 3: Performance and cost data of Bioneer gasification heating plants, from Wilen and Kurkela, 1995

Average performance	
Operation time	8000 h/a
Availability	95-97 %
Personnel (heating plant in total)	3 – 4
Heat generation	
Specific investment costs	350 kECU/MW
Specific operation costs	17 ECU/MWh
Specific heat generation costs	20 ECU/MWh

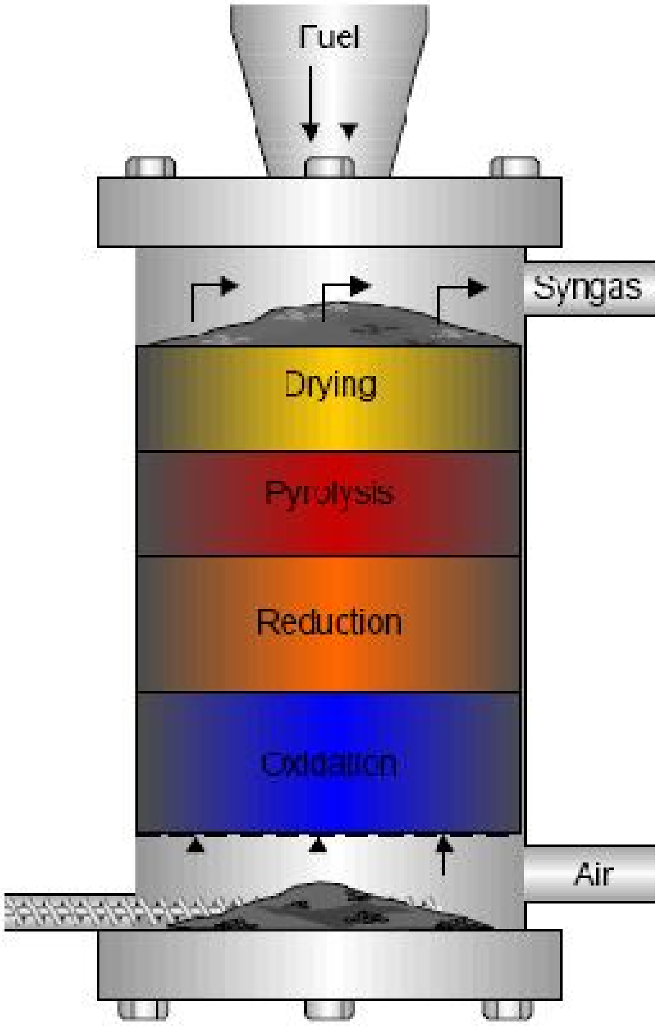

Figure 6: Typical updraft gasifier

The data show a high reliability, a high degree of utilization, high efficiency, even at part load (85 - 90%), low specific emissions, small need of flue gas cleaning and feedstock flexibility within the same plant.

There is a data that Voland (Denmark) developed a counter current gasifier and implemented a plant with a power of around 4 MWt. The plant was intended for district heating in Harboore, Denmark. This plant has had an innovative technology including secondary gasification. The main idea of that secondary unit is to reduce the tar content by adding an extra air at the top of the gasifier. Thus lower tar content is preventing the pipes from blocking happening on the way to burner. “As the gasifier is over-designed Voland plans to install a gas cleaning facility followed by an engine to start production of an additional 1.2 MW of electricity (Stoholm 1996).”

This will be a real conquer the field if system is technically successful and economically viable. Also straw gasification facility is observed in a similar plant in Kynd. But it tends to have a big barrier because of the frequent disturbances of the very thin high temperature oxidation layer.

A new countercurrent updraft gasifier is developed by Kvaerner in Norway, where the fuel for the process can be either waste or biomass. It is very probable that sintering difficulties serve as problem for gasification due to the high ash content of waste materials. The gas cleaning system is based on secondary air injection in the product gas. As a consequence, one can observe an increase of temperature up to 1100 °C which occurs in a secondary chamber. Finally, air injection is the reason of a good mixing efficiency; however the total efficiency of the process might be suffered because of that.

The developing of biomass gasifiers has not left without attention UK Company which has been working under up-draft coal gasifiers' production for the most part of this century but one can expect new biomass gasifiers soon. Furthermore, company is working on the gas cleaning system testing at the 100 kg/h pilot plant and plan to combine the unit to a gas engine.

Daneco SpA has built an RDF updraft gasification plant for electricity production (0.6 MWe) in Italy. The gas is cleaned by pre-heated air in a partial oxidation unit influencing on an efficiency of the system. "A conventional wet scrubber, optionally followed by an active carbon filter precedes the combustion of the gas in a diesel dual fuel engine." A variety of feedstock has been gasified such as RDF pellets, wood chips and briquettes of petroleum bottles. It is evident that electricity price is depending on efficiency, thus the electricity price of 0.16 ECU/kWh is a consequence of the overall biomass to electricity energy efficiency (which is quite low 20%). Nevertheless this company plans to improve their efficiency level to 30 % and become a successful on the Italian electricity market as well [5].

Technology description:

The gasifier represents a cylinder with a several process zones depending on arrangement of fuel feeding and air income (Figure 2). In that type of gasifier the fuel is supplying at the top and the direction of its moving is downstream. Air incomes at the bottom of the gasifier, secondly comes through the fuel bed and moves upwards. The complete combustion process is introduced at the bottom of the bed, where the temperature is about 1000°C. This zone is so called oxidation zone and includes formation of CO_2 and H_2O. “The hot gases then pass through the reduction zone where they are reduced to H_2 and CO and cooled to 750°C.”

Next the pyrolysis process takes place at the same time wet downstream biomass forms quite big amount of tar and other products of incomplete gasification (PIG). Lastly hot gases are mean to dry incoming wet biomass and then come out from the reactor at relatively low temperature ~500°C.

Advantages:

The product gas presents a high heating value content which is possible only due to the arrangement and direction of the gasification agent (air), firstly passing the oxidation zone and then other zones. In addition the design of the gasifier is not complex. And finally, there is no need to reduce or to pretreat biomass because the size and properties such as moisture is not of a big matter.

Disadvantages:

The process does not result in a high quality of the syngas. The reason of low quality is that the syngas passes the pyrolysis and drying zone at the end thus it is quite difficult to eliminate the tar content (10-20% tar by weight) in the syngas. Furthermore, the blocking might occur because of the high temperature near the reactor grate which is the reason of ash fusion. Since the process is not homogeneous and complicated, it causes the process control problems.

3.1.2 Downdraft Gasifiers

An advantage of down-draft gasifiers is relatively low tar content thus it makes these gasifiers to be the most attractive for small scale power generation from biomass. The tar problems might have been even though the tar is more stable compare to up-draft gasifiers. Besides, to operate properly requires for more specific fuel dimensions and properties such as size of particles which is typically 5x7x10 cm for Chevet gasifiers and moisture content (typically 20 Wt % db). The classical design of down draft gasifier might have a difficulty with scale-up production due to its throat construction. “Even with special designs, such as a rotating cone in the throat to increase its efficiency, its maximum size, probably is limited to about 1 MWe.”

Down-draft gasifiers were installed in many developing countries as a basis for hundreds of electricity producing plants in the eighties. “Often these systems were imported from Europe and financed by either national European or international development agencies.” Some of the units have been outfitted with wet gas cleaning system and used a diesel engine to drive a generator of typically 20-100 kWe capacity. It has been establishes that operational properties were not successful but if the exceptional circumstances took place these units would exhibit a satisfactory performance. “Even if the concepts were technically sound many non-technical causes for a complete or partial failure occurred (Corte, 1995)”. Even fact that the plants have shown an operational stable units in developing countries could not build an implementation of them in industrialized countries. Environmental standards have had a big effect on these units application in industrialized world because it seems to be uneconomical feasible case. As a consequence, implementation of down-draft small scale combined heat and power plants is still unprofitable. On the other hand one German company (Wamsler Umwelttechnik GmbH) has made a big step in development of down-draft gasifiers’ technology and has been quite successful in their implementation. There have been created 3 installations with capacities ranging from 600 to 1500 kWt in Germany (1994), when 5 units are planning to be built with 1.5 to 11 MWt power output. These 5 future units will be equipped with different fuel supply options such as wood, plastics and textiles.

The Wamsler Company has used wet gas cleaning system and in addition, gas engine working on the gas fuel with 200 kWe energy output. Even so, there is no data about units working for heat and power generation purpose which have made a commercial implementation.

“Wamsler’s success in implementing gasifiers could not prevent its recent bankruptcy.” Umweltengineering Hugo Petersen Company has offered this technology in Wiesbaden.

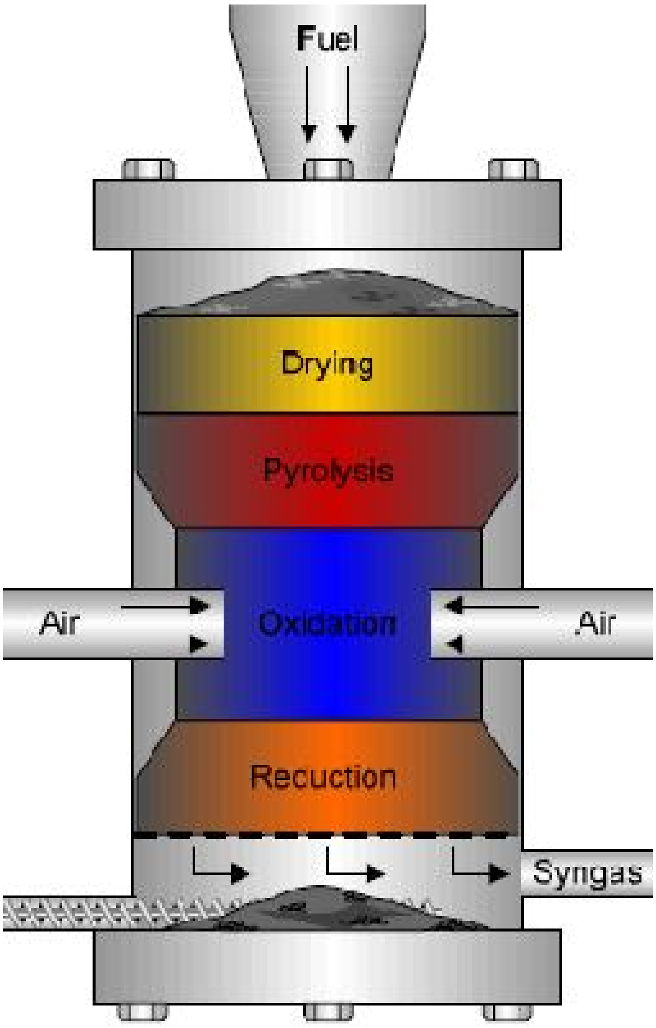

Figure 7: Typical downdraft gasifier

As mentioned above, the most important factor effecting on tar content reduction is well-balanced throat design of the down-draft gasifier. “The air is introduced just above the throat which creates the high temperatures above 1000 °C typical for the combustion zone.” Here the crucial role is playing a well-designed throat which creates a uniform temperature over the whole cross section of the throat. This temperature is good enough to provide a complete size reduction of all tar passing through the throat. It has to be taken into account when designing the gasifier that its relatively big dimensions could be also one of the reasons to form cold areas inside the unit, which is resulting in high tar content in the syngas. The researchers of Twenty University have invented a circumferential type of throat to cope with this problem in early 1979. By adding a rotating cone in the center of the unit the problem with low temperatures was overcome, in other words it means that the only area of a narrowed size is in the center which can guarantee tar cracking while the total dimensions of the gasifier is still quite large, see Figure 7. One of the developing so-called HTVJuch gasifier in Switzerland has been created by using this technology. Furthermore, MHB Multifunktionelle Heiz- und Bausysteme GmbH, Furstenwalde are involved in upscale production of a traditional down-draft gasifier (from Fluidyne (NZ) up to 750 kg/hr (3.3 MWt). It seems to be a biggest down-draft gasifier by now, however this fact does not inform about all available and possible implementations. [5]

Technology description:

The point of the fuel feed is at the top of gasifier and the gasifying medium is introduced into a downward flowing packed bed. The syngas is coming out from the bottom. It can be noticed that this gasifier contains relatively distinct oxidation, reduction, pyrolysis and drying zones. The level of tar is quite low in comparison to updraft gasifier system due to the thermal cracking of the tar in high temperature area, so called combustion zone. “In practice however this is hard to achieve since the tar may slip through the “cold” parts of the combustion zone without conversion, see Figure 3.” Since the large amount of produced energy is converted into heat, the heating value is relatively low.

Advantages:

Regardless of the fact that all units are based on quite simple and inexpensive design the quality attribute of a syngas is quite good whereas tar level is low. Up to 99.9% of the formed tar is consumed minimizing tar cleanup. There is no need for cyclone installation due to minerals remaining with the char/ash. Finally the design is proven and allows producing the final gas with low process expenses.

Disadvantages:

Since the large part of the fuel is oxidized the syngas contains relatively high levels of CO_2 resulting in a low heating value. Another quite annoying drawback is that the ash fusion might occur in the reactor grill causing blocking. In contrast to updraft gasification concept the overall efficiency of downdraft gasifiers is lower and such fuel properties as size, shape and low moisture content of biomass particles have to be taken into account and restricted within close limits. Another disadvantage with this system is that a large portion of the energy is converted into heat with a low heating value of the syngas as a result. The carbon is not completely converted into the energy with 4-7% of remains. As well as updraft gasifiers, this system is not able to be optimized because of the complex and inhomogeneous nature of the process.

Table 4: Typical downdraft gasifier data

Fuel types	Wood pellet and woodchips in controlled within close limits. Low moisture content.
Scale up limit, dry feed (t/h)	<15
Heating Value (MJ/Nm^3)	(air)
Typical gas composition (% volume)	Not of Interest
Tar content of dry syngas (mg/Nm^3)	500 – 1000
Gasification agent	Air, in some cases also steam is used
Operating pressures (OP, bar)	Mainly Atmospheric
Operating temperatures (°C)	300-1000

3.1.3 Cross-draft Gasifier

Cross-draft gasifiers are normally of a small scale (about 10 kWe) where used fuel has been char coal but their application has been found as shaft power generation for only developing countries. Since the opportunity to scale-up this system without special innovations is quite difficult, it was striking to find out that one German company (VER GmbH, Dresden) is planning to implement cross-draft gasifiers for wood and waste as a fuel. The company has invented and tested an installation with burning equipment. The capacity is about 20 kg biomass/hr. It is probable that VER Company will obtain the same tar content for their unit as it could be in updraft technology and updated results with char burning as for the down-draft gasifiers.

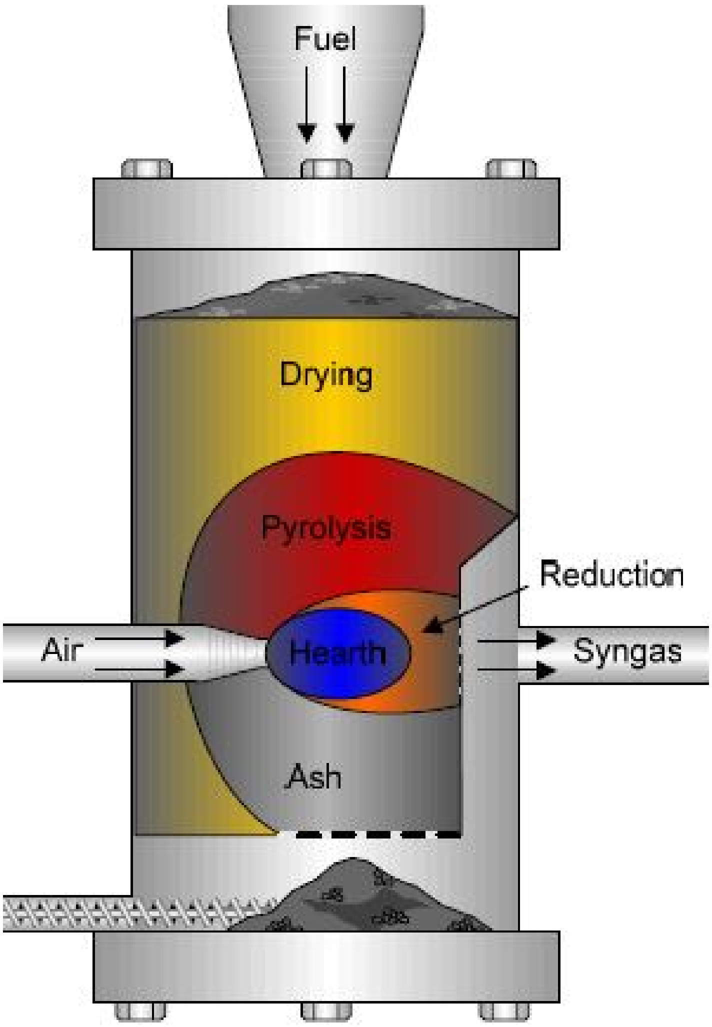

Figure 8: Typical cross-draft gasifier

This technology provides quite diverse options for wood fuels and the dimensions of fuel particle are presented as 1 to 6 cm, if consider that the size is spherical. Thus further development of such system presents quite big interest as an innovative concept [5]

Technology description:

Fuel is supplied at the top of the throat thus gasifying medium is fed from the left side and then coming through the fuel (Figure 4). In spite of drawing from the bottom as it has been mentioned in downdraft gasifiers, the syngas output is introduced from the opposite side of medium input point. It can be noticed that cross-draft gasifiers respond as very similar compare to downdraft gasifiers. For instance, the mixtures of air and steam are introduced from the same side while oxidation and drying zones are presented around the center.

Advantages:

The design of this gasifier type is simple which is in most cases with fixed bed type of gasifiers. Cross-draft gasifiers are working quite well at load changes and the producer syngas suitable for a number of applications.

Disadvantages:

The cross-draft gasifiers require a very sensitive to fuel dimensions and mostly, quality of syngas is relatively low. Another drawback is high tar content and large heat losses due to very high output temperature of producer gas.

Table 5: Typical cross-draft gasifier data

Fuel types	Wood pellet and woodchips in controlled within close limits. Low moisture content
Scale up limit, dry feed (t/h)	<1
Heating Value (MJ/Nm^3)	Not of interest here
Typical gas composition (% volume)	Not of interest here
Tar content of dry syngas (mg/Nm^3)	Nearly saturated
Gasification agent	Air
Operating pressures (OP, bar)	Atmospheric
Operating temperatures (°C)	300-1000

3.2 Fluidized Bed Gasifiers - FBG

In seventies, when it was time of the oil crisis the development and inventions in fluidized bed considerably increased. Economical situation after the oil crisis in many countries was responsible for stopping of the research work in that field. However, even during that period power and heat generation industry was concentrated on the implementation of fluidized bed technology so that a big progress has been done to improve its efficiency and readiness for further expansion in gasifying sector.

The medium of fluidized bed is sand particles with dimension around 250 ?m. The most widespread type of the bed is quartz but other suitable and often active bed materials such as dolomite or blast furnace slag could be added to the main stream with reasonable proportions. The sand bed destination is to improve fuel characteristics such as mixing, heat exchange between the fuel particles and reactions improvement. The total efficiency of fluidized gasifier is enhanced by this reason and fuel flow capacity is also magnified. It has been investigated that bed agglomeration happening is one of the main drawback for biomass usage. To reach desirable operational conditions and to avoid bed agglomeration sand must be exchanged periodically.

In general the fluidization agent is air which has a several steps of access to gasifier.

“The primary air is added in the bottom of the bed as fluidizing medium.” The requirement for velocity of the primary air is to reach the minimum fluidizing velocity (MFV) while air occurs to be as the only medium to sand mixing and bubbling has to be avoided. The MFV can be described as boundary between fixed and fluidized bed thereby indicating bed behavior. In other words MFV occurs during leveling between the pressure drop of the sand bed and total pressure of the bed (i.e. the pressure which the bed exerts on the bottom of the combustor). Formation of bubbles is only possible at MFV and “the bed begins to float – this is the Bubbling Fluidized Bed (BFB).” Increased air velocity (over the MFV) effects on the bubbles behavior making it bigger and in some cases it might result in quite intensive eruption on the bed surface. The bed particles tend to be carried away from the furnace when the air velocity is increased; as a consequence bed material could be involved with the outgoing air up through the furnace. It goes without saying that cleaning equipment has to be installed in order to avoid syngas obstruction by sand particles. For this purpose cyclone is introduced at the top of gasifier thus allowing the syngas to leave the unit while the sand is transported back to the bottom so that the sand is recycled. The term of this type of the gasifier is circulating fluidized bed (CFB).

Depending on bed material and fuel composition, ash related problems begin to occur at fairly low temperatures. This fact is a drawback for biomass fuels utilized in fluidized bed gasifiers. Ash melting causes agglomeration of the sand grains in the bed. The agglomeration process might be accelerated by maintaining or rising the same temperature inside the gasifier. It is necessary to put special additives into the bed; otherwise the bed can collapse causing solid material forming at the bottom of gasifier. It is very problematic to eliminate gasifier from this phenomenon. Moreover cleanup is quite difficult and it brings large economical losses. The agglomeration starts at different temperatures depending on kind of fuel used. It goes without saying that the less melting components (as rule alkali metals) in the fuel the higher temperature of agglomeration that is about temperature of ash melting. There are many approaches to be recommended to mitigate with agglomeration phenomenon such as: gasification temperature reduction, proper mixing of sand particles and additives into the bed, for example dolomite. Nevertheless, these measures do not respond to the low price thus it effects on the total energy production price.

“If the gasification agent is air or oxygen, the methane content in the syngas is often relatively low since the reactor also will function as a high-temperature auto-thermal methane reformer.”

3.2.1 Bubbling Fluidized Bed Gasifier - BFBG

Technology description:

The fuel entrance is from the side of gasifier while the gasifying agent is fed from the bottom with kinetic energy of 2-3 m/s causing bubbles forming (Figure 9). There is interdependence between fluidizing agent velocity and dimension of bubbles as well as their speed. Obviously, the higher speed of fluidization medium the better mixing between sand particles and as a result heat exchange between them is enhanced. The syngas is extracted from the top of the gasifier where it is treated from the sand and fly ash particles in the cyclone.

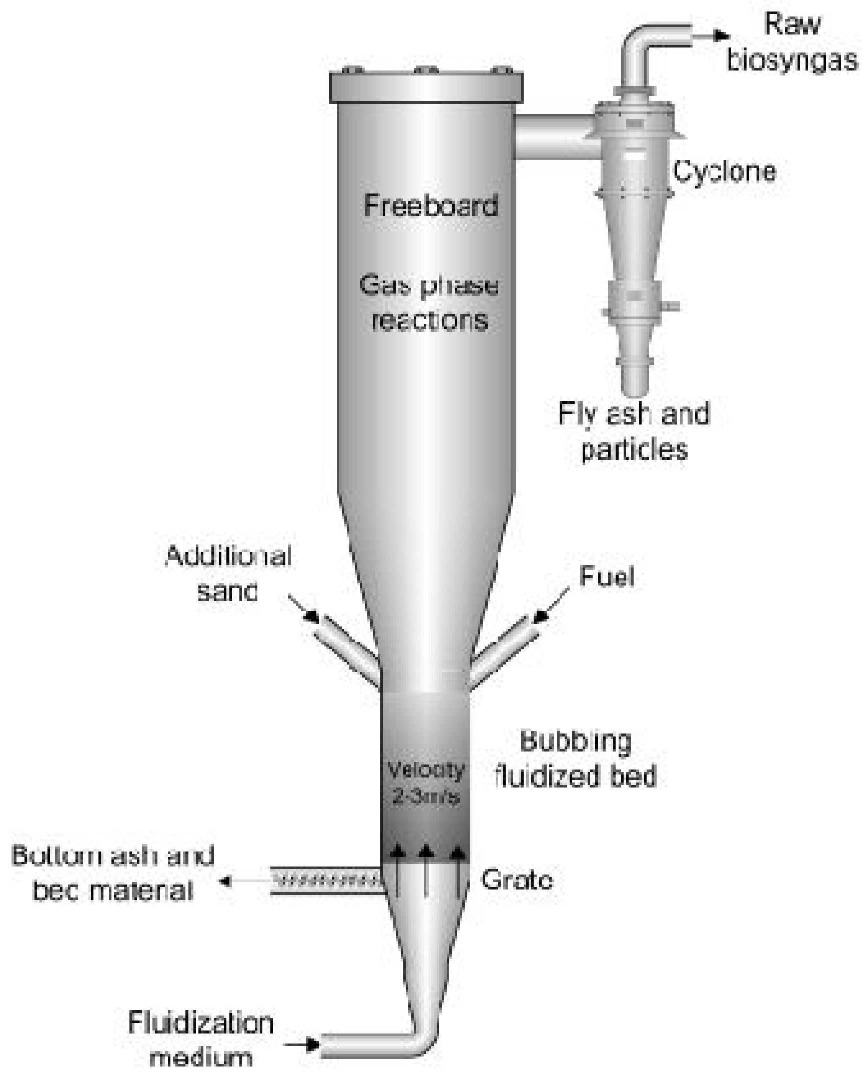

Figure 9: Typical bubbling fluidized bed gasifier

Advantages:

The flow capacity of these gasifiers is considerably higher in contrast to fixed bed reactors. This type of gasifier operates at improved parameters as "good mixing, optimized kinetics, particle/gas contact and heat transfer as well as long residence time". Accordingly the carbon conversion rate is increased, hence high product gas release. Besides, the tar content is quite closely corresponds to previous gasification technologies. "The sand bed makes it possible to use in-bed catalytic processing." Particle size of the fuel, moisture content and unsteady feeding are not crucial factor for bubbling fluidized bed gasification. When considering scale-up margin the only barrier is biomass availability. Since high temperature influences on tar content in producer gas it is suggested to raise temperature level up to 900 - 950°C by improved mixing between fuel and fluidization medium.

Disadvantages:

A big disadvantage of this method is particulate matter appearance such as fly ash and sand particles. Moreover agglomeration of the sand bed can cause many problems as mentioned above. It is probable that too large bubbles might result in bridging that is disturbance of proper mixing and operation.

Table 6: Typical bubbling fluidized bed gasifier data

Fuel types	Wood pellet and woodchips of different size and moisture content
Scale up limit, dry feed (t/h)	5 – 180t/day. No real scale up limit, mostly depending on availability of biomass.
Heating Value (MJ/Nm^3)	4.5-7.9 (air), 4-6 (Air and steam), 5.5-13 (O_2 and steam)
Typical gas composition (% vvolume)	5-26 H_2, 13-27 CO, 12–40 CO_2, 13-56 N_2, <18 H_2O, 3-11 CH_4
Tar content of dry syngas (mg/Nm^3)	13500
Gasification agent	Air/Oxygen/Steam/Mix
Operating pressures (OP, bar)	1 – 35
Operating temperatures (°C)	650 – 950

3.2.2 Circulating Fluidized Bed Gasifier - CFBG

Technology description:

Fuel is supplied in conjunction with sand bed and the fluidization agent is fed from the bottom (Figure 10). The fluidization medium speed is ranging from 5 to 10 m/s. This speed energy of the medium is transferred to sand and fuel particles providing good mixing and heat exchange. Besides it makes syngas with suspended fluidized bed able to pass through the cyclone. In the cyclone entrained particles are separated from the syngas and drop down back into the bed. Syngas is successfully coming out from the top of the cyclone.

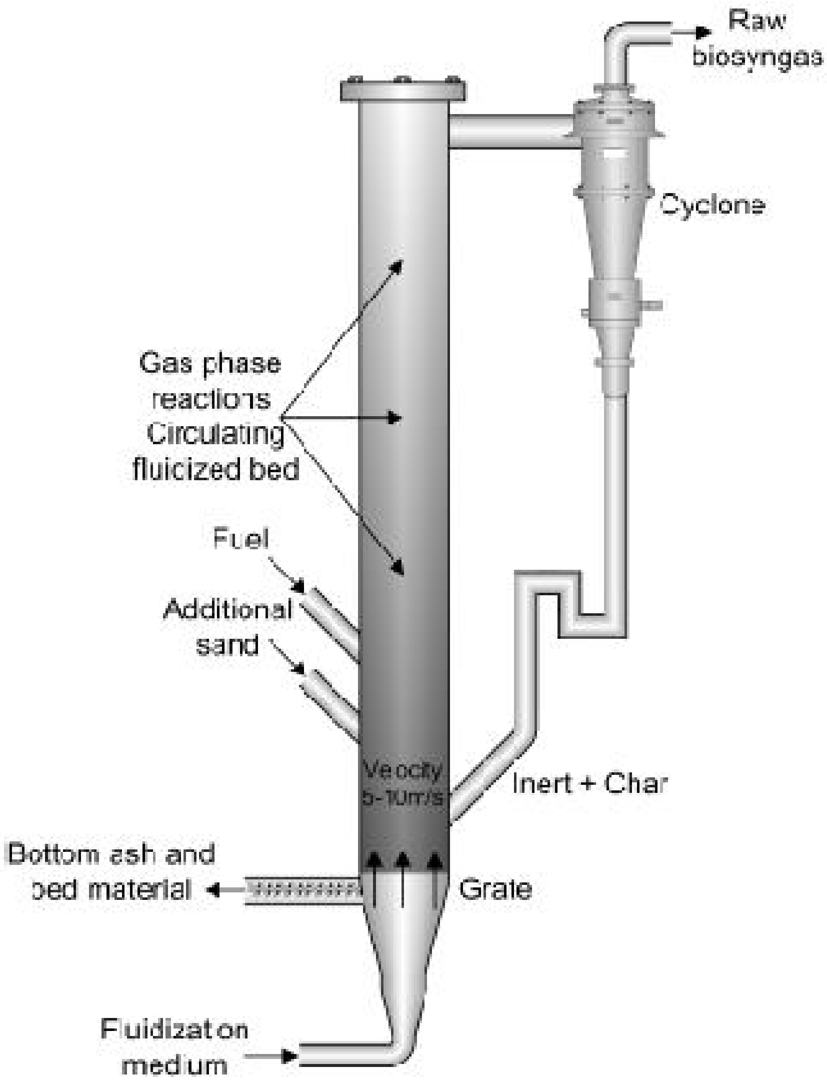

Figure 10: Typical Circulating fluidized bed gasifier

Advantages:

The quality of syngas produced by CFBG and its flow capacity are higher compare to fixed bed gasifiers and BFBG. Good mixing, improved kinetics, particle/gas contact and heat transfer as well as long residence time are advantages of this type. As a result one can expect increase of carbon conversion rates and obtaining relatively high yield of final product. In addition, syngas contains quite small amount of tar but higher than entrained flow gasifiers and downdraft gasifiers tar content. Another benefit is opportunity to utilize in-bed catalytic treatment, owing to the sand bed. Particle size of the fuel, its moisture content and unsteady feeding of gasifier is not a crucial factor for CFBG. When considering scale-up margin the only barrier is biomass availability. Even though, a variety of fuels are suitable for CFBG system.

Disadvantages:

The main disadvantages as high particulate matter content in the syngas, agglomeration appearance in fluidized bed are similar to bubbling fluidized bed gasifier technique. There is interdependence between fuel particles size and transport velocity so that in cases when high velocities occur it is very probable to expect erosion of unit surfaces. Because of the temperature difference in the "direction of the solid flow" the heat exchange can not be reached to the level of bubbling fluidized-bed.

Table 7: Typical Circulating fluidized bed gasifier data

Fuel types	Wood pellet and woodchips of different size and moisture content
Plant size, dry feed (t/h)	10 – 110t/day. No real scale up limit, mostly depending on availability of biomass.
Heating Value (MJ/Nm^3)	4 - 7 (Air)
Typical gas composition (% volume)	7-20 H_2, 9-22 CO, 11-16 CO_2, 46-52 N_2, 10-14 H_2O, <9 CH_4
Tar content of dry syngas (mg/Nm^3)	Low
Gasification agent	Air, oxygen, steam and mixtures
Operating pressures (OP, bar)	1 - 19
Operating temperatures (°C)	800 - 1000

3.2.3 Cratech Gasification System

Cratech plant was built by Western Bioenergy Company in Texas, in 1998 based on implementation of gasification project. The plant is aimed to convert biomass as straw, grass, and shells into power. The pressurized, air-blown fluidized bed gasifier was installed and its capacity is about 1 MW. “Biomass is injected with a biomass pressurization and metering unit.” Cratech project has a complex fuel supply system shown in Figure 11. The unit was equipped with hot gas cleanup system to produced gas treatment purposes. Cleanup system is connected with gas turbine where power generation process takes place. It has been examined that systems efficiency is of a Brayton cycle value that is higher in comparison with Rankine cycle. Figure 11 represents a comprehensive picture of the Cratech process.

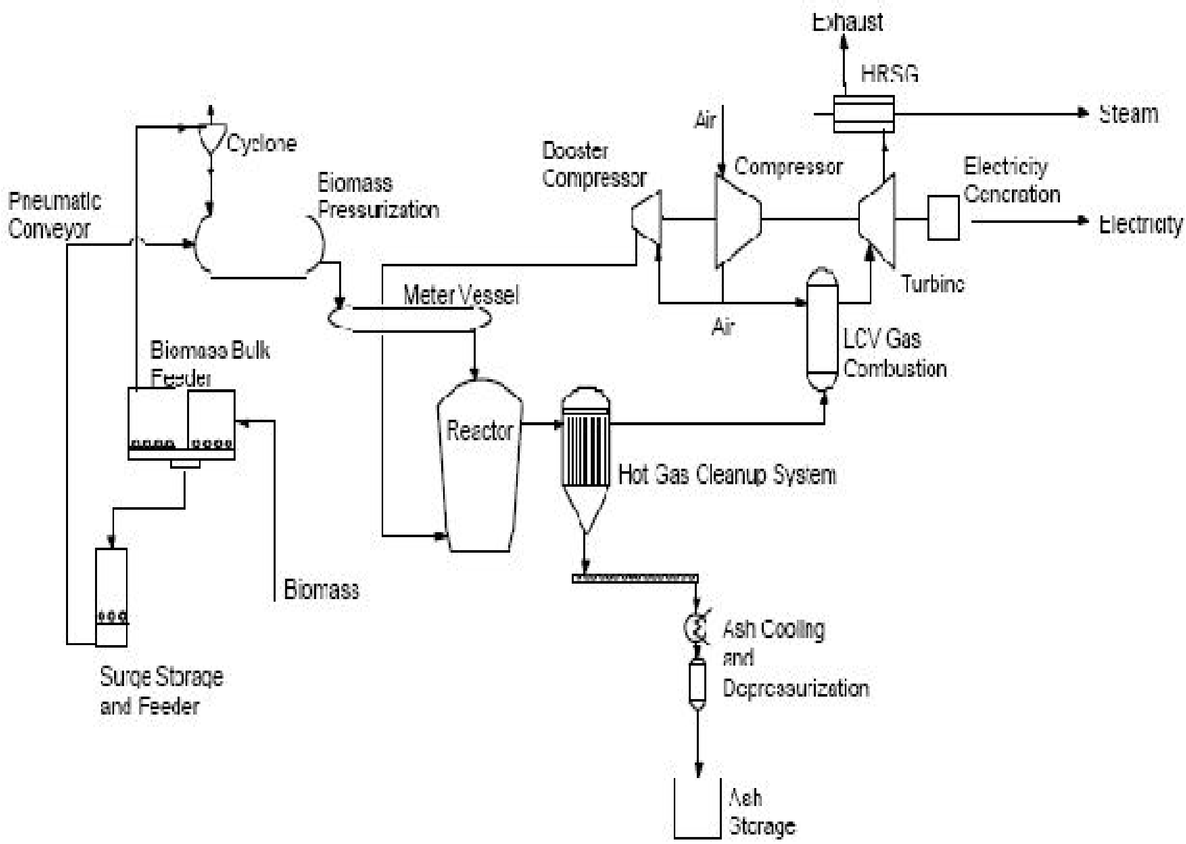

Figure 11: Cratech Gasification System (Purvis and Craig, 1998)

Cratech system has been developed with following parameters: the maximum design pressure is 1,353 kPa (202.8 psi), feed rate of 1,996 kg/h (2.2 ton/h) of wood, temperatures below 730 °C. There is no need in high temperatures to tar cracking before the gasification in this system. In addition wet scrubbers are not installed. The produced gas consists of 10.4% H_2, 3% CH_4, 17% CO, 15.3% CO_2, 41% N_2, 12% H_2O, 1 % C_2H_4, and 0.3% C_2H_6. The power output of the gas turbine is about 1.5 MWe while pressure ratio can be assumed about 11.0 which is maximum value. Finally, the syngas lower heating value is approximately 5.18 MJ/scm [9].

3.3 Entrained Flow Gasifiers

In general, gas, dust and fluid are used as a fuel when considering the entrained flow gasifiers. At first fuel must be mixed with gasifying agent (air or steam) and then injected into the gasifier forming high temperature flame. There are two approaches of pretreatment of the biomass in this process. First method based on the pulverization of the biomass fuel by crashing it in special devises. Another method is based on pyrolysis of biomass thus fuel is converted to gaseous matter. Slurry can be created after pyrolysis process. “If the gasifier operates at very high pressures, alternative operation of pressure locks with a low-bulk-density biomass will become too expensive.” The process efficiency might be reduced at high water content in biomass slurry, because of this factor it is not recommended to pump mixed with water biomass directly to gasifier.

A few Integrated Gasification Combined Cycle (IGCC) plants have been equipped with entrained flow gasifiers where product gas is burned in combination with coal and petroleum coke. The most of plants are tolerant to slurry fuel feeding and “high ash contents”. Generally, temperature of gasification process is about 1200^0C and pressure is about 20 bars. Owing to these operational characteristics, the tar content in producer gas is very low thus cleaning step is not necessary. Furthermore these conditions provide molten slag leaching. Of course entrained flow gasifiers are not perfect, in other words the problem occurs with undesirable heat generation to be utilized which in some cases is problematic.

3.3.1 Entrained Flow – Down Flow Gasifier

Technology description:

The fuel is fed at the top of gasifier where it is mixed with gasifying agent (steam, oxygen) and then reacts forming high temperature (above 1200°C) turbulent flame. The reaction of fuel conversion is very fast (Figure 12). “At these high temperatures, an almost tar-free syngas and a leach-resistant molten slag are produced.” The pressure inside the gasifier is relatively not high. The carbon conversion reaction occur effective due to the suitable pressure value and fuel in form of powder. This type of gasifier contains heat exchanger generating steam and cooling syngas at the same time. Feed water is supplied from the side and exits gasifier at the opposite side where syngas discharge outlet is located. The slag is then removed fro the bottom of the gasifier and utilized in a slam and finally in a lock hopper. “The black water flowing out with the slag is separated and recycled after processing in a dewatering system.”

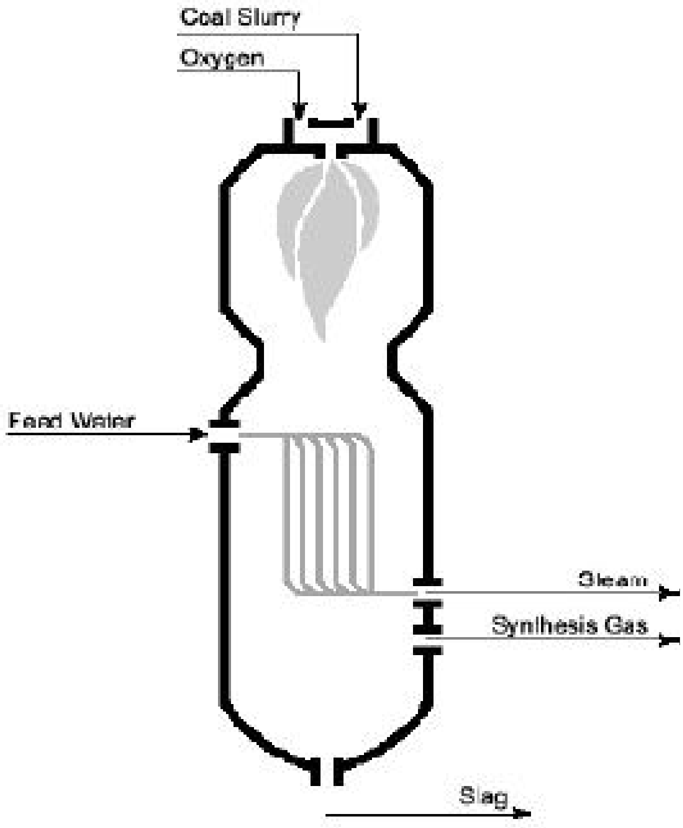

Figure 12: Entrained flow gasifier

Advantages:

As mentioned above high temperature provides favorable circumstances for production of tar free syngas and leach-resistant molten slag.

Disadvantages:

“A high percentage of energy is converted into sensible heat, requiring integration with steam user industry or electricity production, the latter associated with higher costs.” The biomass pretreatment process, such as pulverization, requires a lot of energy thus consumption of this energy causes an extra cost, even so expenses can be minimized by using of dry fuel.

Table 8: Entrained flow gasifier data

Fuel types	Coal powder/ slurry, possible biomass powder/slurry or pyrolysis oil
Plant size, dry feed (t/h)	Up to 700 MWt
Heating Value (MJ/Nm^3)	10.4 (Oxygen and steam)
Typical gas composition (% volume)	31.2 H_2, 62.1 CO, 0.8 CO_2, 31.2 N_2, dry H_2O, low CH_4 (if gasifier operated at high temperature and moderate pressure)
Tar content of dry syngas (mg/Nm^3)	Very low, almost tar free
Gasification agent	Air/Oxygen/Steam/Mix
Operating pressures (OP, bar)	>20 bar to 50 bar
Operating temperatures (°C)	>1200°C

3.3.2 The Chemrec Black Liquor Gasifier

The Chemrec gasifier has been developed by Sweden Company and its design is very similar with regular entrained flow gasifier. There have been demonstrated two different concepts: atmospheric booster and pressurized types of black liquor gasifiers [4].
The gasification reactions take place at moderate pressure and quite high temperature ranging from 950 to 1000^{0}C. Chemrec gasifier technology has been developing from early 1987, it has been tested quite many options to improve its operational characteristic [20].

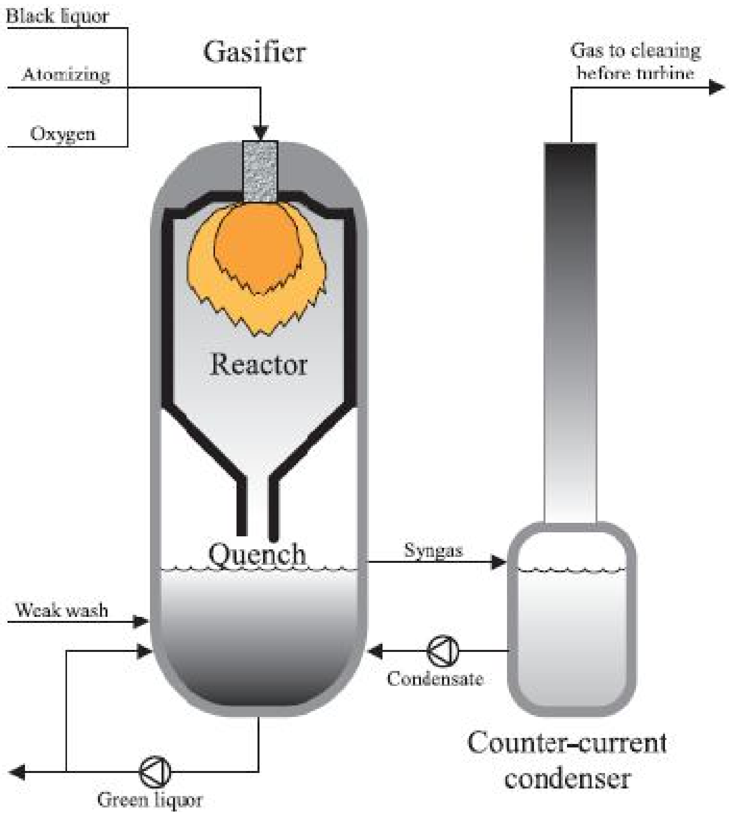

Figure 13: The Chemrec pressurized BL gasifier

Technology description:
The fuel (black liquor) is fed and mixed with steam and air which is preheated before the process up to 500^{0}C (Figure 13). The gasifier operates at high temperature and pressure thus black liquor is gasified inside the reactor. Besides, the temperature depends on air injection velocity, generally with proportion 45 % of stoichiometric air coefficient. By means of steam pulverization process occurs which is of a big importance for proper gasification as well as droplet size. This type of gasifier is

equipped with air burner for heating purpose when starting the operation and with counter-current condenser. “The chemical smelt is recovered from the gas stream at the base of the gasifier by quenching with green/weak liquor.” The green liquor is recovered at the mill. Finally producer gas has to be cleaned before the power generation in gas turbine. Air-blown gasifier allows to produce gas with heating value which is approximately 3.2 – 3.7 MJ/m^3. On the contrary when oxygen is used as a gasifying agent heating value is raised up to 9.1 MJ/m^3.

A disadvantage of Chemrec gasifier is reactor lining materials. Moreover problems occur when air blower is inactive during operation and black liquor pumping system failure. Another drawback is equivocation of the counter-current condenser and scrubber. In addition the quenching must be improved to provide good conditions for gasifiers work [21].

Table 9: The Chemrec pressurized BL gasifier data (Pilot plant 1)

Fuel types	Black liquor
Plant size, dry feed	0.83 t/h
Heating value (MJ/Nm_3)	7.9 (LHV with O_2 as gasification agent)
Typical gas composition (% volume)	31.3 H_2, 31.4 CO, 27.5 CO_2, 6.0 N_2, 0.3 H_2O, 1.5 CH_4, 2.0 H_2S
Gasification agent	Oxygen (100% O_2)
Operating pressures (OP, bar)	30 bar
Operation temperatures (^{0}C)	975

3.3.3 Entrained flow – Up flow Gasifier

Technology description:

The up flow gasifier operates in the similar manner as down flow gasifiers. The reactor represents vessel with two smaller cylinders from the sides where burners are installed (Figure 14). Coal slurry is fed partially with 75 % of it is supplied to the first stage of exothermic reactions and mixed with oxygen delivered from air separation plant. Exothermic reactions take place in the shortest possible time at very high temperatures (1300-1400^{0}C). The coal ash is transformed to a molten slag which is a by-product of the first stage reactions.

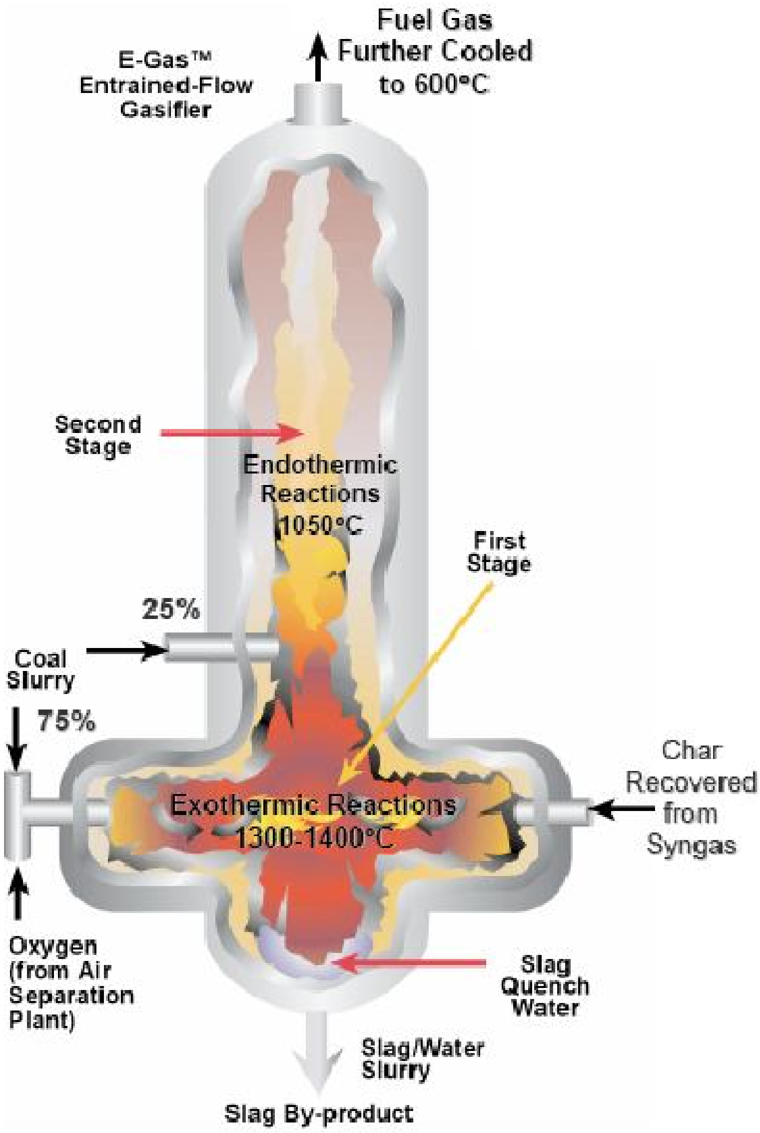

Figure 14: The entrained up flow gasifier

After that the by-product is cooled by the quench water and dumped from the bottom of the reactor. The rest amount of slurry is fed to the second stage of reactor where endothermic reactions occur at temperature of about 1050^0C. During this stage relatively low amount of char is created due to quite low quantity of loaded fuel. It is believed that the higher reactivity of the fuel the bigger char production. The produced gas is then extracted form the top of the unit and further cooled to 600^0C. The cooling process takes place in water-tube heat exchanger generating saturated steam for further power production in steam turbine. One can notice that recycled char is added to the first stage of reactor and gasified. The gasifier is lined by slag-resistance refractory material and not equipped by cooling devises.

Advantages:

The main benefit of this technique is production of the syngas with very low tar content and obtaining of leach resistant molten slag.

Disadvantages:

Not all fuel is converted into the syngas, to put it another way, the additional heat energy is produced during the process therefore the effective chemical energy content of the syngas is not reached as maximum possible. This results in less effective energy generation from additional heat of gasification process. The extra cost is consequence of biomass feedstock pretreatment. Finally tar free syngas production requires maintenance of extremely high temperatures during the gasification.

Table 10: The entrained up flow gasifier data

Fuel types	Coal
Plant size, dry feed	105
Heating value (MJ/Nm_3)	10.2 (O_2 and typical coal), 9.9 (O_2 and petroleum coal)
Typical gas composition (% volume)	34.4 H_2, 45.3 CO, 15.8 CO_2, 1.9 N_2, dry H_2O, 1.9 CH_4 (typical coal) 33.2H_2, 48.6 CO, 15.4 CO_2, 1.9 N_2, dry H_2O, 0.5 CH_4 (petroleum coal)
Gasification agent	Oxygen
Operating pressures (OP, bar)	27.5 bar
Operation temperatures (^{0}C)	1050-1400
Tar content of dry syngas (mg/Nm^3)	Low

3.4 Indirect gasifiers

The idea of indirect gasification is separation of combustion stage from gasification reactions. In spite of feedstock incineration, gasification agent has to be added into the reactor. As a rule gasification agent is steam which transfers its energy to the feedstock, thus obtaining gasification process. This method allows creating oxygen free conditions and quite low nitrogen content inside the reactor. Typically, the constant oxygen blowing occurs in direct gasification and furthermore it claims to monitor an air feeding rate. This problem is overcome when using an indirect gasification method. Steam as a gasifying agent also reduces nitrogen content eliminating its dilution reactions. Hence one can increase heating value of this system.

A considerable drawback of indirect gasification method is concealed under continuous heat adding and the reason is heat energy consumption by highly heat-absorbing reactions appearing during the process. There are three approaches to heat transfer:

1. By adding air or oxygen to the feedstock it is incinerated partially thus the gasifying medium is mixed with steam which is typical for direct gasification.
2. The temperature of steam has to be increased but another way is adding bigger amount of the steam to the reactor.
3. This approach is based on external heat supply to the sand bed by using heat exchangers or heat pipes.

In comparison with direct gasification, indirect one allows to obtain higher heating value of the producer gas. It is possible only due to high methane content in the syngas. It has been investigated that increased amount of methane is the consequence of steam using as a gasification agent which occurs at quite low temperature regime ranging from 800 to 900°C and relatively high pressures inside the reactor(20-60 bar). In case of syngas application as a fuel catalyst, methane has to be extracted by implementing special technique or methane reformer. Methane content has to be increased when using syngas for electricity production.

3.4.1 Gas Indirect, Single Stage with Steam reforming

The design of single stage indirect gasifier is quite similar to the bubbling fluidized bad gasifier had been presented in 3.2 chapter of this paper (figure 15). The gasifier is equipped with burner which uses recycled gas as a fuel. Then, heat obtained from the combustion process is delivered to the heat exchanger arranged inside the reactor where finally heat is transferred to the steam. Thus feedstock is gasified by steam which passes through the bed as a gasifying agent. “When black liquor is used as feedstock the remaining ashes are used to retain the green liquors to close the loop in the pulp mills.”

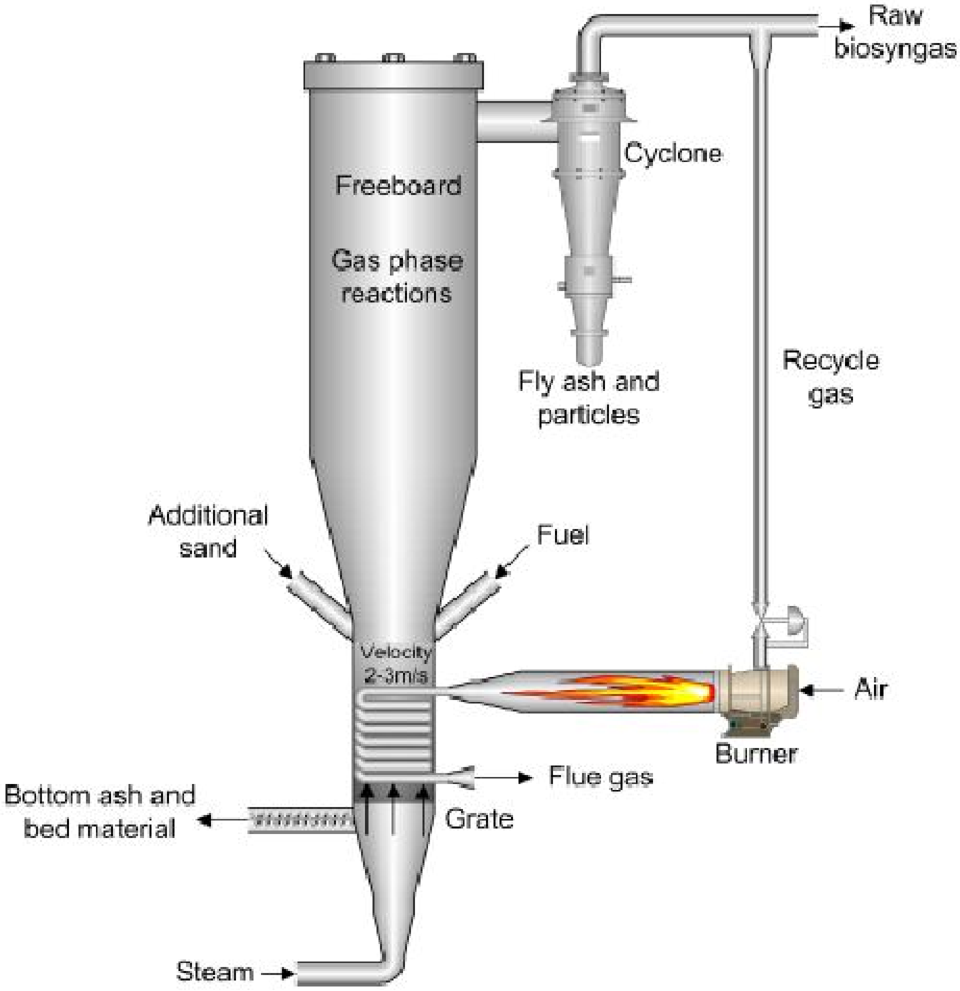

Figure 15: The Single Stage Gasifier with steam reforming

Advantages:

As noted before the method allows creating oxygen free conditions and quite low nitrogen content inside the reactor. Therefore stable oxygen feeding is not necessary compare to direct gasifiers. The heating value is increased with reduction of the nitrogen bonding due to its low amount. Taking into account that gasifier is of a high flow capacity and the fact that it is possible to solve its entire challenges coupled with reliable cleaning and heat recovery system, this gasifier tends to be the most efficient gasifier for wide-ranging energy production.

Disadvantages:

The main disadvantage of single stage gasifier with steam reforming is complexity of design and quite problematic situation with refractory material due to the high temperature of reactor. Apart from black liquor using as a fuel, influencing on bed agglomeration so that sand bed collapse occurs. Besides, complicated construction is needed if black liquor is used. Finally this concept is designed for large scale operation.

Table 11: The Single Stage Gasifier data

Fuel types	Wood pellet and woodchips of different size and moisture content also black liquor can be used
Plant size, dry feed (t/h)	No real scale up limit, mostly depending on availability of biomass.
Heating Value (MJ/Nm^3)	X (air), X (O_2), 17 (Steam) (MTCI)
Typical gas composition (% volume)	43.3 H_2, 9.2 CO, 28.1 CO_2, 0 N_2, 5.6 H_2O, 4.7 CH_4 (MTCI)
Tar content of dry syngas (mg/Nm^3)	Medium or low (potentially, if proper bed material or fuel mix is used to increase the gasification temperature without agglomeration problems)
Gasification agent	Air/Oxygen/Steam/Mix
Operating pressures (OP, bar)	Atmospheric and pressurized
Operating temperatures (°C)	790-815 (MTCI)

3.4.2 Char Indirect, Two-Stage with Steam Reforming

Technology description:

The system consists of two reactors with different function (Figure 16). In general these reactors are similar to the circulating fluidized bed gasifier. But the function of char combustor is to incinerate char arriving from the cyclone of another vessel and to provide sand particles with heat obtained during combustion reactions. The sand heated in char combustor is in turn medium of feedstock's gasification in gasifier.

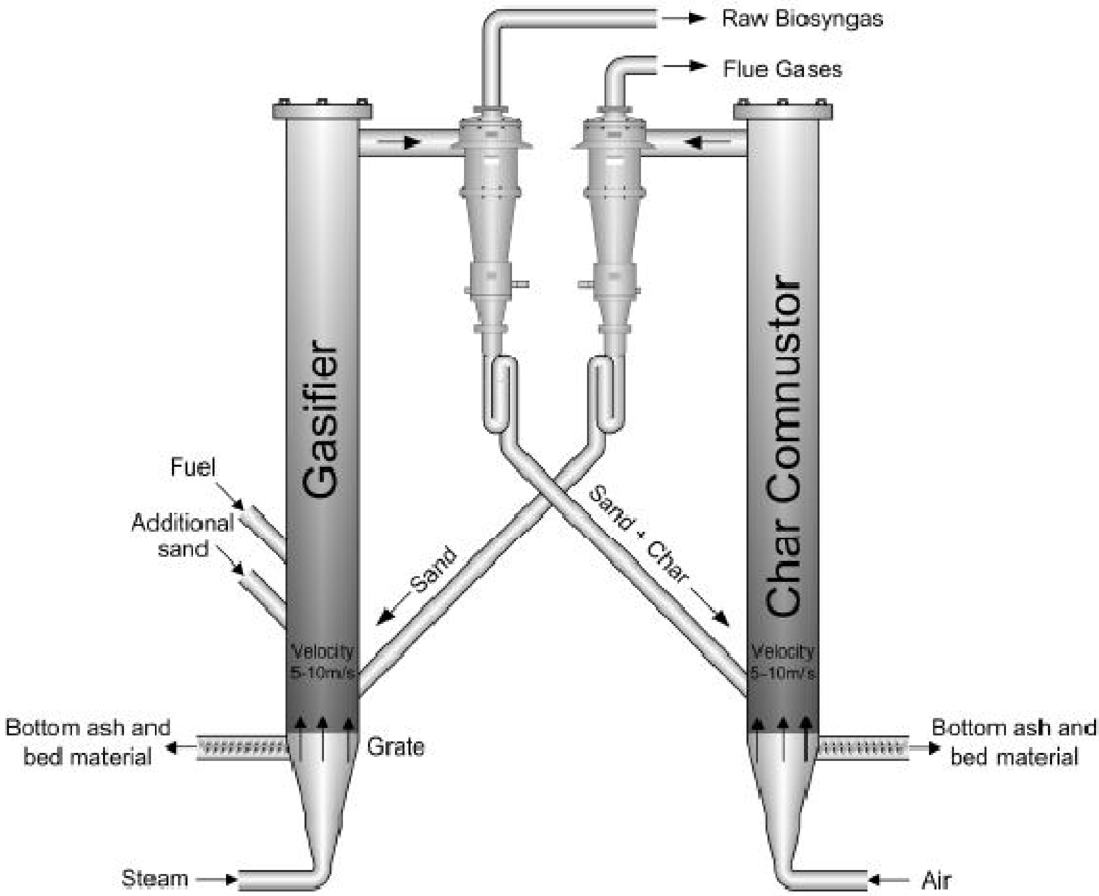

Figure 16: The Char Indirect, Two-Stage gasifier with steam reforming

Advantages:

As for the single stage gasifier, the need of steady oxygen feeding is exhausted. In addition the nitrogen content is very low because of the absence of air in the reactor. The only reactor has to be supplied by air is char combustor and latter flue gases pass the cyclone for sand separation. The heating value is increased with reduction of the nitrogen bonding due to its low amount. Heat exchange of the sand is reached as high as possible due to the two-stage system. This technique pretends to be one of the most successful designs of gasification systems together with single-stage design.

Disadvantages:

The only challenges of this gasifier occur when calculating an investment expenses and the method is applicable merely for large scale.

Table 12: The Char Indirect, Two-Stage gasifier data [4]

Fuel types	Wood pellet and woodchips of different size and moisture content
Plant size, dry feed (t/h)	No real scale up limit, mostly depending on availability of biomass.
Heating Value (MJ/Nm^3)	X (air), X (O_2), X (Steam), 15 (Max H_2), 18 (normal) (Air and steam)
Typical gas composition (% volume)	14.9 H_2, 45.6 CO, 14.6 CO_2, 0 N_2, dry H_2O, 17.8 CH_4 (normal) 24 H_2, 14 CO, 42.7 CO_2, 0.6 N_2, dry H_2O, 14.2 CH_4, 2 C_2H_4 (Max H_2) 25-35 H_2, 20-30 CO, 15-25 CO_2, 3-5 N_2, dry H_2O, 8-12 CH_4 (Guessing)
Tar content of dry syngas (mg/Nm^3)	1500 – 4500 Medium or low (potentially, if proper bed material or fuel mix is used to increase the gasification temperature without agglomeration problems)
Gasification agent	Air/Oxygen/Steam/Mix
Operating pressures (OP, bar)	Atmospheric and pressurized
Operating temperatures (°C)	600 - 1000

4 MODERN PROJECTS AND RESEARCH IDEAS

In most cases modern projects concerning improved gasification approaches indicate a number of combinations with other cycles. Thus the highest efficiency of energy generation is obtained as well as economical benefits. As a rule systems contain combination of feedstocks to be used and options for further usage of the syngas. It has been investigated that combined gasification cycles are relevant for the Western countries promoting control of greenhouse gas emissions [9].

4.1 Co-gasification with coal

Biomass availability barriers have resulted in developing of the new systems as co-gasification which might be a great help to overcome these barriers. Moreover the possibility of large scale gasifiers' implementation proposes expansion of biomass scale which also is a big challenge. "Finally there might be synergetic effects with respect to char reactivity, tar formation and emission of harmful components."

First gasification project called "EC-APAS programme" has been studied by the groups of Sjostrom at KTH, Stockholm and VTT, Finland. A lot of research work was made with a 14 cm pressurized fluid bed at 2.5 - 10 bars. The results indicate that coal and wood could be used as a feedstock for gasification process. Besides, the results had shown an interdependence of the reactivity and char content in the ash as well as amount of produced gas. Thus, increase in reactivity results in a higher yield of the producer gas and lower char content in the ash.

Some countries are quite interested in straw to be used as a fuel in gasification, especially in Denmark. But recent research of downdraft gasifier was not satisfactory to prove reliability of this technology, in addition fluidized bed gasifiers were tested and it has been revealed that the temperature of ash fusion is not sufficient for proper operation. Moreover, two gasifiers, fluidized bed (VTT and Enviro-power companies) and entrained flow (NOELL, Germany) concepts have been investigated using straw and coal as a feedstock by Elsam and Elkraft in 1994 and 1995. The outcome of this research showed that a high efficiency might be obtained when using straw separately or as a mixture with coal, particularly in the entrained flow gasifier. Besides, that the gasification process of straw and coal can be completed fully. Despite, fluidized bed gasifier indicated that approximately 45% of supplied coal tends to be caked.

Thus, fluidized bed reactors are possible to be used in co-gasification process. But gasification of wood and coal mixture makes it possible to lower the tar content in the syngas. The consequence of this fact is that the European Commission reared up the development so called “JOULE project” concerning this field in 1996. Many companies such as Delft Technical University, KTH, TPS and IC (Andries and Hein, 1996) took part in the project. To research this concept pretends to create the unit with capacity about 1500 kWt of Delft University, see Figure 17.

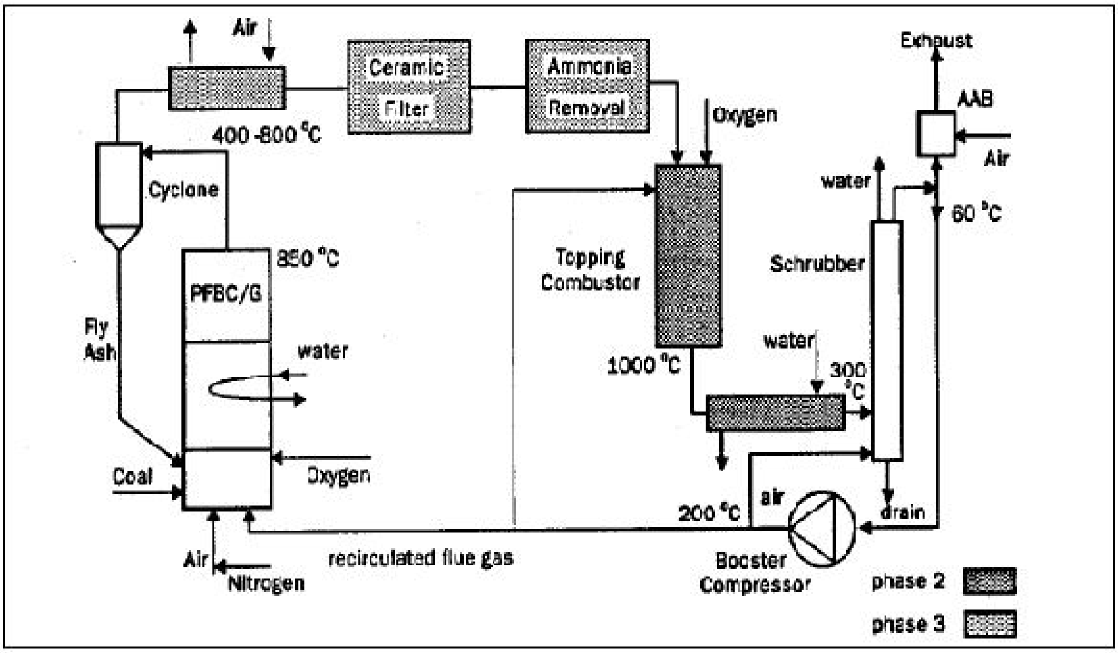

Figure 17: Pressurized fluid bed pilot of Delft University [5]

4.2 Small district heating

Small district heating has been introduced by Foster Wheelers and the main component of the system is atmospheric updraft gasifier. This concept is called BIONEER gasifiers. Plants have been equipped by ten BIONEER gasifiers with capacity ranging from 3 to 10 MWth of fuel input. The feedstock does not include sawdust due to its particle size which is unsuitable for proper and efficient process. “These gasifiers are simple to operate, and the technology is well proven [9].”

The tarry LCV fuel gas is produced during the gasification process. The interior of reactor is lined by refractory material and the grate is built as rotational cone. As mentioned in chapter 3.1.1, feedstock is supplied at the top of the gasifier and later is drown down while drying, pyrolysis, gasification and combustion take place in the reactor. Gasifying agents are steam and air passing upwards the gasifier. Ash is remover from the bottom where rotational grate is introduced. “The temperature of the combustion zone is regulated by humidifying gasification air.” The characteristic property of BIONEER gasifier is high tar content in producer gas; therefore, the gas can not be consumed by IC engines or transported but incinerated in a boiler which is arranged closely to the reactor. In general, boiler is used to provide heat and electrical energy for consumer. Many experiments were carried out by VTT and BIONEER and diversity of fuels such as wood chips, forest wastes, peat, straw, RDF pellets, and coal and RDF mixed with wood chips were tested at pilot plant with capacity about 1.5 MWth situated at BIONEER’s Hameenlina shop. The results introduced gas composition of wood chips as a feedstock: 30% CO, 11% H_2, 3% CH_4, 7% CO_2, and 49% N_2, in addition, high heating value is 6.2 MJ/Nm^3. Dry product gas contains approximately 50-100 g/Nm^3 of tar . During the oil crisis eight commercial BIONEER power plants have been built with 4-5 MWth of capacity but the big part of them is located in Finland and the rest is located in Sweden. Generally, gasifiers are installed at the plants for district heating purposes (hot-water supply) and mostly, it is fed by woody biomass and less by peat. Another characteristic property of BIONEER plants is that all units are controlled automatically which provides low employee recruiting. The BIONEER Company was originated from YIT Corporation but later Ahlstrom Corporation purchased it and finally, Foster Wheeler bought Ahlstrom and built a new plant with capacity of a 6.4 MWth in eastern Finland in 1996. “The estimated investment cost for district heating applications is about 350 kECU/MWth and the operating cost is about 17 ECU/MWh.”

4.3 Biomass to electricity

The elaboration of integrated gasification combined cycle has begun in 1991. By 1993, plant has been built by Sydkraft AB (currently E.ON) in Sweden with capacity about 6 MW_e of electrical energy and 9 MW_{th} of thermal power. The plant was constructed in association with Ahlstrom Corporation (1991-1993 periods) which currently is Foster Wheeler Energia OY. The concept is one of the most uncommon designs of integrated cycles due to combining of fluidized bed gasifier and gas turbine as well as steam turbine. Since the gasification feedstock is biomass which is finally used to produce electrical energy this method might be called “biomass to electricity”. Originally, the plant was concerning as insufficient for exploitation goals whereas the first demonstration of plant was finished in 2000.

Technology description:

The IGCC process adapted at Varnamo Demonstration Plant in 1993 is presented in this part of the paper. (see figure 18)

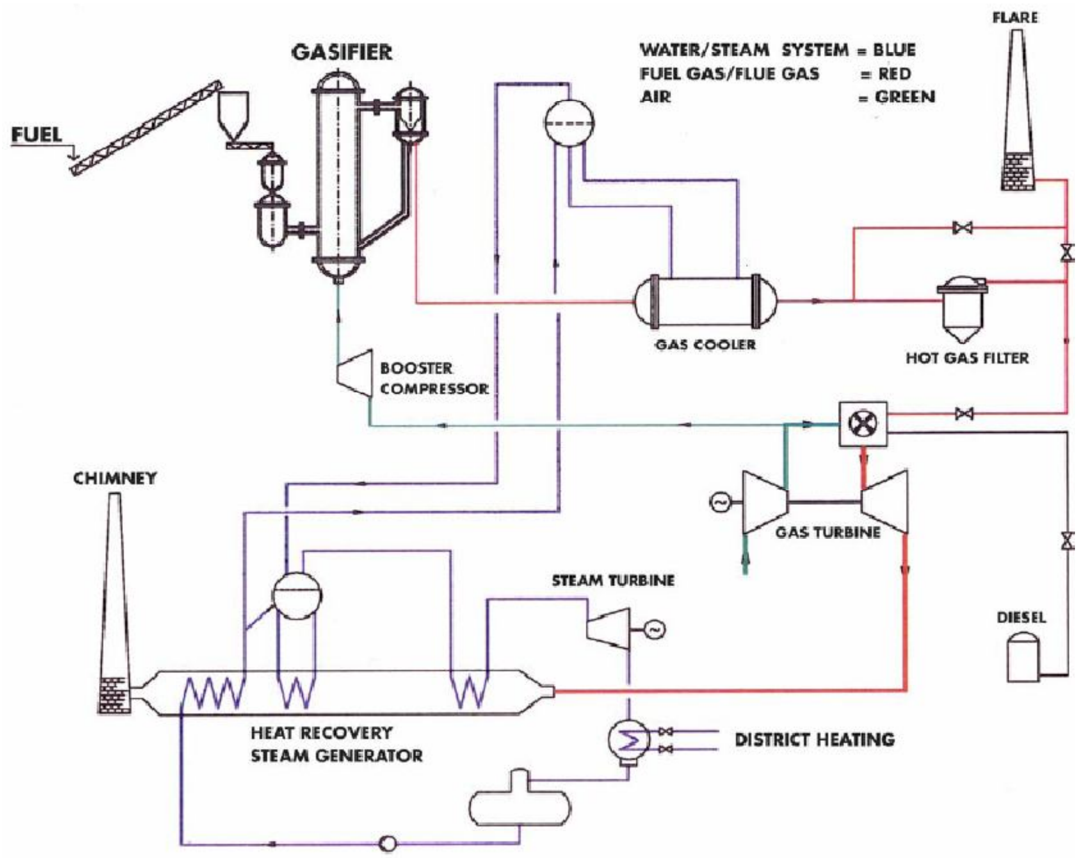

Figure 18: Integrated gasification combined cycle

The fuel supplying system contents several stages such as conveying fuel from the silo, fuel transporting to the lock hopper device and finally, fuel passes through the pressurizing system before feeding to the gasifier. After the scraper conveyor, fuel fall into the day silo and then, it is pressurized in the special vessel to feed it into the reactor. Another feeding system supplies the bed material and it is mixed with the fuel at the moment of entering the gasifier. The bed material increases the process efficiency because it serves as a heat transfer medium. Increased efficiency is the consequence of a highly improved heat transfer rate because of the circulation effect. From the bulk carrier track bed material is conveyed to a storage silo and later, it is fed to the point of mixing with the fuel by pneumatic conveying system. To obtain proper mixing dosing apparatus is used. Figure 19 represents reactor utility and its equipment installed inside the gasification building.

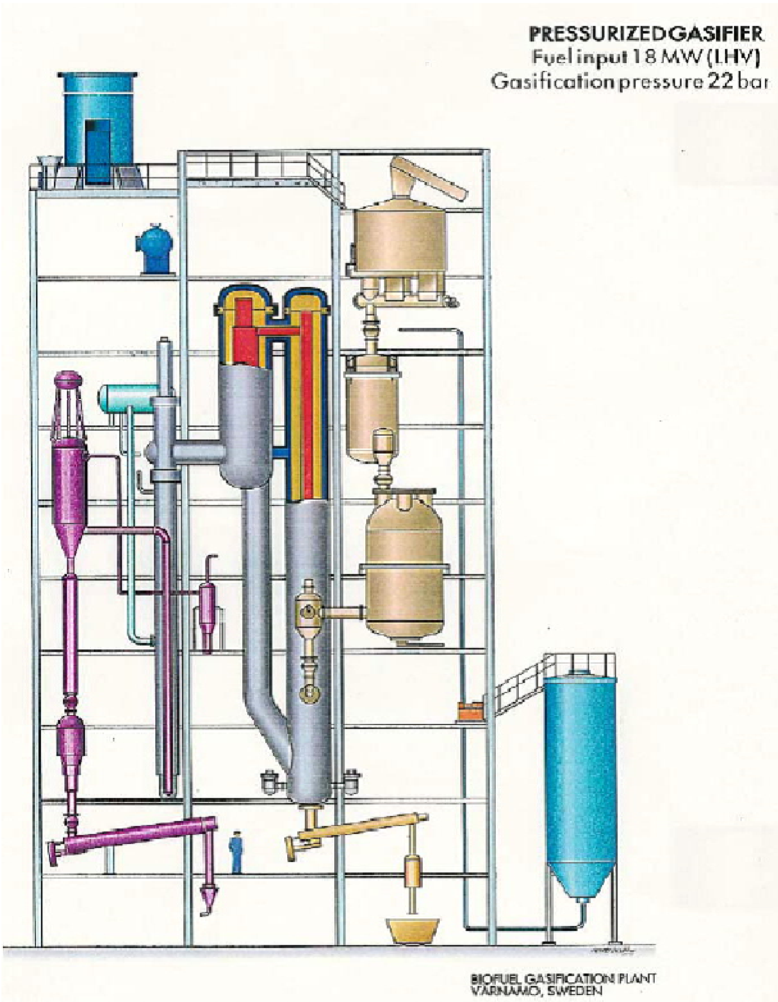

Figure 19: The gasifier building, Varnamo

The gasifying agent(air) exiting from the gas turbine compressor is cooled, pressurized and reheated to the temperature ranging from 200 – 250^{0}C. Besides, air extraction from the compressor prevents from its surging. Air cooling processes take place at the district heating heat exchanger and at the additional cooler; further air pressure is increased up to needed one in the booster compressor and finally, air supplied to the bottom of the reactor. In spite of air, light oil is used in the burner to start the system. The gasification reactions result in ash appearance which is then damped from the reactor's bottom and treated in the ash handling system. Refractory lining as well as water enclosure are installed inside the gasifier preventing from the overheating of reactor thus creating a stable temperature circumstances. Moreover, gasifier is equipped by blow-off valve for excess pressure relief.

The material bed is separated from the producer gas in cyclone and later supplied at the bottom of the gasifier passing start-up burner system and then appearing in the gasifier nozzles. Clean producer gas is cooled in the gas cooler device and later, is treated by the hot gas filter. The pressure of the filtered gas is maintained by safety damper which is working in the same manner as blow-off valve of gasifier.

"A nitrogen system is used for the pressurized lock hopper system and for pulsed cleaning of the hot gas filter, as well as for various inserting requirements, e.g. when shutting down the gasifier."

The next step for the producer gas is feeding to the gas turbine but dust separation and cooling are required. These processes occur in the cooler and hot gas filter which was mentioned earlier. In the cooler, heat transfer occurs by means of radiation and convention processes resulting in saturated steam generation. The filtering based on the absorption ability of filter elements thus the dust is removed from the gas and added to the ash handling system.

In the end, cooled and cleaned gas is fed to the combustion chamber of gas turbine. The initial temperature of the supplying gas is about 350-400^{0}C. In addition, the turbine is equipped by the start-up system with light oil as a fuel.

The discharge gas passes all stages of a single-pressure type heat recovery steam generator. The purpose of a heat recovery steam generator is to provide heat transfer from the flue gases exiting gas turbine at temperature of approximately 470^{0}C to heat exchanger system of steam turbine. The pressure of feed-water is about 4 MPa (40 bar) and is naturally circulated. The direction of the gas flow is horizontal. Superheater, evaporator and economizer are installed inside the heat recovery steam generator. Thus, the temperature of the flue gases is considerably lowered to 120^{0}C in order to exhaust its energy completely obtaining high efficiency. And finally, gases exit the system from the stack.

One can noticed that two steam drums are installed in the system, thus the drum located near the gas cooler is a medium to generate saturated steam that further is heated in heat recovery steam generator drum and superheated before inlet of steam turbine as high as 450^0C. In back-pressure steam turbine, superheated steam is expanded so that thermal energy of the steam is transformed into the mechanical energy of shaft rotating. Since the steam turbine is connected with electrical generator, around 1.8 MWe of electricity energy is produced at this stage.

Even if district heating heat-exchanger does not consume all the output energy of the steam turbine which works with the maximum demand power, heat can be used by air cooler unit.

Steam is condensed in the district heating exchanger to the temperature of 70^0C and then, supplied to the deaerator where all gases such as $CO_{2,}$ O_2 diluted in the water are separated and thus water can be used as a feed-water in the cycle. Shortage of water is filled up by adding of specially treated water supplied from another plant.

An advantage of The is possibility to use diversity of biomass fuels such as mixtures of wood and bark, wood chips based on SRF, pelletized straw and as well as pelletized RDF. Accordingly, the plant is more tolerant to fuels with quite high concentration of chemicals as Cl, K and Na. However, exploitation of these kinds of fuels has to be proved by long term research and experiments before the start of operation based on them. But it has been investigated that problems could occur not only in the gasifier but during handling and supplying processes. For instance, bulky biomass fuel handling might cause some difficulties when handling compare to the wood chips. Nevertheless, it can be pelletized but pellets also have several drawbacks as mechanical durability problems and probability of moisture absorption. Thus, every aspect has to be considered taking into account all advantages and disadvantages.

When considering gas turbine selection at IGCC, pressure of the turbine operation is crucial factor because it determines the pressure level of plant. In case with Varnamo plant there have been two options which are atmospheric and pressurized gasification.

In comparison to the atmospheric, pressurized gasification intends for a larger scale of the plant. Several improvements have been added to the gas turbine of Varnamo plant such as air extraction, modified burners and combustion chambers. As a result, no operational faults occurred. In addition the turbine has performed its operation as reliable device.

The pretreatment of the fuel includes drying to 15% moisture content and in some cases it's pelletized. Varnamo plant has been admitted as very successful plant with integrated gasification combined cycle.

It has to be mentioned that the most demanding gas at IGCC plant is inert gas. The application of inert gas is to pressurize fuel, discharge ash and to pulse the hot gas filter. Since the inert gas demand is quite high it is possible to obtain it through the catalytic combustion or to reduce its consumption by means of piston feeding system and syngas that might be used to pulse the hot gas filter.

The gasifier has been tested with a high numbers of startups and shut-downs during 14 day period of time which is quite close to long term exploitation period. Operational characteristics shown sufficiently reliability of the system, however, refractory lining material had to be renewed with selection of suitable material for this purpose.

Another cost effective factor is bad material which is highly consumed as well as inert gas consumption. Therefore, bed material claims to be selected properly. The Varnamo plant bed material is magnesite and it responds of a relatively low cost and operational simplicity. Alternatively, dolomite and limestone might be used as a bed material. It has to be taken into account that bed tends to agglomerate causing perturbation of gasifier operation. In addition, deposits on the gasifier interior could occur due to the catalytic tar cracking effect with further recarbonization process.

Designing of the plants has to start with efforts of lowering bed material demand which is very considerable for operational cost of the plant. Furthermore, gas cooling and gasifier design have to be considered properly, especially bed material recarbonization is a field for research work to be done.

The necessary condition to monitor the tar content is temperature maintenance within the limits from 300 to 950^{0}C where the lowest temperature indicates the beginning of tar condensation process. In general, temperature inside the reactor is maintained as high as 950^{0}C. The fuel pollutants such as alkaline, chlorine have to be eliminated because of their hazardous effect on the gasifier operation.

It goes without saying, that emissions play an important role in gasification process. As mentioned in chapter 3, NO_x emissions are eliminated from the gasifiers of this type as a result of a high heating value of producer gas. In other words, nitrogen oxide formation is a consequence of ammonia appeared during gasification process due to nitrogen reaction with the fuel. The solution of this problem could be a catalytic lowering or oxidation of the ammonia. The last method has been successfully examined at the Varnamo plant.

Sulfur content of a fuel determines the amount of sulfur emissions generated. However this emissions as well as hydrogen sulfide can be eliminated by means of a low temperature operation.

It has been checked for redundancy of carbon monoxide, hydrocarbon and heavy metals. As a consequence, incomplete combustion process results in carbon monoxide and hydrocarbon existence in the flue gas. However, Varnamo plant shown quite good results of hydrocarbon content in the flue gas. Heavy metals bonded with the ash material and discharged to the ash handling system in gasifier.

Hot gas filter is a mean of dust emission elimination, thus no tests indicate any dust particulates in the flue gas at Varnamo plant. But it has to be mentioned that dust has a potential harm effect on the gas turbine to the point of its damage.

The crucial factor of integrated gasification combined cycle is availability of this technology. Since the plant had a demonstrational nature and many experiments as well as tests were realized, it might be a field for future development and investigation of IGCC method. Different availability research and trends have to be done to have an effect on technology improvement.

The time duration for a startup process is very important and by creating special temperature and pressure conditions, short-form time interval can be reached. In addition, it has to be noted that the hot and cold star-ups time duration is not of the same value.

Future improvements and development is needed to be aimed on fuel handling system, to be exact, drying and fuel feeding. The factor of equipment selection depends on fuel characteristics such as particle size, moisture and its composition.

The handling problem appears when fuel is treated causing compelled stop of the system. To avoid system shutdown the additional amount of treated and stock-produced fuel must be included and arranged closely to the feeding technique. When considering large plant design it is probable that several feed-lines are needed to be installed providing continuous fuel supply to the gasifier.

Currently, the Varnamo plant is investigated under the new R&D project so called CHRISGAS. “The project started in 2004 and is financed by the collaborating industrial partners, the European Commission and the Swedish Energy Agency.” The project is aimed on further research and improvement in order to generate syngas in the most possible efficient way.

The main components of the syngas are hydrogen and carbon monoxide and its applications could be liquid, gaseous fuels production such as methane, FT-diesel, methanol, ethanol and hydrogen. But ethanol production does not seem to be an attractive technology from the efficiency and product yield sides of view.

The Varnamo plant has to be modified by equipment modernization, for instance, gasifier, gas cooling and hot gas filtration units. “In addition, several changes as reformer, water gas shift and hydrogenation have to be added to the process and oxygen supply has to be arranged.”

The produced gas is not of a desired quality which means the calorific value is low and the gasifying medium has to be substituted by oxygen or steam. Thus it makes possible to obtain syngas of a medium heating value. “Nitrogen is not desired to have in the gas since it dilutes the gas and makes the downstream systems more costly.” Lastly, the gasification would be the most efficient if the product gas was eliminated from pollutants and supplied straight to the reformer at the temperature of output from the gasifier. However, the challenge appears due to the hot gas filter maximum possible temperature of operation. To be more precise, a cooler must be arranged before the hot gas filter to prevent it from the damage [8].

4.4 Co-gasification with natural gas and coal

Foster Wheeler Company presented and developed a new concept of circulating fluidized bed gasifier so called Pyroflow gasifier in eighties. The figure 20 shows the construction of the Pyroflow gasifier which is an atmospheric type.

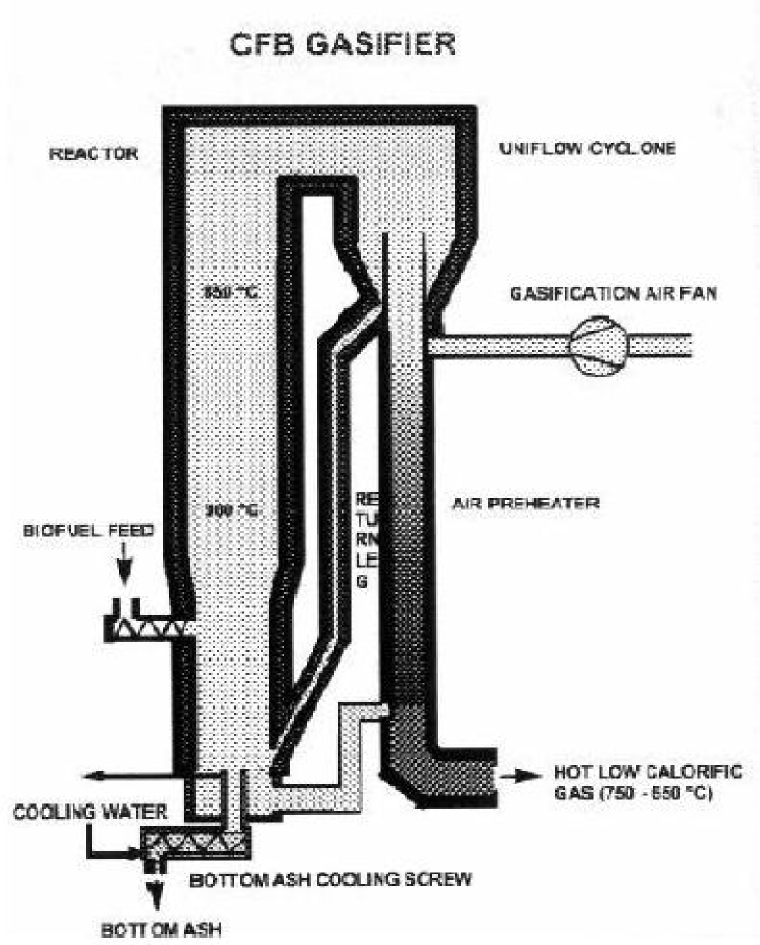

Figure 20: Foster Wheeler's Pyroflow ACFB Gasifier

In 1983, Wisaforest Oy pulp and paper plant was built as a business demonstrational plant by Foster Wheeler Energia Oy. The capacity of the plant was about 35 MW. In addition, two pulp plants were equipped by gasifiers with capacity of 27 MW for each unit. Later, in 1986, 17 MW’s gasifier has been performed into the Portucell pulp mill in Portugal. And finally, Kymijarvi Power Station was modified by the new gasifier unit in Lahti, Finland. The Lahden Lampovoima Oy firm is the owner of this facility and the plant is generated heat as well as electricity. The schematic figure of Lahti plant operation is presented in Figure 21.

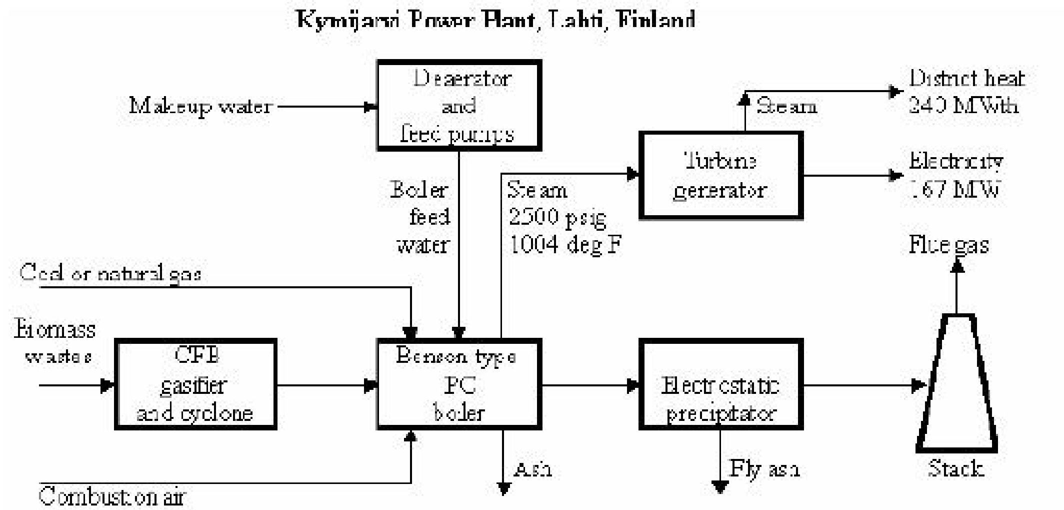

Figure 21: Flow Diagram for the CFB gasifier at Lahti, Finland

The Lahti plant was built in 1976 and its electrical power capacity is about 167 MW_e besides, the heat power is about 240 MW_{th} where oil is used as a fuel. However, the boilers were converted for coal to be used as a fuel in 1982. The plant is equipped by a gas turbine with power capacity of about 40 MW_e in 1986. Annual fuel flow rate of the plant is determined as 163,295 metric ton/a, which is equal to 1,200 GWh/a operating on coal and 800 GWh/a on natural gas.

It was decided to constitute approximately 15% of the overall fuel consumed with the biomass based fuel. As a result, the plant was modified in 1997. All revising have been finished on January 14, 1998. Specifications of the Gasification Plant at Lahti are presented in Table 4. The heating value of the produced gas is relatively low thus; it is more profitable to use it for co-combustion application. “The boiler is a Benson-type once-through boiler with steam conditions of 125 kg/s (275.6 lb/s), 540 °C (1004 °F)/17,000 kPa (2,466 psi) and 540 °C (1004 °F)/4,000 kPa (580 psi) reheat.”

Table 13: Specifications of the Gasification Plant at Lahti, Finland

Design Capacity	Boiler	167 MWe
		240 MWth
	Gasifier	45 MWth
Fuels (GWh/a thermal)	Coal	1200
	Natural gas	800
	Biomass	300

The intentions of the plant were to prove that it is possible to generate energy by using biomass with high moisture content ranging from 40 to 60 % and upgrade plant so that the producer gas with low figure of heating value could be burnt in the near-located boiler. The gasification process takes place in the atmospheric circulating fluidized bed reactor and the gasifier can operate not only on biomass fuels such as wood chips, bark and sawdust but also on REF (recycled refuse), railway sleepers (chipped onsite), shredded tires, and plastics. The system does not include drying which is a desirable factor from the cost side of view. The feedstock can effect on the temperature inside the reactor which is ranging from 800 to 1000 °C. The reactions inside the gasifier have been detailed described in chapter 2.2 of the paper.

The cyclone is used to separate bed material from the product gas thus the obtained gas is clear from the particulates and the bed is recycled to be fed into the gasifier for further usage. Emissions control indicated quite good availability to eliminate and lower such hazard chemicals as, and. For instance, NOx and Sox emissions were reduced to 10 mg/MJ and 20-25 mg/MJ accordingly. But HCI could be eliminated but increased due to REF fuel which contains quite high chlorine quantity.

Annual energy capacity for the first year of exploitation was about 230 GWh where the feedstock is biomass fuel. The plant was operating during 4,730 hours with gasification process involved, in 1998. “The highest monthly availability was 93%, and the average availability was 82%.”

To sum up, Lahti gasification plant has performed quite successful with no faults appeared [9].

4.5 Replacing oil and natural gas making transportation fuels

Changes in producer gas quality indicators as heating value and purity can influence on efficiency of Fischer-Tropsch-synthesis process which produces liquid fuel from the syngas. Thus, tar and methane content as well as pollutants (sulphur, oxygen, ammonium and halogens) in producer gas are the crucial factors for gas quality. To be more precise, the higher impurities content the lower quality of syngas.

When considering entrained-flow gasifiers, one can expect quite high quality of produced gas but on the other hand, low concentration of methane and hydrocarbons still exists. Use of biomass as a fuel in this type of gasifier is quite difficult to effort because it is not suitable for liquid, gaseous or powdery materials. The other drawback is a high temperature of exiting gas compares to other gasifiers which results in quite low cold gas efficiency.

Therefore, the Choren company prospect was to create process where biomass would be gasified and later, supplied as a gaseous or powdered matter into the entrained flow reactor. The problem with low efficiency of cold gas can be overcome by reducing the temperature of gas extracted from the gasifier. Low temperature can be, in turn, lowered by use of char dust so called “chemical quenching”.

It is possible to develop a process with very high efficiency if considering all aspects of the manufacturing such as cold gas efficiency, tar and methane content in the raw gas, flexibility of feed material, maximum possible capacity, technical sufficiency, investment and operating costs.

The Carbo-V® process has been created by the CHOREN group and the Figure 22 represents process of biomass conversion to syngas.

When investigating fixed bed gasifiers, it is possible to produce syngas with relatively high cold gas efficiency. Despite of this, fixed bed reactors do not respond to all criteria for Choren process due to the gas purity level which is very low and the fact that plant can not be expanded. Fluidized bed gasifiers are of a higher syngas quality but however one can not reach sufficient results for synthesis process.

These methods are needed to be modified to reduce impurities content in the producer gas but this treatment is quite expensive and can result in undesirable cost investments.

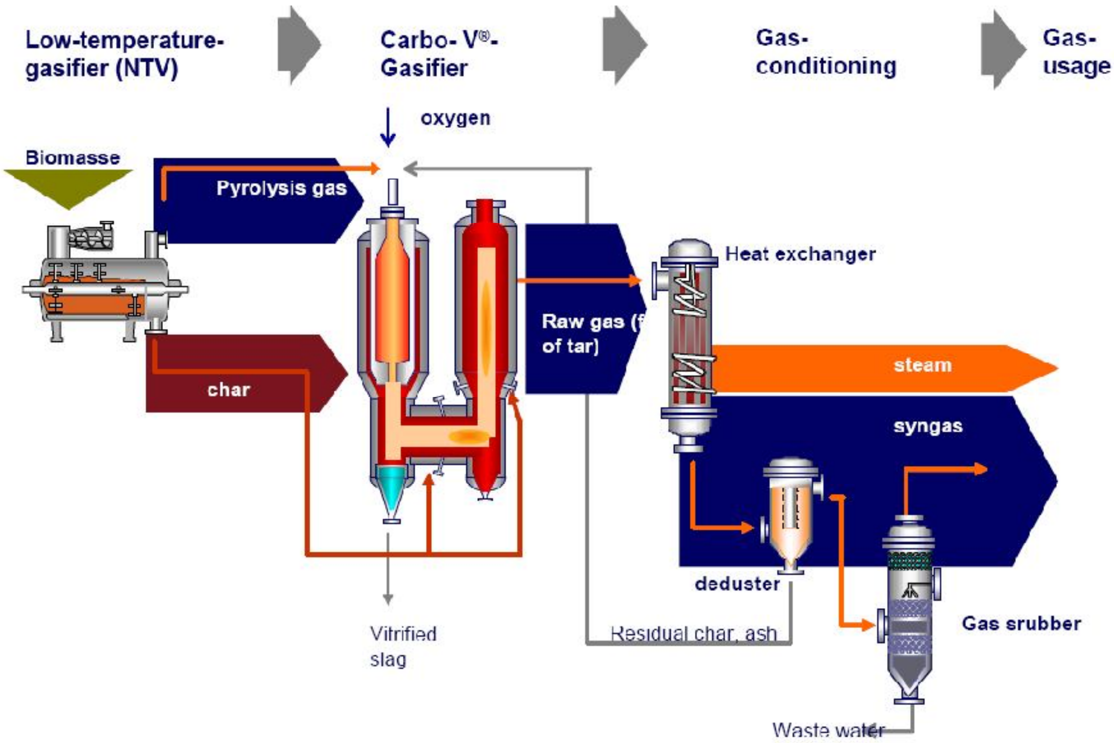

Figure 22: Carbo-V® Process for manufacturing synthesis gas from solid biomass

After all, entrained-flow gasifiers have proven their advantages from the syngas quality side of view. In addition, this method allows expanding the manufacture scale with respect to capacity which could be as high as 1,000 MW. As mentioned in chapter 3, this type of gasification implies pre-treatment of solid fuels as biomass to obtain suitable form of the fuel (gaseous, liquid, powder) for proper reactor operation. It goes without saying that pre-treatment could effect on the process cost. In comparison with biomass fuel heating value, liquid synthetic fuel as oil is of the same value. Therefore, it is clear that one can not obtain any benefits from oil in transportation aspect because the crucial factor for transport is energy content with respect to weight of the fuel. “Logistics advantages are only achieved if biocoke (charcoal) is manufactured as an intermediate product, as the specific energy content in terms of weight is almost twice as high as with bio-oil.”

The ideal condition for highest efficiency to be obtained is the conversion of thermal enthalpy of the gas at highest temperature into the heating value of syngas. But in practice, this thermal energy is absorbed when conditioning the gas after gasification process to reach suitable temperature level.

The waste heat in the Choren process is used to reduce moisture content of the biomass feedstock to 15 – 20 %. Next, it is converted into bio-coke by means of low temperature gasifier. The carbonization takes place at temperature ranging from 400^0C to 500^0C therefore it is called low gasification process.

The next stage for gas after the low-temperature gasification unit is supplying to the entrained flow Carbo-V gasifier where the gasification process occurs with oxygen as a gasifying medium. The gasification takes place at significantly high temperature level of about 1,300 °C – 1,500 °C. In other words, the fuel is subjected to the purification from the tar and methane due to this temperature inside the reactor. As a result, the composition of produced gas is follows: carbon monoxide, hydrogen, carbon dioxide and steam.

The by-product of the low gasification process (char) flows to the Carbo-V gasifier and is fed at the bottom. Inside the reactor, chemical quenching process takes place due to the char gasifying which significantly reduces temperature of the producer gas. Thus, one can obtain raw syngas at relatively low temperature of about 800 °C – 900 °C with high heating value and zero tar and methane content. Later, the gas has to be treated, cooled in the heat exchanger and separated from the residual char and ash in the deduster. It makes possible to generate a steam in the heat exchanger and then use it efficiently. The char and ash obtained during dedusting process is recycled and supplied to the Carbo-V reactor by means of pneumatic system. As the temperature inside the reactor is higher than ash melting point, all ash is melted and flows downstream to the discharger at the bottom. “The vitrified, solid ash can then be used as a slag granulate, e.g. for road building purposes.”

After the deduster, syngas is directed to the gas scrubber where it is fully treated up to necessary conditions by spreading water on it. Finally, ready for service produced gas is extracted from the device and waste water is removed to be recovered later.

The Carbo-V® process has proven high efficiency of synthesis gas generation in entrained flow gasifier with preliminary low temperature gasification and novel chemical quenching process without water involving.

5 CHALLENGES

5.1 Gas Cleaning

Generally, produced syngas contains solid impurities (ash, tar), vaporous metals as mercury and undesirable gases (sulfur chloride) and others such as ammonia, hydrogen chloride. In order to avoid theses components in syngas, it has to be treated in special units as scrubber, deduster or eliminating gas from impurities during the gasification process by maintaining high temperature. In addition pre-treatment can be a solution of production of a tar-free and clean gas. Another quite important aspect of gas cleaning is characteristic property of the gasification process. Therefore, it has to be taken into account which gasifier type is involved in the gasification. Different reactors ought to be considered in different ways depending on the string and weak side of the gasifiers' type.

In Choren process case, syngas is cleaned employing two stage scrubbing process. As mentioned above, firstly, produced gas leaving the reactor is already tar-free due to the chemical quenching process. Secondly, it is cooled in the heat-exchanger generating useful heat energy. Next, it is separated from the dust from the solid particles which are recycled and returned back to the gasifier. And finally, it is fed to the scrubber and hydrogen chloride, ammonia and residual dust are separated from the gas. This two-stages process includes adding of Fe $(OH)_2$ to the spreading water so that H_2S is reacted with Fe $(OH)_2$ thus remaining in the water and damped from the bottom of scrubber. "The second stage involves washing the gas with clean water, also at the steam dew point of the gas." It helps to obtain dust-free gas eliminated from the soluble impurities [10].

5.2 Gas Conditioning

Since the gas composition is determined by process conditions, the syngas ought to reach desirable composition with respect to its further application trends. In general, gas is subjected to the conditioning process which can be divided into three processes such as CO conversion, CO_2 washing and ultra-purification.

The first stage determines the necessary mole ratio of H_2 to CO for the Fischer-Tropsch synthesis process. The process includes washing of the gas and only after this process the syngas is supplied to the unit equipped by catalyst inside. Thus, the conversion of CO to CO_2 and hydrogen occurs due to the catalyst. Besides, the reaction takes place with "the homogenous water gas reaction".

The heat extracted during reaction of CO conversion is directed to generate steam for the gas saturation. The excess of steam can be supplied to the point of gas saturation process or used to generate steam of a low pressure, in one way or another.

In the next stage of conditioning process, gas is cooled and carbon dioxide obtained during CO conversion stage is leached from the gas by means of "Selexol" adding. Finally, the gas is eliminated from the CO_2 but carbon dioxide concentration must be reduced to the level according to the permitted limits by catalyst.

The ultra-purification process is aimed to prevent the sensitive Fischer-Tropsch catalyst from the hazardous effect of pollutants such as sulfur and chlorine compounds. It can be reached by bonding the pollutants with special cleaning agents.

"After the ultra-purification stage, the synthesis gas is fed on to the Fischer-Tropsch synthesis process [10]."

5.3 Biomass handling

This is evident that biomass for energy generation purposes is the most popular as it contents quite big potential in this field. An important aspect is biomass handling before it can be used to produce energy. It goes without saying that the biomass handling prospect contains a lot of challenges as erosion of feeding devices, harvesting, and storage and equipment shutdown problems connected with bridging appearance. To put it another way, these factors can strongly effect on the applicability of the biomass and its investment cost when considering handling equipment and exploitation barriers. In addition, there can appear transportation difficulties due to the low bulk density of biomass and its relatively high moisture content. “Transportation distance, storage and other handling concerns will need to be addressed when considering biomass.”

Biomass drying is an important step in handling in order to increase product gas heating value. The moisture content of biomass must be reduced to 15% level to obtain sufficient calorific value. Taking Varnamo plant as an example, it has been necessary to develop efficient drying system using a flue gas stream, especially for large plants. On the contrary, biomass originated fuel granular as pellets are processed so that it does not need to be dried. The temperature of flue gas supply must be maintained within the limits as 140°C due to the probability of fuel incineration and elimination from the terpenes ejection.

At some point of handling process fuel has to be pressurized by nitrogen injection in the special lock-hopper facility. But this approach to the pressurizing by nitrogen is quite expensive and probably, could be used only in short-term period for research goals and does not suit for commercialization purposes. Therefore it has to be substituted by another solution which responds to the requirements concerning cost efficiency. One way of solving the problem is nitrogen consumption reduction by involving piston feeder or gas of a lower cost. In comparison with wood chips, wood pellets show higher heating value, thus the energy demand for the mass of fuel is lower and nitrogen use is justified.

Handling process stability and efficiency depends on the feeder construction which must be as flat as possible. Otherwise, unsuitable feeder design might cause negative outcomes as unsteadiness of the synthesis gas quality and excessive air supply into the burner. “In the Varnamo gasifier, it was sufficient to have one fuel feeder, but in a large scale plant it will be necessary to introduce the fuel at different locations.”

5.4 Gasifier lining

The gasifier lining is significant factor effecting on the reliability and durability of the reactor as well as operational properties. The black liquor gasifiers were tested and the results indicated that it might be the most challenging for gasifiers refractory materials due to its highly aggressive environment inside the reactor.

Currently, two types of gasifiers based on black liquor exist: high temperature black liquor reactors where the temperature is about 1000^0C and pressure is higher than atmospheric and atmospheric low-temperature gasifier where gasification takes place at 600^0C. The low-temperature gasifier is presented in Figure 23.

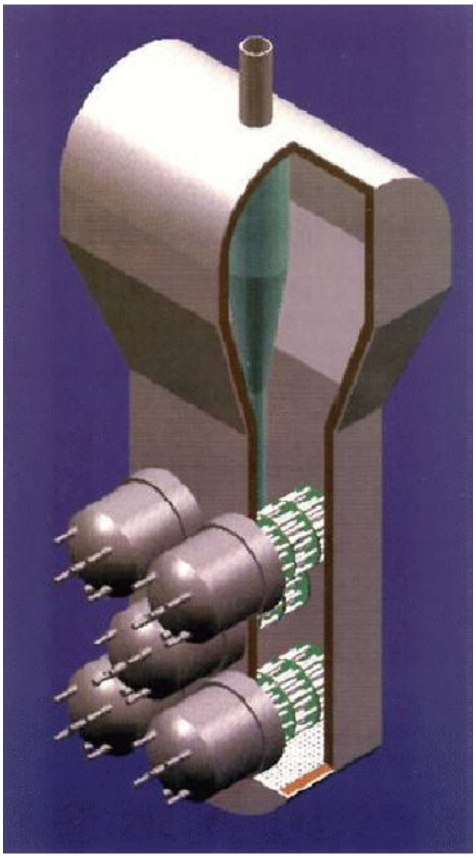

Figure 23: Schematic drawing of the low-temperature steam reformer/gasifier.

By means of material bed which consists of sodium carbonate particles and steam as a gasifying agent; the conversion of black liquor occurs during the process. The pulsed incineration is involved into the process to improve heat transfer in heat exchanger which is a matter of the endothermic conversion of black liquor. Owing to this, one can obtain several benefits as equal apportionment of heat inside the tubes, high heat flow rate and relatively reduced NOx emissions level.

The reactor is equipped by so called shield tubes, thus preventing the tubes from the high temperature and melting on their heat transfer surfaces.

It has been investigated that the steel heater tubes are tolerant to the intergranular attacks from the chromium carbide which is possible only at high temperatures mode.

“In the New Bern case, sensitization of the stainless type alloy along with formation of acid during a shutdown when moist air contacted the sulfide scale present on the tubes resulted in intergranular cracking characteristic of acid stress corrosion cracking.” To prevent tubes from hazardous effect of the sensitization is use of type 321 titanium stabilized stainless steel as a material fro tubes. In addition, the shield tubes, which were mentioned above, are made from the type 330 stainless steel and alloy 800H in order to prolong the lifetime of the heater tubes. The selection of these resistance materials depend on the material availability and tubes strength with respect to oxidation phenomenon.

As one might expect, the refractory lining materials are not researched completely, for this reason U.S. Department of Energy project “Performance of Materials in Black Liquor and Biomass Gasifiers” gave a prospect for further development in this field and two goals such as “laboratory studies in simulated environments to identify alternate materials for shield tubes and heater tubes in a reformer/gasifier processing kraft black liquor” and the investigation of the destruction reasons.

The research work carried out at two U.S. plants with black liquor gasification systems shown that most of the tubes and shield tubes had deposition on their surfaces and no visual damages. The deposition is a result of carburizing process. In addition, it has been discovered that corrosion of tube surface might be a consequence of chromium carbides formation and acid precipitation due to the forced shutdown of the system. During the shutdown the chromium carbides components effect on the tube stress-strain properties due to the temperature reduction.

The research work was also aimed at the gas composition features and the carbon activity shown excessive level. The carburizing process has been scrutinized as well as selection of tube material with the best resistance properties. To determine the resistance level of alloy material to carburizing, special circumstances and environment, as far as shield tubes removing, were created inside the reactor during the experiment. The results after six weeks experiment indicated that stainless material ? 321 and a Ni-Co-Cr alloy are quite similar in their resistance [13].

Another quite interesting test has been carried out to determine refractory resistance to the corrosion process. The experiment took place by means of material foundering into the environment which is fairly close to real operational circumstances.

The test facility is shown in Figure 24. The sample is foundered into the molten smelt to fully imitate conditions inside the real gasifier. Thus, the temperature is maintained as high as 1200^0C which is enough to make sample resist at the breaking point. The furnace is employed with thermocouple well which is used to control the temperature level and to obtain uniform temperature and smelt composition. The system is checked for redundancy of water content at the same time the operating gas is extracted.

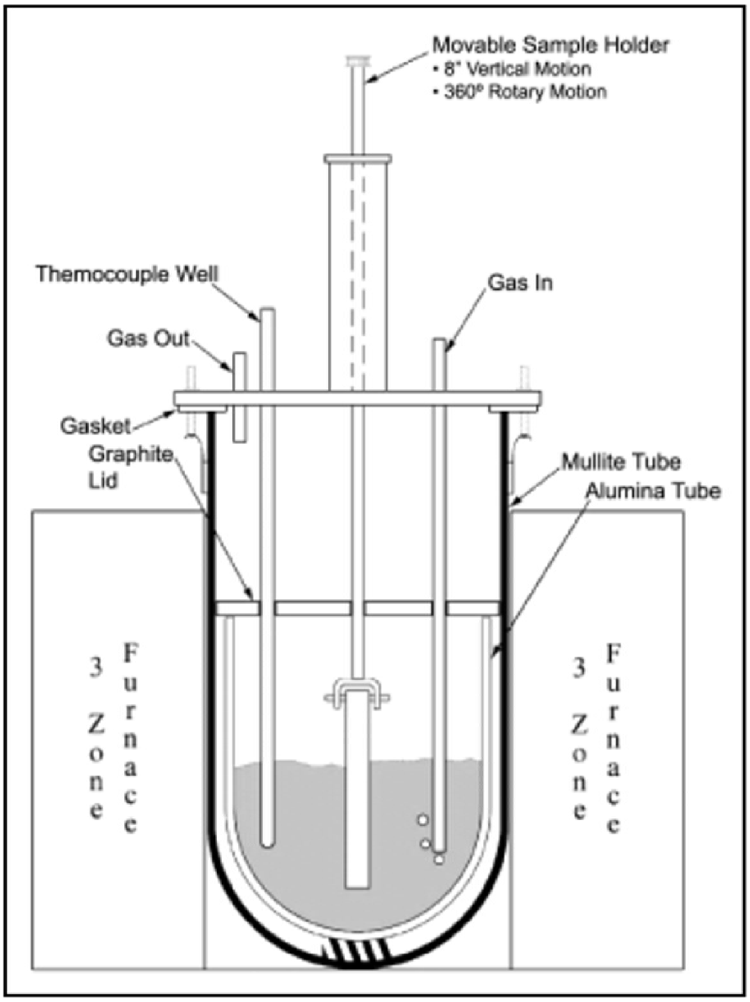

Figure 24: Schematic of ORNL immersion test system

“To mimic the gasifier environment as much as possible, the smelt used was supplied from the recovery boiler at Weyerhaeuser’s pulp and paper mill in New Bern.” After the experiment sample is cooled during 24 hours to be properly examined and investigated. The length fluctuations were not considered due to its partial foundering into the smelt during the test. Microscope and XRD equipment were used to test the sample. “Test materials included mullets, aluminosilicate bricks, fusion cast aluminas, alumina-based and chrome-containing mortars, phosphate-bonded mortars, coated samples provided under an MPLUS-funded project, bonded spinels, different fusion cast magnesia-alumina spinels with magnesia content ranging from 2.5 to about 60%, high-MgO castable and brick materials, spinel castable, and alkali-aluminate materials.”

Only several materials were selected as reliable and resistant under conditions simulated real gasifier operation. One of them is fusion-cast aluminas, its lifetime was suspected to be around one year as well as magnesia-alumina spinels which are operable for two years of exploitation. For reserve lining the most suitable are alkali-aluminates and high-MgO-content materials.

The area for future development is the temperature distribution in the gasifier which reaches its maximum value at the bottom. Thus, to eliminate refractory materials of reactor from overheating it is possible to reduce the temperature stress by substituting the liquor spray. “Also, modeling showed that because of the strong swirl, a separation zone could be formed at the corner of the conical wall where it meets the vertical barrel wall, and some the liquor droplets could be suspended in this zone.” Hence the corrosion danger of the lining occurs and unstable behavior in operation [11].

6 OPPORTUNITIES

6.1 A vision for biofuels

By 2030, it is probable to supply 25% of the EU's transport fuel demand by implementing ecologically neutral and effective biofuels. Considerable development has to be made by European industry in the direction of biofuel use expansion by means of sustainable and novel technologies. Thus many possibilities are provided for biomass refining companies, biomass suppliers and finally, for automobile sector of industry. The trend to biomass world-wide trade is to be increased. Besides, the technology development rate is an important factor for determination of biomass application. In other words, the most probable consumers of biomass are conventional internal combustion engines and gasoline providers taking into account that today's techniques will not be changed until 2030. "However it is possible that specialized drive trains (as for instance fuel cells) will be used in certain applications or in dedicated fleets."

One can expect that assembled biomass-processing combined with chemicals generation as well as biofuels and other renewable energy sources will be continuously developed in future. The integrated mills will consist of many different manufacturing process stages such as biomass handling, treatment of biomass, and further use in energy form conversion devices (gasifiers), chemical recycling and fuel purification. The flexibility of plants and their less dependence on the availability of raw material are expected to be reduced. Bio-refinery units must be equipped by the most reliable and durable equipment in future, owing to the accumulated experience of technology improvements.

Further implementation of biomass fuels on the international market fully depends on the level of novel and modern researches and large investment association. As a consequence, it is probably might assist to rural economical situation and promote large scale industry rising [12].

6.2 The technical potential underpinning the vision

European Environmental Agency study results indicate that the possibility and biomass potential of EU countries to reach desirable goals of renewable energy sustainable development are quite high. In addition, the study forecasted biomass availability value which is ranging from 243 to 316 Mtoe in 2030.

To calculate the energy that can be produced by burning biomass when considering that current average efficiency of plant is about 40%, results in about 97 Mtoe. Besides, maximum energy production if consider future technological progress and as a result increased efficiency, approximately up to 55% which is quite close to the IGCC process efficiency, can be obtain as high as 174 Mtoe from biofuels.

Therefore, it can be estimated that with future energy potential from biomass, 48 % of transportation and traffic demand of EU (360 Mtoe) will be covered in 2030. In order to make technical potential economically feasible, the cost-efficiency of energy generation must be lowered considerably which is approximately 30% using future technology (beyond 2010).

The opportunity of reaching 25% of the EU traffic fuel demand seems to be realizable taking into account that almost 50% of EU energy can be produced from biomass and the rest part is imported from other countries [12].

6.3 Considerations for reaching the vision

As mentioned above, 97 Mtoe of energy produced from biofuels is feasible in 2030 thus approximately 275 million tones of biomass must be converted into biofuels. Considerable cost investments have to be paid in all areas of development of biomass-to-energy industry. “These investments in new technologies would give European industries the possibility of increasing and accelerating their expertise as compared to their global competitors, both for first and second generation biofuels.” To be more precise, it is might assist to rural economical situation and promote large scale industry rising. Thus, this assumption could mean that EU will cover its cost in medium to long term period of time. Obviously, if one can provide desirable political situation with sufficient legislative and pecuniary foundation, the investment value will be obtained.

“Increased use of biofuels will have direct and indirect employment effects.” The paper of the European Renewable Energy Council claims that with meeting the EU target for renewable energy for 2010, tremendous growth up to 424 000 job places in the biofuel sector. Direct and indirect effects mentioned above are interdependent so that increase in indirect effect can cause the possibilities growth resulting in increase the direct effect. However, increase in biofuel sector job places might substitute other areas of employment. As a result, the direct effect will be lowered. The salary and unemployment payments can be affected by increased energy price, as mentioned in a Commission (DG ECFIN) modeling study using the QUEST model, resulting in indirect effect instability which is ranging from 40 000 to 15 000 job places.

It goes without saying that cost benefits from the society side of view will be possible if the EU goal is obtained.

The competitive war between bioethanol, biodiesel and oil prices in EU will be finished at oil prices of about ˆ90 per barrel and about ˆ60 per barrel accordingly. Meeting of the indicative target of the Biofuels Directive requires ˆ 6 billion per year of profits by 2010, which can be reached by means of the EU’s local biofuel industry and import. In addition, a great support for these profits is possible with regulated market-based approach which in turn accelerates the development of local EU biofuels. Moreover, the increase in diesel and oil prices up to 2.5 euro cents per liter, turn out to be as a profit for supplementary investments in biofuels in order to reach the goal for 2010.

“The uncertain development of oil prices and of the cost of biofuel production makes it difficult to quantify the cost to society of reaching the vision for 2030.” Vision Report indicates that utilization of 25% of biofuels for traffic application by 2030 might be assumed as ˆ 31 billion per year which is equal to the increase in oil and biodiesel prices of 6.6 euro cent and 8.2 euro cent per liter, accordingly. In other words, reaching the goal will not only require investments but also careful analysis where society impact must be compared to the currency amount of the benefits as follows: green house gas emission reduction, integration of energy production from different feedstocks, improved security of supply and employment in rural sector. Finally, the sustainable development of biofuels in the future depends on complex action such as research, development and modernization [12].

6.4 Improving existing conversion technologies

As current technologies can not provide the goal of EU it has to be improved considerably. The only way to reach desirable conversion percentage from biomass to energy is development and improvement of biomass incineration process as well as pre-treatment technique and catalytic process. In addition, product purification field must be researched which involves following adding as membranes, new adsorbents, ionic liquids or supercritical extraction.

When considering ethanol product, the feedstock change to starch might result in a great economical benefit as well as reduction of hazardous effect on the environment. This is possible only because of the increase in the yield and high quality of co-products. Ethanol fuel can be on the one level with fossil fuels by means of special adding.

An increase in outcome and cost-efficiency of fatty acid methyl ester (FAME) and fatty acid ethyl ester can be obtained by using of a novel heterogeneous catalysis process. In case of fatty acid methyl ester production, an improvement of glycerol treatment process can result in enhance of its competitiveness.

Biodiesel production from vegetable oil can be enhanced by involving of biological processes based on enzymes. “Diesel fuel can also be produced by hydrocracking of vegetable oil and animal greases.” Currently, this method is being demonstrated and seems to be involved in short term period. The flexibility of the feedstock is an important factor for oil refinery due to its affect on a fuel quality.

To increase the yield of a product and ameliorated cleaning technique is crucial factors with respect to biogas production development. In addition, generation of syngas from the biogas has to be considered.

“The design and operation of existing biofuel plants is largely based on empirical experience.” Thus, optimization of the plants has to be based on thermodynamic, fluid dynamic and kinetic data research. It is the field for the future optimization technology research [12].

7 CONCLUSION

Gasification shows a huge potential for further research work as all industrialized countries have been using gasification as mean to produce electricity, chemicals, hydrogen, synthetic or substitute natural gas.

The greatest opportunity occurs when combining the biomass gasification combined cycle with the renewable energy available through wood residuals and spent pulping liquors, and as a result the forest products industry affects on the EU goals. Thus, in most cases modern projects concerning improved gasification approaches mention a number of combinations with other cycles as well as the electricity supply system base on biomass fuel can no longer be neglected, and it tends to progress in future.

Thus the highest efficiency of energy generation is attained with economical benefits. However, several numbers of these projects were not considered as commercialized due to its non-competitiveness on the market which is a direct result of low cost-efficiency of the plants.

For example, fixed bed gasification technology suffers from another problem which is up-scaling limit. In other words, the difficulties with uniform temperature distribution are a big disadvantage since it is quite problematic to achieve a large fuel bed – the larger the bed, the larger the temperature differences. As a consequence of this problem, many inhomogeneous processes suffering from process control difficulties and syngas quality. Despite this, the Bioneer Company has reached very remarkable results in that field in the beginning of 1980 which could be potential only owing to one of the most successful fixed bed gasifiers in the market - counter-current gasifier based on the classical design. The aim of this gasifier is district heating applications. But, the process does not result in a high quality of the syngas.

Another challenge occurs because the produced syngas contains solid impurities (ash, tar), vaporous metals as mercury and undesirable gases (sulfur chloride) and others such as ammonia, hydrogen chloride. Therefore, gas cleaning technology is crucial when considering biomass gasification development.

It goes without saying that the biomass handling prospect contains a lot of challenges as erosion of feeding devices, harvesting, and storage and equipment shutdown problems connected with bridging appearance. To put it another way, these influencing features can strongly affect on the applicability of the biomass and its investment cost when considering handling equipment and exploitation barriers.

The gasifier lining is the significant factor effecting on the reliability and durability of the reactor as well as operational properties. Systems based on the black liquor gasifiers were tested and the results showed that it might be the most challenging for gasifiers refractory materials due to its highly aggressive environment inside the reactor. As a consequence, abundant options for selecting the most reliable material are a field to research. Furthermore, the area for future development is the temperature distribution in the gasifier which reaches its maximum value at the bottom. Thus, to expel refractory materials of reactor from overheating it is prospective to reduce the temperature stress by substituting the liquor spray.

All mentioned above challenges of the gasifiers operation effects on the cost-efficiency of the technology. In addition, another cost effective factor is bed material which is highly consumed.

Further implementation of biomass fuels on the international market fully depends on the level of novel and modern researches and large investment association. As a consequence, it probably might assist to rural economical situation and promote large scale industry rising.

European Environmental Agency study results show that the possibility and biomass potential of EU countries to reach desirable goals of renewable energy sustainable development are quite high.

Besides, maximum energy production if consider future technological progress and as a result increased efficiency, approximately up to 55% which is quite close to the IGCC process efficiency, can be obtained as high as 174 Mtoe from biofuels.

Finally, the sustainable development of gasification from biofuels in the future depends on complex action such as research, development and modernization. As current technologies cannot provide the goal of EU it has to be improved considerably. The only way to reach desirable conversion percentage from biomass to energy by means of gasification is development and improvement of biomass incineration process as well as pre-treatment technique and catalytic process.

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