OPET Finland

Review of Finnish biomass gasification technologies

OPET Report 4

TECHNICAL RESEARCH CENTRE OF FINLAND

ESPOO 2002

Preface

This report is part of the OPET Network work carried out under the Promotion of Gasifiers co-ordinated by OPET CORA c/o Saarländische Energie-Agentur GmbH (SEA). The core task is to allow potential investors to receive a good overview on the most promising gasifier technologies.

OPET Finland is a member of the OPET Network (Organisations for the Promotion of Energy Technologies). The OPET Network aims to promote the results of new energy technologies and their introduction in society. The Network operates under the fifth EU Framework Programme for Research and Development (1998-2002) as part of the Energy, Environment and Sustainable Development Programme. OPET currently includes over 100 partner organisations in 44 countries within the European Union, the candidate countries of Central and Eastern Europe and Cyprus, as well as Norway, Iceland and Israel. OPET Associates have also been established in key work regions such as the former CIS, Latin America, China, India and Southern Africa.

OPET Finland partners are National Technology Agency Tekes, Motiva Oy and VTT Processes.

OPET Report 4 summaries the current situation of the gasification technologies in Finland. The report is written by Mr. Esa Kurkela, head of the gasification and gas cleaning research group at VTT Processes.

Espoo, May 2002

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1. Introduction

In the late 1970s, the Energy Department of the Finnish Ministry of Trade and Industry initiated several research and development projects on the gasification of indigenous fuels. The R&D work in the early 1980s was related to simple atmospheric-fuel-gas applications, including a gasification heating plant, lime kilns and other close-coupled end-users [1]. This development was accomplished in the mid-1980s by commercialisation of two gasifiers. Nine Bioneer updraft gasifiers, originally developed in co-operation by an SME Company and VTT were constructed in 1982 - 1986 with outputs of the order of 5 MW_{th}. These gasifiers are coupled to district heating boilers and drying kilns [2,3]. The Pyroflow circulating fluidised-bed (CFB) gasifier (developed by A.Ahlstrom Corporation) was also commercialised in the mid-1980s, when four gasifiers in the output range of 15 - 35 MW_{th} were constructed. The product gas from these gasifiers is used for fuelling lime-reburning kilns of pulp factories [1,4-5]. Both the CFB and Bioneer gasifiers have been very successful and most of the plants are still in commercial operation.

In the late 1980s, the interest in integrated gasification combined-cycle (IGCC) power plants increased in Finland [1, 6-7]. The Finnish R&D was mainly focused on the development of simplified IGCC processes based on pressurised air gasification and hot gas cleaning. The main potential of this technology is in medium-scale combined heat and electricity production (from 20 to 150 MW_e). The driving force of this development in Finland was the need for higher power-to-heat ratios in cogeneration, since the heat loads in district heating and process industry are no longer increasing whereas the consumption of electricity still grows. Two processes were developed and demonstrated in pilot-scale (ca. 20 MW_{th}) in late 1990's, but no industrial-scale plants has so far been realised [8-11].

However, the economic competitiveness of IGCC technology requires so large plant sizes (>30 -50 MW_e) that this technology is not feasible in all applications utilising biomass. The conventional fluidised-bed combustion has become commercially available also in a relatively small scale (10 MW_e), but this technology has a rather low power-to-heat ratio and consequently its potential is limited to applications with district or process heat as the main product. Thus, there is also a real need to develop more efficient methods for small-scale power production from biomass. One of the alternatives having clearly higher power-to-heat ratios than can be reached in conventional steam cycles [12] is gasification followed by an internal combustion engine. As part of the hot gas cleaning R&D for IGCC applications, VTT has extensively studied catalytic gas cleaning methods [13,14], and now this experience is utilised in developing efficient methods for tar removal in atmospheric-pressure engine applications.

In addition to the engine power plants, there are other interesting applications for atmospheric-pressure gasification technology. One of the most interesting alternatives for cost-effective biomass utilisation is co-firing of biomass-derived product gas in existing pulverised coal fired boilers. This concept has been the main focus of Finnish gasification development work since 1995. At present two industrial-scale (40-60 MW) fluidised-bed gasifiers are in operation in Finland.

2. Fixed-bed gasification technologies for small-scale heat and power production

2.1 General

Two basic types of traditional fixed-bed gasifiers are illustrated in Figure 1. Both reactor types are based on natural slowly descending fuel flow caused by gravity. The residence time of the fuel in the gasifier is long and the gas velocity is low. Generally these gasifier-types are used in small-scale energy production (< 10 MW_{th}). The traditional fixed-bed gasifiers are suitable only for sized feedstocks, which have high enough bulk density to guarantee stable fuel flow. Both types of fixed-bed gasifier have been developed and used in Finland. In addition, new gasifier designs have been developed recently. The most well known fixed-bed gasifier operated with a range of biofuels is the Bioneer gasifier, which has been in successful commercial operation in Finland and in Sweden already since mid-1980's.

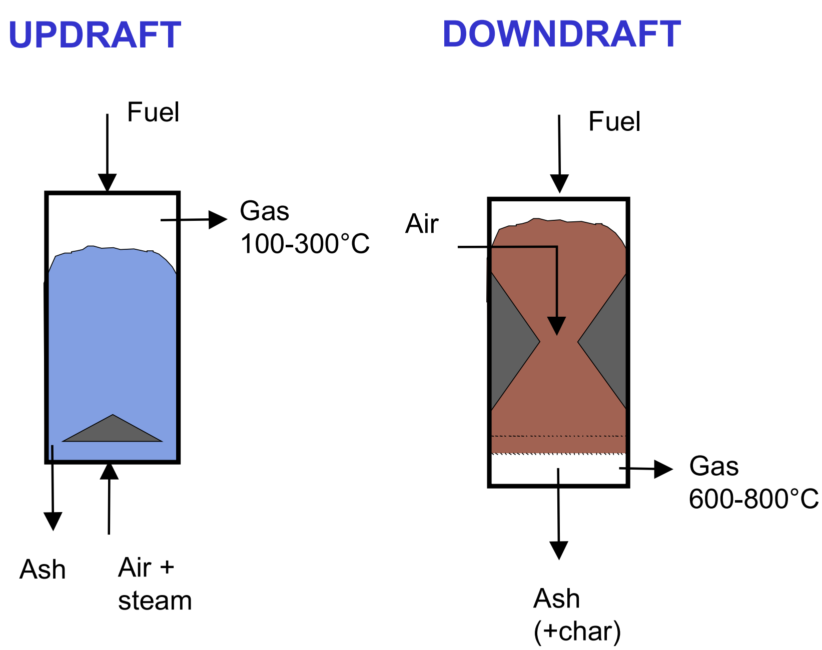


Figure 1. Conventional fixed-bed gasifier types.

2.2 Updraft gasifiers

2.2.1 General

In an updraft gasifier the fuel is fed to the top of the gasifier, wherefrom it flows down slowly through drying, pyrolysis, gasification and combustion zones. Ash is removed from the bottom, where the gasification air and steam are introduced. As the products of drying and pyrolysis zones are directly drawn into the product gas without secondary decomposition reactions, the product gas of an updraft gasifier contains an abundance of oils and tars. In addition, the product gas temperature is low (with biomass fuels 80-300 ^oC and with coal 300-600 ^oC). Bottom ash is usually completely oxidised and does not contain significant amounts of unburnt carbon. Usually, the dust content of the product gas is rather low due to low gas velocities and due to "filtering effects" of the drying and pyrolysis zones.

2.2.2 Bioneer-gasifier

The BIONEER gasifier is an updraft fixed bed gasifier, producing tarry LCV fuel gas. A photograph and schematic diagram of a Bioneer district heating plant is presented in Figure 2. The gasifier consists of a refractory lined vessel with a rotating cone-shaped grate. Biomass fuel is fed from the top, wherefrom it flows downwards through drying, pyrolysis, gasification and combustion zones. The residual ash is discharged from the bottom by the rotating grate. The temperature of the combustion zone is regulated by humidifying gasification air. Air and steam are fed as the gasification media through the grate. Since updraft gasification produces a raw gas with significant amount of tar, the gas cannot be either transported long distances or directly used in IC engines.

In the existing BIONEER plants the gas is burnt in a boiler to generate hot water for district heating. During the mid 1980's, VTT and BIONEER conducted extensive tests with a variety of feedstocks (ex. wood chips, forest wastes, peat, straw, RDF pellets, and coal and RDF mixed with wood chips) in a 1.5 MW_{th} pilot plant located at BIONEER's Hämeenlinna works. A typical gas composition with 41% moisture content wood chips consists of 30% CO, 11% H_2, 3% CH_4, 7% CO_2, and 49% N_2, with a HHV of 6.2 MJ/m^3_n. The tar content of dry product gas is estimated to be in the range of 50 to 100 g/m^3_n. Between 1985 and 1986, when fuel oil prices were high, eight commercial BIONEER plants, with capacities ranging from 4 to 5 MW_{th}, were commissioned, five in Finland and three in Sweden. Four plants are operated with wood or wood and peat mixtures while the rest are operated with peat only. Most of the gasifiers are in operation at small district heating plants to provide circulating hot water [1-3].

The BIONEER plants are completely automated and operated with minimal personnel costs. A. Ahlstrom corporation bought the BIONEER Company. After Foster Wheeler acquired Ahlstrom, in 1996 a 6.4 MW_{th} plant was installed at Ilomantsi, in eastern Finland. At present, similar updraft gasification technology is offered also by Carbona Oy, which also has the required knowledge on this updraft gasifier.

The performance and experiences of the commercially operating Bioneer gasifiers were collected and evaluated in 1998 by VTT and by one of the plant operators [15]. The following is a short summary of the experiences.

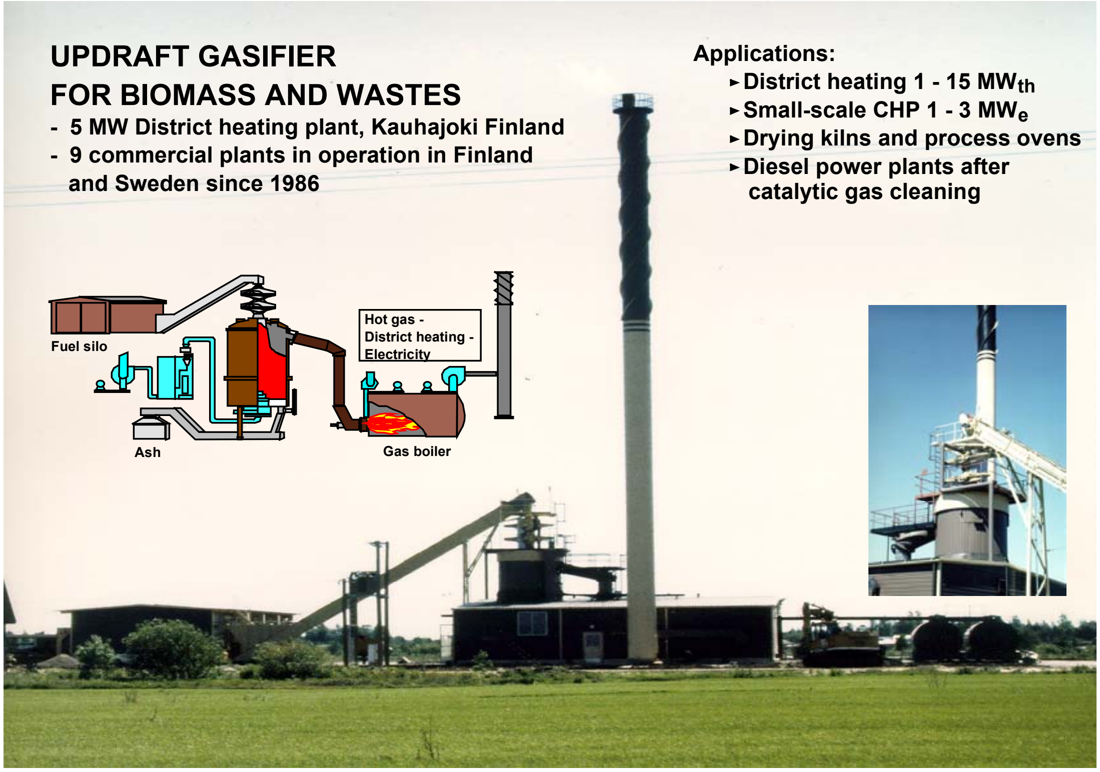


Figure 2. Bioneer-gasifier in the district heating plant of Kauhajoki, Finland.

The original fuel requirements given by the manufacturer were as follows [15]:

- Moisture content less than 50% of the weight of moist fuel
- Ash amount less than 10 wt% of dry matter
- Minimum softening point of ash > 1 190 ^oC (DIN 51730)
- Heat value 0.65 - 1.7 MWh/ m^3

In addition, the manufacturer has given minimum and maximum values for the piece size of the fuel. These values are dependent on the dimensions of the conveyor system and on the requirements of the gasification process. The main fuels of the gasification plants in operation in Finland have been sod peat and wood chips. The most significant deviation from the specification given by the manufacturer is the maximum moisture content, which in real plants has hardly ever exceeded 45%, and shall not exceed 40% if the peak efficiency of the gasifier is required for a longer time. The main reason for this limitation is that the combustion of the low-temperature product gas containing a lot of tar aerosols and water vapour becomes unstable when the moisture content exceeds 45%. No lower limit has been found for the moisture content in practice, not even due to safety issues [15].

On the whole, fixed-bed updraft gasification has proved to be a good and economically feasible combustion method in small district heating systems. Fuel requirements are not unreasonably stringent considering the requirements of the process. However, several potential fuels, such as crushed bark, saw dust and crushed demolition wood cannot without problems be used at these plants (due to fuel flowing problems). In addition, the use of updraft gasifier gas without further gas treatment is limited to applications, where the gas can be burned close to the gasifier. The tars also foul the gas pipe leading from the gasifier into the boiler and shorten the period after which the gas pipe must be cleaned by burning the tars. In Finnish plants, the gas line has been cleaned once in 2-6 weeks (depending on the fuel properties and output of the gasifier).

2.2.3 The Novel fixed-bed gasifier of Condens Oy

VTT Energy and Condens Oy have developed a new type of fixed-bed gasifier (Figure 3), which is based on forced fuel flow and consequently allows the use of low-bulk-density fibrous biomass residues. This gasifier is a combination of the updraft and co-current gasification technologies. The main idea of the developers of this new gasifier type was to combine the best features of Bioneer updraft gasifier with the low-tar content typical to downdraft gasifiers.

In 1999-2001, the 500 kW_{th} pilot-plant has been operated in the test hall of VTT [15]. Based on the positive test results, Condens Oy is offering this technology for a wide range of feedstocks. The main features of the Novel process are:

- fuel feeding is not based on natural gravity alone
- suitable for various biomass residues and waste-derived-fuels
- high carbon conversion and low tar content
- can be scaled up to above 8 MW (which is the usual upper limit of Bioneer gasifiers)
- no problems with leaking feeding systems or blocking gas lines
- demonstrated at pilot scale with
    - forest wood residue chips (moisture 10 - 55 wt-%)
    - sawdust and wood shavings
    - crushed bark (maximum moisture 58 %)
    - demolition wood
    - residues from plywood and furniture industry
    - recycled fuel manufactured from household waste
    - sewage sludges (together with other fuels)

The Novel gasification system of Condens Oy is planned to be commercialised first in heating applications, where the first demonstration plant is expected to start operation in 2002. Condens together with VTT has also developed gas cleaning methods to produce clean gas, which is suitable to be used in modern turbo-charged gas engines. The complete gas purification line has also been demonstrated in pilot-scale by VTT [15].

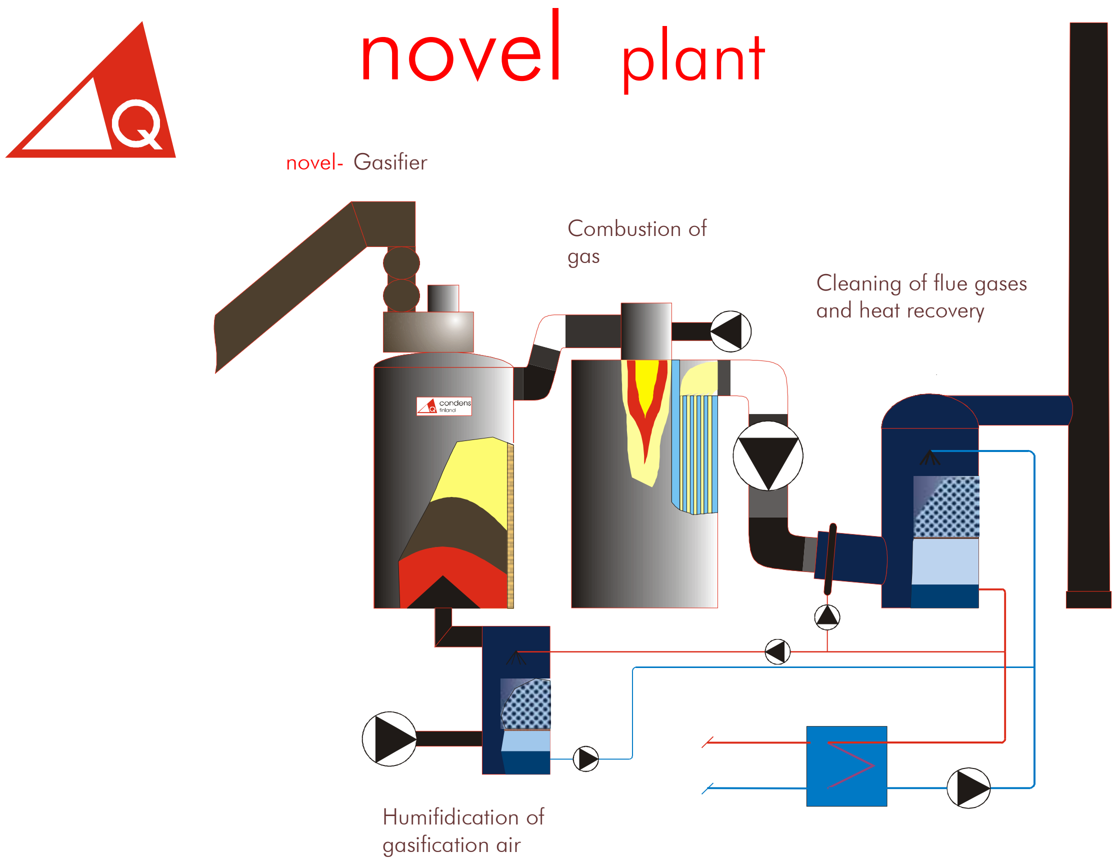


Figure 3. Novel fixed-bed gasifier of Condens Oy in heating application.

2.2.4 Other updraft gasifiers

Ekogastek Oy has constructed a full size test plant (4 MW) for waste gasification in the town Lappeenranta in East Finland. It is based on updraft gasification equipped with innovations of Russian origin. The plant was commissioned 1998 and it has been tested with various waste-derived feedstocks. The special feature of the gasifier is the operation based on circulation of ceramic balls that are fed to the gasifier with the fuel and removed and separated from the ash.

2.3 Downdraft gasifiers

The use of small downdraft gasifiers has long history in Finland, where hundreds of cars, busses and boats were operated by wood gas during the II World War. Even today, there are still a group of 10 - 15 active persons in Finnish country side, who are driving with a car fuelled by downdraft gasifiers. The potential advantage of downdraft gasifier is the fact that the pyrolysis products have to flow co-currently through the hot combustion and gasification zones, were most of tars are decomposed and oxidised. Thus, the product gas of an ideal downdraft gasifier can after simple filtration and cooling be used in an internal combustion engine. During the last two decades, there have been a few of trials to develop a simple power production system based on downdraft gasifiers and IC engines. So far, none of these trials have resulted in the development of commercially viable process. The main reason has been that the ideal (low-tar) operation of downdraft gasifier is limited to extremely high-quality sized wood fuels, which do not exist in practice at reasonable cost [15].

At present, the most promising system based on modified downdraft gasification is developed by Entimos Oy. Entimos Oy (established in 1997) is constructing a new type of gasifier and a CHP plant in Tervola, which is community of ca. 2000 inhabitants in Lapland. The gasifier (Figure 4) combines feature from both updraft and downdraft gasifiers and is based on innovations partly originating from the times of the WWII. The special feature of this gasifier is two product gas lines: Gas B that is directly combusted and clean gas A, which is utilised in an engine.

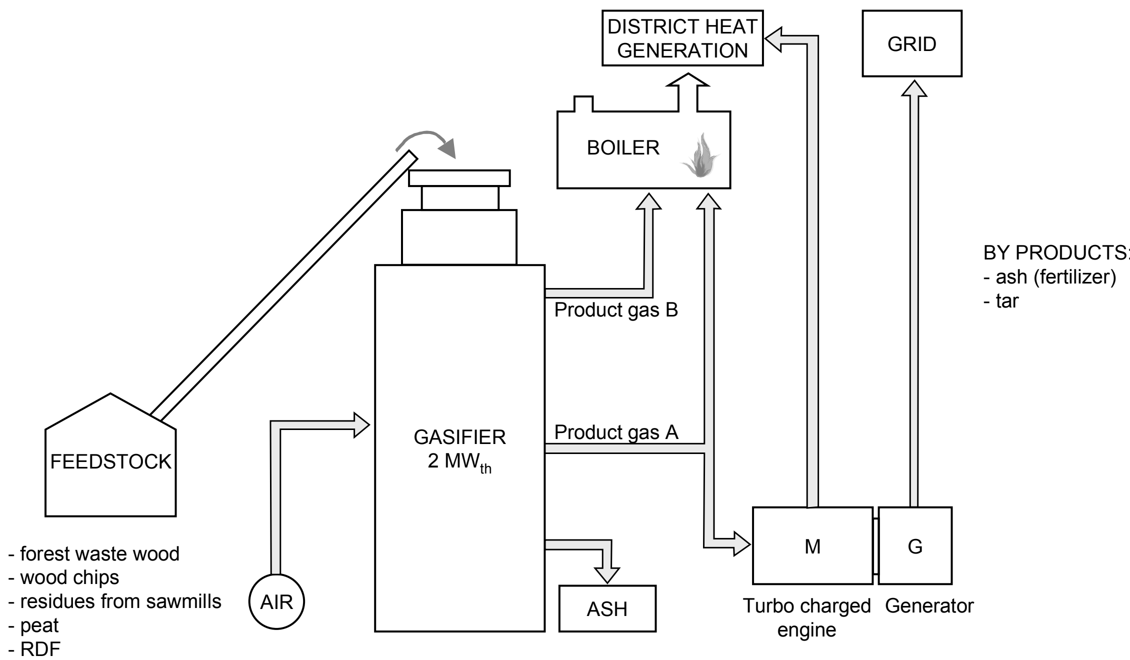


Figure 4. The demosntration gasification and engine plant of Entimos Oy in Tervola, Finland.

The main features of the ENTIMOS gasification process are:

- combined updraft and downdaft gasification
- innovative feeding, grate and ash removal systems
- adjustable in large range: 20 - 100% of nominal capacity

The Tervola CHP plant will be commissioned in summer 2001. The gasifier has fuel capacity of 2 MW and it is connected to a boiler and a Jenbacher engine. The plant will generate 1.1 MW of heat and power about 450 kW, which corresponds about 90 % of the district heat and 10 % of the power capacity, required by the Tervola community. Local feedstocks are used, like various residues from sawmills and forest waste wood.

Another downdraft gasification R&D project has been realised by Lehtimäki community in Central Finland, where a small-scale CHP process based on downdraft gasification has been built. The objective of this project is to develop a commercial unit available in capacity range 30 - 3000 kW_{th} for farms, greenhouses and communal CHP stations. The project has focused on the R&D of the gasifier and automation of the process.

3. Low-pressure fluidised-bed gasification

3.1 CFB gasification

The first commercial Circulating Fluidised Bed (CFB) gasifier supplied by Foster Wheeler Energia Oy (previously A.Ahlström Oy) has since 1983 replaced 35 MW fuel oil in a lime kiln at Wisaforest Oy, Pietarsaari, Finland. Since then similar gasification plants having the same basic technology have been installed at two pulp mills in Sweden and one mill in Portugal. These gasifiers produce lime kiln fuel from bark and waste wood and they also utilise part of the generated gas in drying plants [4-5, 16].

The atmospheric CFB gasifier is very simple. The system consists of a refractory-lined reactor where the gasification takes place, of a uniflow cyclone to separate the circulating material from the gas and of a return leg for returning the circulating material to the bottom part of the gasifier. The operating temperature in the reactor is typically 800 to 1000 ^{o}C, depending on the fuel and the application. The fuel is fed into the lower part of the gasifier above a certain distance from the air distribution grid. When entering the reactor, the biofuel particles start to dry rapidly and the pyrolysis also occurs. The gaseous products of drying and pyrolysis flow upwards in the reactor. Part of the char coal flows down to the more dense part of the fluidised bed while part of the char coal flows up together with the circulating media into the uniflow cyclone. Most of the solids are separated from the gas in the cyclone and returned to the bottom of the bed, where the char coal is combusted with the air that is introduced through the grid nozzles to fluidise the bed [16].

In 1998 a new CFB gasifier supplied by Foster Wheeler Energia Oy was taken into operation in the Kymijärvi Power plant in Lahti, southern Finland. This gasifier (Fig. 5) is connected to an existing coal-fired boiler. The gasifier utilises roughly 300 GWh/a of different solid biofuels and refuse-derived fuels from the Lahti area. From the process points of view the major difference compared to the lime kiln gasifier of 1980's is that in Lahti the fuel is gasified without drying. The moisture content can be up to 60 %. The capacity of the gasifier is 40-70 MW depending on the moisture content and heating value of the input fuel.

In Lahti biofuels and REF are converted to combustible gas in the gasifier at atmospheric pressure at a temperature of about 850°C. The hot fuel gas flowing through the uniflow cyclone is slightly cooled down in the air preheater before it is fed into the main boiler. Simultaneously, the gasification air is heated up in the air preheater before feeding it into the gasifier. The fuel gas is led directly from the gasifier through the air preheater to two burners, which are located below the coal burners in the boiler. The gas is burned in the main boiler where it replaces roughly 15 % of the coal consumption [16].

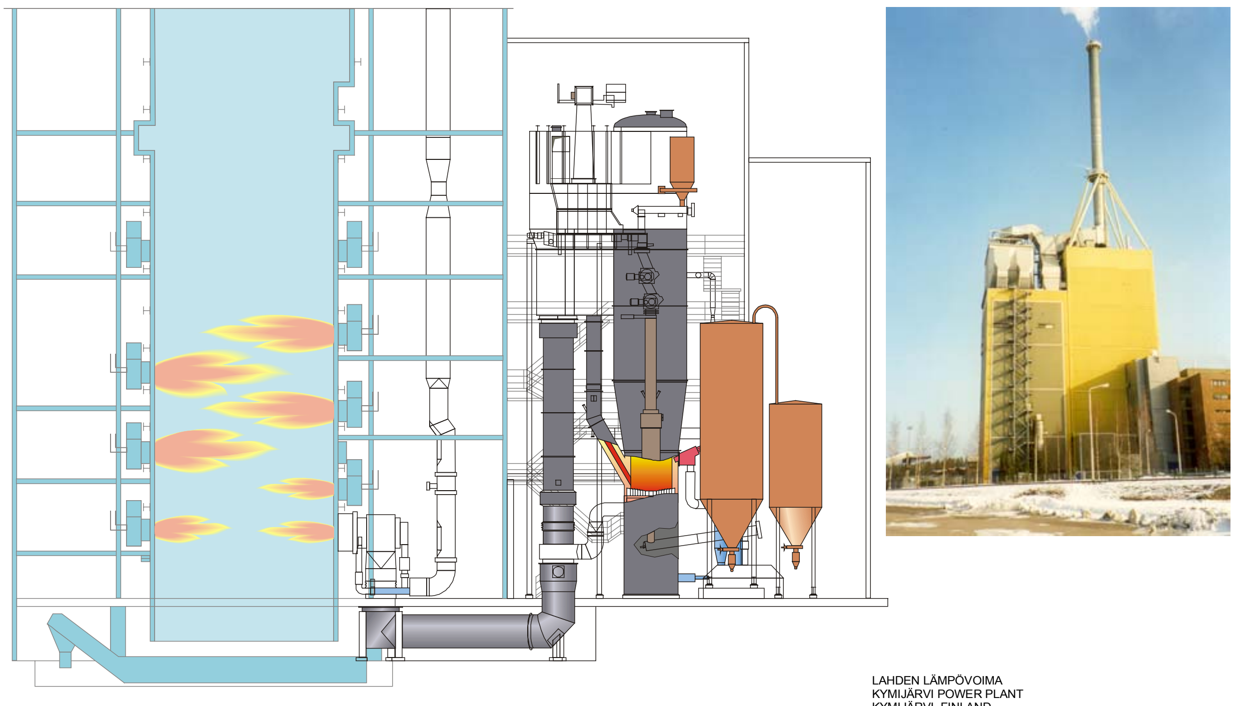


Figure 5. The gasification plant in Kymijärvi Power Plant of Lahden Lämpövoima Oy in Lahti, Finland, supplier Foster Wheeler [9].

The most simple CFB gasification concept realised in Lahti can be utilised only for woody biomass fuels and clean waste-derived feedstocks. In this process a large part of the biomass ash is led together with the product gas into the coal-fired boiler. Many potential biomass feedstocks, such as straw and many fast-growing energy crops as well as industrial and municipal waste fuels often contain high amounts of chlorine, and alkali metals or aluminium, which have a tendency to cause severe corrosion and fouling problems in boilers. Perhaps the most critical factor controlling possibilities for utilising these problematic biofuels in the simple Lahti concept is the usability of coal ash for cement industry and construction purposes. Demolition wood waste is another example of a locally important renewable feedstock, which is difficult to be introduced into ordinary coal-based combustion plants due to the relatively high content of heavy metals (Zn, Pb, Cd, As) and chlorine. Thus, in many cases, gas cleaning is required to avoid operation problems in the main boiler, to achieve the emission limits or to avoid the contamination of the coal ash by biomass alkalis or heavy metals from waste fuels.

VTT has since 1997 studied and developed hot gas cleaning methods for the removal different contaminants from the product gases of CFB gasification of different feedstocks. The scientific and technical knowledge basis for the present gas cleaning development work was to a large extent created already in early 1990's during the development of hot gas cleaning for pressurised gasification cycles [17]. In the basic process concept the product gas is cleaned by dry gas cleaning system before the combustion in the boiler. The dry gas cleaning is based on filtering the gas at about 400°C and using sorbents for chlorine removal. An example flowsheet of this process type is presented in Figure 6. The product gas is first cooled by preheating of gasification air and high-pressure boiler feed water. The cooled gas is cleaned in bag filters. Calcium hydroxide is injected to the gas before the bag filters for binding of HCl. The cleaned product gas is led to gas burners, which are located below the coal burners in the boiler. The dry gas cleaning process has been developed and verified in a PDU scale (300 kW) by VTT using demolition wood, straw and waste fuels. The removal of particles, alkali metals and chlorine has also been demonstrated in the pilot-scale (3 MW) test runs of Foster Wheeler carried out using straw as the feedstock.

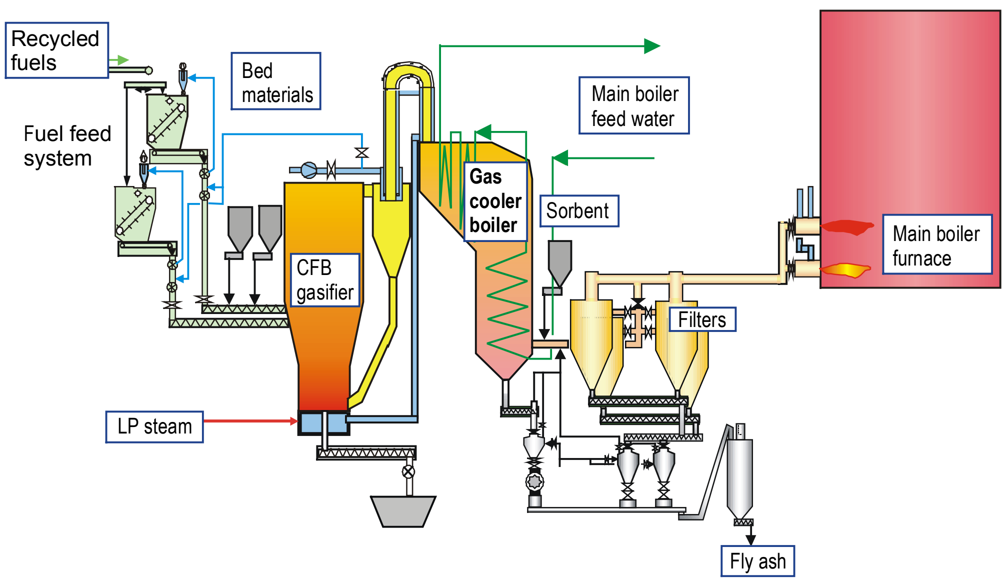
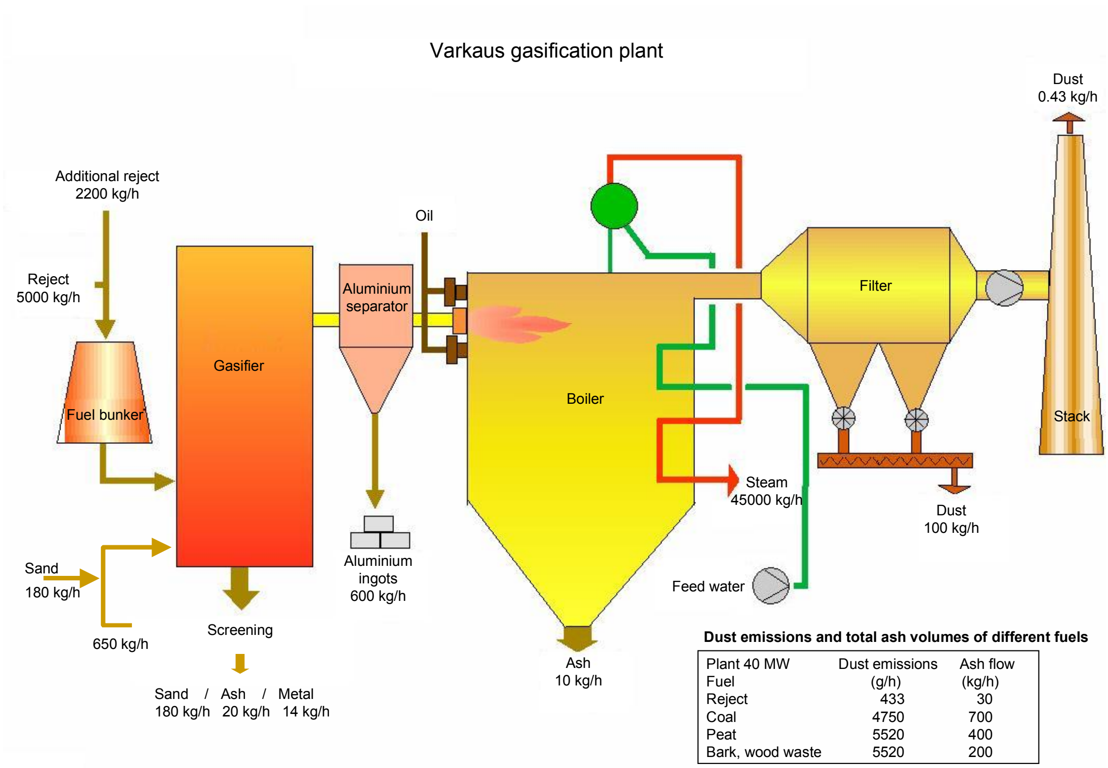


Figure 6. Process concept for CFB gasification of REF followed by dry gas cleaning, Foster Wheeler.

3.2 BFB gasification

Atmospheric-pressure bubbling fluidised-bed gasification (BFB) technology has also been studied and developed in recent years by VTT in co-operation with it's industrial partners. The BFB technology seems to be economically more suitable to medium size applications (15-40 MW) while the CFB technology is most economic on larger scale (40-100 MW) [18]. Similar dry gas cleaning technology can be applied for BFB gasification as for CFB gasifiers.

The first commercial application of the atmospheric BFB gasification in Finland was realised in Varkaus, central Finland by Corenso United Ltd. This gasifier (Fig 7) utilises plastics and aluminium containing reject material coming from the recycling process for used liquid cartoons. In this process, the aluminium is removed from the gas as utilised for recovered aluminium production while the product gas produced from the plastic material is combusted in a steam boiler (replacing fuel oil consumption in the power plants of Stora Enso in Varkaus). The 40 MW_{th} gasifier has been taken into operation in 2001.



Plant 40 MW Fuel	Dust emissions (g/h)	Ash flow (kg/h)
Reject	433	30
Coal	4750	700
Peat	5520	400
Bark, wood waste	5520	200

Figure 7. Gasification plant for plastic residue of Corenso Oy, Varkaus.

Carbona Oy is also planning to commercialise its BFB gasification technology (developed primarily for pressurised gasification) first in atmospheric-pressure applications. In addition to co-firing in boilers, Carbona is looking for medium-scale power plants based on large gas or diesel engines.

Pohjolan Voima Oy and Vapo Oy are developing a new concept for utilising industrial and household wastes in existing coal/peat/oil-fired power plants. This concept is based on optimising the whole chain of waste fuel handling and pretreatment, gasification and gas cleaning as well as final power plant technology. VTT is supporting this team by carrying out gasification and gas cleaning tests and development work. Pilot-scale tests are scheduled to start in late 2001 and simultaneously the first industrial demonstration plant is being designed.

4. Pressurised fluidised-bed gasification

The main market for biomass-based IGCC plants is in combined heat and electricity production in a medium-size range (30 - 100 MW_e). In this size range the IGCC based on oxygen-blown gasification and multistage wet gas cleaning is not economically attractive and, consequently, more simple process configurations are needed to keep the specific investment costs at a reasonable level. The most promising process alternative is the so-called simplified IGCC based on air gasification and subsequent hot gas cleaning [1,6,12].

In 1988 - 1996 several Finnish companies had undertaken significant process development work related to IGCC technology. This development work was supported by extensive research projects conducted at VTT and at Finnish universities.

In the most simple case of the IGCC concept [5], biomass is gasified in a bubbling or circulating fluidized-bed at a temperature of 800 - 1 000 ^oC and at a pressure of 1.8 - 2.5 MPa, and the produced fuel gas is first cooled to 350 - 550 ^oC and then cleaned from particulates and condensed alkali metals by ceramic filters before leading into the combustion chamber of the gas turbine. Perhaps the most critical technical questions of this process concept are the formation of contaminants (particulates, alkalis, tars and nitrogen-containing compounds) in the gasification of different biomass feedstocks and the removal of these contaminants in a both environmentally and economically acceptable way. Almost complete removal of particulates and alkalis is required to protect the gas turbine blades from erosion and corrosion. In some operation conditions tars may block gas coolers and ceramic filters due to condensing or polymerising to soot-like deposits. Ammonia and hydrogen cyanide, on the other hand, are potential sources of fuel-bound NO_x emissions when the gas is combusted.

In 1988 - 1996, different laboratory, bench-scale and PDU test facilities of VTT were used to study the most critical technical questions of the simplified IGCC processes [7, 18]. The most essential part of the work has been carried out at the Process Development Unit (PDU) designed for the R&D of pressurised fluidised-bed gasification and hot gas cleanup for gas turbine applications. A wide range of feedstocks from hard coals, lignite and peat to different wood-derived fuels and straw were used in the gasification tests carried out in 1988 - 1996. The main conclusion from this work was that the technical feasibility of the gasification and hot gas cleaning steps of the simplified IGCC process had been demonstrated in a PDU scale with a wide range of biomass, peat and coal feedstocks. The product gas derived from these feedstocks can be cleaned from particulates and alkali metals by ceramic filters operated at an intermediate temperature of 350 - 550 ^oC. During gas cooling and filtration the volatilised alkali metals react into condensed products, which can be removed together with dust particles to such a degree that the very stringent gas cleaning requirements set by the gas turbines are met.

The whole biomass IGCC process was demonstrated in 1993 - 1999 by Foster Wheeler Energia Oy and the Swedish utility company, Sydkraft. These companies decided in 1991 to start jointly the development of the Bioflow Energy System based on IGCC technology utilising biomass as fuel. The first step in this co-operation was the construction of a small demonstration plant (6

MW electricity and 9 MW district heat) at Värnamo in southern Sweden (Fig. 8). This process is based on pressurised air-blown CFB gasifier and on dry gas cleaning carried out at about 350 °C. The technical feasibility of the biomass-IGCC technology based on the CFB gasification technology of Foster Wheeler was demonstrated in Värnamo with different Swedish wood wastes. Process design and economic studies for larger-scale commercial plants have also been made by Foster Wheeler and Sydkraft, but so far no commercial-scale plants are under design or construction. The Värnamo demonstration program ended in October 1999 and at present the plant is shut down and conserved for possible future R&D projects.

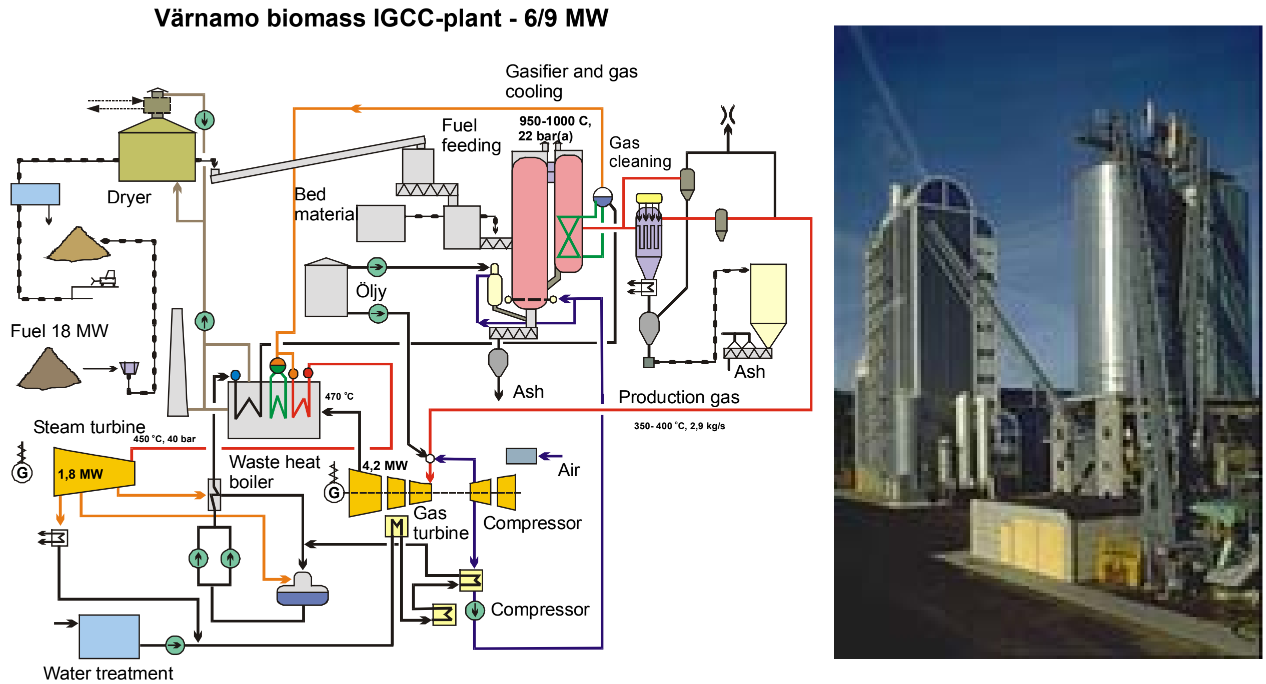


Figure 8. The simplified IGCC plant in Värnamo based on CFB gasification technology of Foster Wheeler Energia Oy.

The other biomass-IGCC technology was developed by Enviropower Inc. based on the U-GAS coal gasification process, originally developed by the Institute of Gas Technology, USA. This process concept is based on pressurised air-blown BFB gasification and hot gas cleanup and the technology is developed both for biomass and coal feedstocks. The gasification and hot gas cleaning steps of the process were demonstrated during extensive test series carried out at a 18 MW_{th} pressurised pilot plant in 1991 - 1995 [6]. Presently, the process is being further developed and commercialised by Carbona Inc, however, so far none of the planned projects have resulted in a positive decision to build the first commercial-scale demonstration plant.

In spite of the fact that the PDU- and pilot-scale tests carried out with a range of fuels were successful and the process was considered to technically ready for larger-scale demonstration, no industrial-scale plants were built in Finland or Sweden in late 1990's. Main reasons for this have been non-technical: a) the electricity markets were deregulated in Scandinavia and at the same time the market price for electricity has been already several years at very low level, b) the production of district and process heat from renewable fuels has become more economic in late 1990's due to increased taxation of the use of fossil fuels for heating, which has resulted in improved economy of conventional district heating plants and c) the public investment support has not been sufficient to make the first demonstration projects economically attractive.

The latest R&D projects of VTT and its industrial partners on pressurised fluidised-bed gasification carried out in 1996 - 99 were focused on the following topics:

a) The development of improved method for recycling the carbon-containing filter fines which makes it possible to achieve complete carbon conversion also in co-gasification of coal and biomass; this system was demonstrated in the PDU test rig at VTT,

b) The development of the Selective Catalytic Oxidation (SCO) process for ammonia removal. The process was also tested with real gases in a slip stream of the Värnamo IGCC plant.

5. Conclusions and future outlook

In Finland, the most likely application where the gasification technology will significantly enter in the market already before 2005, is the utilisation of different industrial and household wastes in existing district heating and industrial CHP plants. The economic studies made by VTT [19] have showed that it seems to be economical to replace part of coal by cleaned refuse-derived product gas, if the price for waste-derived fuel (REF) is close to zero. All developed gasification processes (CFB, BFB and novel fixed-bed) seem to have their own suitable size classes and markets (CFB > 60 MW, BFB 20 - 60 MW and Novel <20 MW).

In the co-firing concepts using product gas derived from REF, the cleaning of product gases seems to play a key role, as the co-firing plants evidently have to obey the new EC directive for waste incineration. Another critical issue, which has a significant effect on the economy of this co-combustion method is the quality and possible end use (or further treatment) of the produced fly ashes of REF gasification. Also fuel taxes, like the other promotion measures for increasing the competitiveness of renewable energy sources, may have a significant role in the economy of REF co-combustion if REF is considered at least partly as a renewable energy source.

There are large markets in several European countries for the utilisation of waste/biomass-derived clean gas in replacing coal and oil in existing power plants. The existing CFB/BFB gasifiers in Lahti and Varkaus together with the promising R&D results on gas cleaning give the Finnish gasification technology suppliers a good starting position in entering the European markets.

In many European countries (e.g. Denmark, Italy, Germany, Austria) the conditions for commercialization of small-scale gasification-engine power plants are more favorable than in

Finland, where the difference between electricity and district heat prices is at present too small to justify high-efficiency power cycles. However, the concept of biomass gasification followed by complete catalytic tar decomposition should preferably be demonstrated first in Finland after which it would be much easier to enter into commercial projects in other countries without too high risk levels.

In many countries, there is a major long-term trend in replacing coal-fired power plants by natural gas combined cycle plants. Consequently, within next ten years there will be increasing market also for combining biomass/waste gasifiers to gas-fired combined cycle power plants. In this application, the most natural process is based on pressurized gasification and mixing cleaned gas with natural gas. Other combinations may, however, also be feasible; e.g. combustion of waste-derived gas in the waste heat boiler and other applications of atmospheric-pressure gasification technology.

On longer run, the IGCC processes based on advanced pressurised gasification systems still have a huge potential in increasing the power to heat ratio of industrial combined heat and power plants (mainly pulp and paper and sugar industries) and district heating. This gives possibilities for increasing substantially the share of renewable electricity production. However, the first industrial-scale demonstration plants require substantial public support (of the order of 50 %) in order to compensate the remaining technical risks and the high investment costs typical to first-of-kind plant.

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