

# Progress in Biomass Gasification: An Overview

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**ABSTRACT** Gasification is an energy process producing a gas that can substitute fossil fuels in high efficiency power generation, heat and/or CHP applications, and can be used for the production of liquid fuels and chemicals via synthesis gas. Gasification technology consists of several unit operations, the most critical of which is gas cleaning and conditioning for utilisation in power production engines. Numerous types of gasifiers have been developed and tested and many industrial applications can use the technology. Significant progress has been achieved over the last five years and some applications are on the threshold of becoming commercial. However, for most of the applications the efficient and economic removal of tar still presents the main technical barrier to be overcome.

This overview reports on the progress achieved over the past five years in thermochemical gasification of biomass and waste recovered fuels. The status of all major projects is reviewed while new trends are briefly presented. The paper concludes with recommendations for future R&D needs and demonstration requirements while attempting to present a strategy for the commercialisation of gasification technologies.

## INTRODUCTION

Biomass is considered the renewable energy source with the highest potential to contribute to the energy needs of modern society for both the developed and developing economies world-wide (1,2). Energy from biomass based on short rotation forestry and other energy crops can contribute significantly towards the objectives of the Kyoto Agreement in reducing the green house gases emissions and to the problems related to climate change (3).

Biomass fuels and residues can be converted to energy via thermochemical and biological processes. Biomass gasification has attracted the highest interest amongst the thermochemical conversion technologies as it offers higher efficiencies in relation to combustion while flash pyrolysis is still in the development stage.

However, although gasification technologies have recently been successfully demonstrated at large scale and several demonstration projects are under implementation (4,5), they are still relative expensive in comparison to fossil based energy and, therefore, face economic and other non-technical barriers when trying to penetrate the energy markets (6,7,8). Their penetration into the energy markets can

only be achieved at present via economic development through biomass systems integration. Thus the innovation in practically all demonstration projects under implementation lies not only on the technical aspects of the various processes but also in the integration of the gasification technologies in existing or newly developed systems where it can be demonstrated that the overall system offers better prospects for economic development (9).

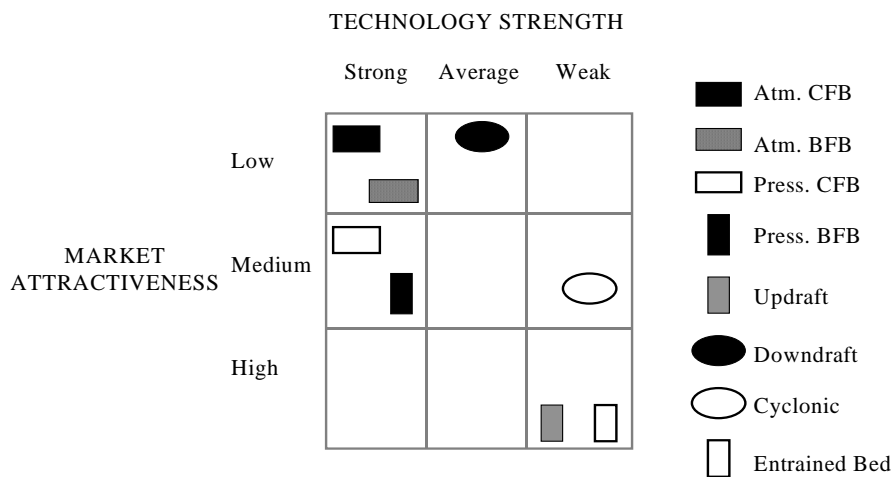
The overview starts with the present status of the various gasification technologies and after a brief introduction to their market prospects the most important projects are briefly presented and discussed based on their market segments. Developments in the various fields are also discussed as well as the R&D needs for an accelerated penetration of gasification technologies in the energy market.

### ***STATUS OF GASIFICATION TECHNOLOGIES***

An extensive review of gasifier manufacturers in Europe, USA and Canada (10) identified 50 manufacturers offering 'commercial' gasification plants from which:

- (1) 75% of the designs were downdraft type,
- (2) 20% of the designs were fluidized bed systems,
- (3) 2.5% of the designs were updraft type, and,
- (4) 2.5% were of various other designs.

However, there was very little information on cost aspects, emissions, efficiencies, turn-down ratios and actual operating hours experience. Above all, no single manufacturer was ready to give full guarantee for technical performance of their gasification technology. This indicates that the actual operating experience is limited and there is little confidence on the technology, which is due to the general poor performance of the various prototypes. *Figure 1* presents a tentative status for gasification technologies in view of their market attractiveness for power generation and the present strength of the various gasification technologies.



*Figure 1* Technology development and strategic planning for power

Atmospheric Circulating Fluidized Bed Gasifiers (ACFBG) have proven very reliable with a variety of feedstocks and are relative easy to scale up from few MWth

up to 100 MWth. Even for capacities above 100 MWth, there is confidence that the industry would be able to provide reliable operating gasifiers. It appears to be the preferred system for large scale applications and it is used by most of the industrial companies such as TPS (11), FOSTER WHEELER (12), BATTELLE (13), LURGI (14) and AUSTRIAN ENERGY (15). Therefore ACFBG have high market attractiveness and are technically well proven.

Atmospheric Bubbling Fluidized Bed Gasifiers (ABFBG) have proven reliable with a variety of feedstocks at pilot scale and commercial applications in the small to medium scale; up to about 25 MWth. They are limited in their capacity size range as they have not been scaled up significantly and the gasifier diameter is significantly larger than that of ACFBG for the same feedstock capacity. On the other hand ABFBG are more economic for small to medium range capacities, thus their market attractiveness is relative high as well as their technology strength. Companies promoting ABFBG are CARBONA (16) and DINAMEC (17).

Pressurised fluidized bed systems either circulating (PCFBG) or bubbling (PBFBG) are considered of medium market attractiveness due to the more complex operation of the installation and to the additional costs related to the construction of all pressurised vessels. On the other hand, pressurized fluidized bed systems have the advantage in integrated combined cycle applications as the need to compress the fuel gas prior its utilisation in the combustion chamber of the gas turbine is avoided. Pressurised systems have been proposed mainly by CARBONA (16) and FOSTER WHEELER (18) with the successful application of SYDKRAFT's Värnamo IGCC plant in Sweden.

Atmospheric Downdraft Gasifiers (ADG) are attractive for small scale applications (<1.5 MWth) as there is a very big market not only in developed but developing economies too (19). However, the problem of efficient tar removal is still a major problem to be addressed and there is a need for more automated operation especially for small scale industrial applications. Nevertheless, recent progress in catalytic conversion of tar (see below) gives credible options and ADG can therefore be considered of average technical strength.

Atmospheric Updraft Gasifiers (AUG) have practically no market attractiveness for power applications due to the high concentration of tar in the fuel gas and the subsequent problems in gas cleaning. Also the technology is considered weak for the same reasons. There is no company proposing AUG for power at present.

Atmospheric Cyclonic Gasifiers (ACG) have only recently been tested for biomass feedstocks and although they have medium market attractiveness due to their simplicity, they are still unproven. No well known company is promoting ACG.

Finally, Atmospheric Entrained Bed Gasifiers (AEBG) are still at the very early stage of development and since they require feedstock of very small particle size, their market attractiveness is very low.

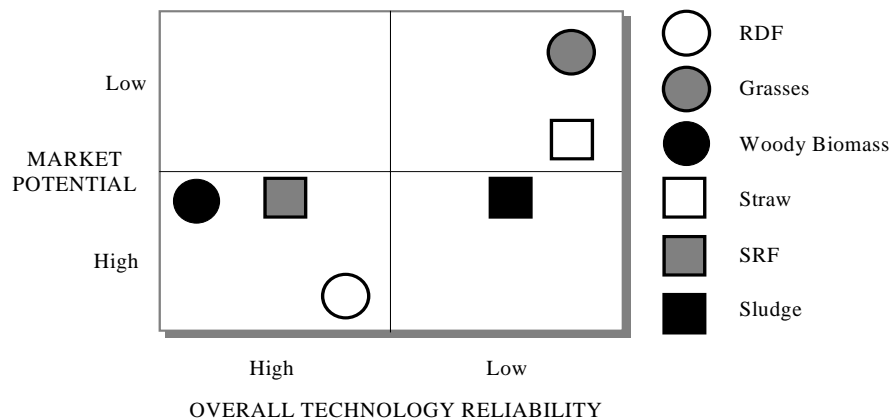
No company is presently developing pressurised systems for downdraft, updraft, cyclonic or entrained bed gasifiers for biomass feedstocks and it is difficult to imagine that such a technology could ever be developed into a commercial product due to the inherent problems of scale, tar removal and cost.

In conclusion, for large scale applications the preferred and most reliable system is the circulating fluidized bed gasifier while for the small scale applications the downdraft gasifiers are the most extensively studied. Bubbling fluidized bed gasifiers can be competitive in medium scale applications. Large scale fluidized bed systems have become commercial due to the successful co-firing projects (see below) while moving bed gasifiers are still trying to achieve this.

For heat applications there is no need to eliminate the tar from the fuel gas and thus any reliable gasifier system can be used successfully. However, although heat applications are relative easy, there are very few examples in the market. The most successful has been the BIONEER updraft gasifier (20), which has been used successfully in ten commercial applications in Finland. This gasification technology was originally commercialised for lime-kiln applications with peat as main fuel and was later applied to co-utilisation of locally available residues and wastes in existing boilers.

### FEEDSTOCK TECHNOLOGY RELIABILITY

One of the most important barriers to an accelerated penetration of all biomass conversion technologies is that of adequate resource supply. *Figure 2* depicts the technology reliability of using the most important feedstocks in gasification applications.



*Figure 2* Status of feedstock technology reliability and market potential

Clean biomass feedstocks are becoming scarce and there is hardly any reliable supply. In some countries like Germany, all industrial wood waste and other wood residues are consumed completely and there is no other clean biomass available to increase the contribution of bioenergy. Thus, the industry has been obliged to look into relative difficult fuels and fuels with little practical industrial experience in order to create new market opportunities. Waste recovered fuels present the advantage that they often have a negative cost associated with their disposal, which can significantly decrease the operating costs of a plant. In addition, since the last decade there has been a significant interest in energy crops and especially short rotation forestry (SRF) as a means to increase the production of biomass fuels while simultaneously creating new jobs for the farming community. SRF operations can also contribute significantly towards sustainability and meeting the Kyoto's obligations.

Woody biomass has the highest reliability in feeding into a gasifier and most problems related to bed sintering in fluidized bed gasifiers or slag formation on heat exchange surfaces are relative well understood and the industry has sufficient confidence to use effectively most types of woody biomass (21). The industry has also attained a high degree of reliability for the pretreatment operations such as

drying, size reduction and storage. However, the market potential of woody biomass is limited as most of the locally available feedstocks are already consumed in various industrial or district heat applications.

Short Rotation Forestry has relative good potential to be used in non arable land and provides a sustainable approach to energy (22), however, since the land has to be blocked for about 15-20 years, farmers in the EU are reluctant to implement SRF schemes. The only exceptions are Sweden, where there is a long tradition for SRF mostly for pulp and paper and the UK where recently successful schemes have been introduced to the farming community (23). The USA (24) has also an ambitious programme for the development of SRF while Canada also has carried out significant work and is examining various SRF implementation schemes. Brazil has successfully established eucalyptus plantations (23). On the other hand, very few tests have been carried out with SRF feedstocks and the industry is a somewhat uncertain about the properties of SRF fuels. A sensitive area is that of heavy metals some of which are easily up taken by the plants (e.g. cadmium).

Grasses (25) have attracted interest recently since they can be cultivated on various places, even on the sides of highways, however, their market potential is still uncertain as there are no dedicated plantations yet and there is relative little experience with such feedstocks. Technically grasses present problems in all pretreatment operations such as size reduction, storage, drying and even their relative fast biodegradability which can result in significant weight loss unless dried and properly stored. Their low bulk density results in solids flow problems and can create local hot spots in the gasifier.

Straw has a relative low market potential for gasification applications since successful combustion technologies have been developed. There is little experience with straw gasification and severe problems of ash sintering and bed agglomeration are known to exist in fluidized bed gasifiers. Due to the low bulk density it is not possible to use straw in moving bed gasifiers unless the straw has been palletised; an expensive operation. However successful operation of the Värnamo plant was achieved with 100% straw feeding (18).

Refuse Derived Fuel has significant potential for gasification applications since gasification does not have such a negative public image as incineration and there is sufficient experience by TPS (26) and FOSTER WHEELER (12). However, the feeding systems for fluff RDF need to be developed further to ensure reliable operation and more experimental results at large scale applications are needed to prove efficient operation.

Finally sludge can also be utilised in gasification applications and although there exists little experience, it is expected that the application with sludge may increase in the future. Technical reliability still has to be demonstrated.

Recently two feedstock databases have been established where a significant amount of information is provided for a variety of biomass feedstocks (27, 28). In the databases, the basic physico-chemical properties of biomass fuels can be found which will provide basic information to gasifier developers as well as gasifier users on the quality and suitability of the various fuels for the gasification technologies they either develop or use.

## ***BIOMASS & RECOVERED FUELS STANDARDISATION***

The guaranteed supply of biofuels is an important element for the promotion of bioenergy in general and gasification technologies in particular. This requires the

creation of a biofuels market, which necessitates the development of standards to govern any transaction between producers and users of biofuels. The availability of standards for biofuels would provide guidance to the farmers, foresters and producers of recovered fuels of the types and quality of the fuels the market requires as well as a guarantee to the users of the quality of the fuels they procure from the market.

The European Commission took the initiative to instigate an action in 1998 with the industry and several EU National Organisations on this issue, which resulted in a mandate to the European Centre for Normalisation (CEN) for the elaboration of standards for Solid Biofuels (CEN/TC 335). For Solid Recovered Fuels, originating from waste streams, the European Commission gave only a programming mandate to CEN (CEN/BT/Task Force 118), which may eventually result into a full mandate subject to the contents of the various classes of fuels. Both mandates are to be supported by quality assurance systems to ensure the quality of the fuels entering the future biofuels market. This action was evolved to an IEA Bioenergy Task, “Task 28 Standardisation of Solid Biomass Fuels” with the inclusion of US Department of Energy in the standardisation activities (29).

In particular for gasification technologies, which require well calibrated and defined feedstocks in terms moisture, size, ash and inerts, the standards will facilitate the production of dedicated fuels for gasifiers.

## **TAR REMOVAL**

The efficient removal of tar still remains the main technical barrier for the successful commercialisation of biomass gasification technologies and unless this barrier will be properly addressed biomass gasification applications for power, with the exception of pressurised IGCC, will never materialise. There are several groups which have been working extensively on tar, however the most prominent teams are those (in alphabetical order) of the University of Madrid (30, 31), The Royal Institute of Technology in Stockholm (32, 33) and VTT (34, 35).

## ***TAR REMOVAL TECHNOLOGIES***

The main attempts to eliminate tar concentrate on three approaches: scrubbing, catalytic reforming followed by scrubbing and hot gas clean up. In the later case the producer gas is kept above 400 °C in order to avoid tar condensation and the hot fuel gas is burned in the combustion chamber of a gas turbine. However, this approach applies only to pressurised gasification IGCC systems and has been successfully demonstrated at the Värnamo plant (18) while recently the quality of the tar produced by the FOSTER WHEELER gasifier has been reported (36). This approach has been proven successful as there were no problems due to tar (either in the filters or in the gas turbine) during the operation of the Värnamo plant for more than 3600 h on IGCC operation.

The simple scrubbing approach has failed repeatedly to prove long term operational reliability and in addition it creates a serious environmental problem because of the large quantities of condensate produced. Between wet and catalytic cleaning methods, the latter is preferred because it actually destroys/modifies the tars instead of transferring them to a liquid phase, which needs further and expensive waste water treatment. Among the possible catalytic cleaning methods, two are being adopted by most of the institutions and companies working on biomass gasification:

they are either based on the use of calcined dolomites (or related materials) or of steam reforming (nickel-based) catalysts located downstream the gasifier. Calcined dolomites have proved their usefulness for tar removal but they have two operational problems. First they have low mechanical strength, which result into significant erosion and thus catalyst consumption, with the associated increase of the particulates content in the fuel gas. Second because of their low catalytic activity, it is very difficult to reduce the tar contents in the exit fuel gas below 0.5-1.0 g/Nm<sup>3</sup>.

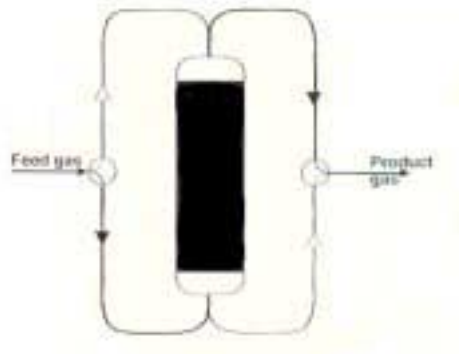
Catalytic tar elimination over nickel-based catalysts mainly proceeds by steam and dry (CO<sub>2</sub>) reforming reactions, although there can be simultaneous thermal reactions of cracking and, perhaps, of hydrocracking. Therefore, the steam and CO<sub>2</sub> contents in the flue gas have an important role in the overall tar elimination. Tar conversion (elimination) depends on the properties of the catalyst used, on the space-time (or space-velocity), bed temperature, H<sub>2</sub>O to carbon to be reformed ratio and on the operation variables of the upstream gasifier such as equivalence ratio and temperatures in the bed and in the freeboard.

The combination of catalytic reforming followed by scrubbing offers the only remaining hope for the gasification industry to effectively address the tar problem. Three main configurations have been proposed and are under development:

1. reverse flow catalytic bed with dolomite,
2. second, fluidized bed with dolomite, and,
3. catalytic bed with monolith based catalyst.

#### ***Reverse flow catalytic bed with dolomite***

The reverse flow catalytic bed has been proposed by BTG (37) and Wellman (38). The principle is based on transferring heat by the partial combustion of the fuel gas to maintain the temperature of the catalyst bed to about 900 °C from the gas to the catalyst bed and vice-versa. The hot reaction front moves along the catalyst bed and when the reaction front reaches the end of the catalyst bed the flow of the gas changes (*Fig. 3*).

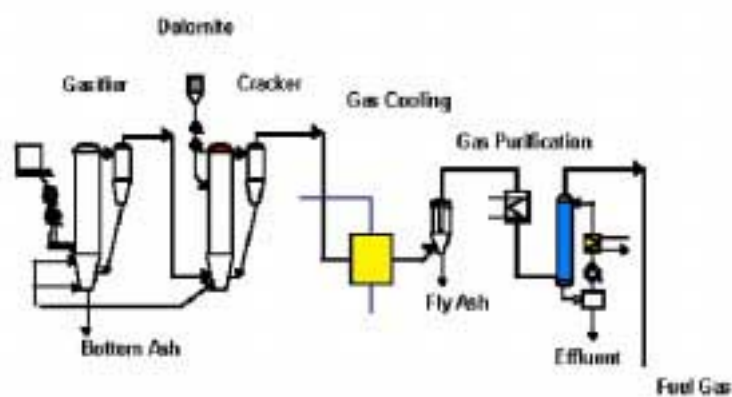


*Figure 3* Schematic of the catalytic fixed bed reverse flow tar removal system

This technology has been demonstrated at pilot scale by both organisations, however, it still has to be operated in demonstration scale applications to prove its reliability and economics. BTG will use the technology in a demonstration project (39), which is scheduled to start operation by 2002.

### ***Secondary fluidized bed with dolomite***

This approach has been proposed by TPS (11, 40), (*Fig. 4*) and has been demonstrated extensively at pilot scale with a variety of feedstocks. Full scale demonstration is expected to be achieved soon when the ARBRE plant (41) is commissioned in Spring 2001. An important element in the ARBRE demonstration project would be the operational cost for the calcined dolomite catalyst as well as the associated waste disposal costs. The successful demonstration of the ARBRE project would provide reliability for large scale IGCC and will also be the 'springboard' for other large scale projects in preparation such as the second generation of ARBRE (35-40 MWe) in the UK, (41) and the Brazilian project (30-35 MWe), (11).



*Figure 4* Schematic of second fluidized bed and subsequent gas cleaning

### ***Catalytic bed with monolith based catalyst***

The monolith catalysts are the least tested in pilot scale, however they have the advantage that they offer good mechanical strength and have high catalytic activity. On the other hand their cost is considerably higher and they are more prone to poisoning and deactivation than dolomite and related catalysts. Because of their cost, the most important operational variable is the life of the catalyst.

There are three causes that can deactivate the catalyst, coke (formed from tar), sulphur poisoning, and particulates. Deactivation by coke is not important if the tar content in fuel gas is below 2 g tar/Nm<sup>3</sup> and this can be achieved with a good operation of the upstream gasifier (with in-bed dolomite and high temperatures in the gasifier freeboard, for instance). Deactivation by sulphur remains to be verified in very-long term tests although the sulphur content in biomass feedstocks is not high. Finally deactivation by particulates can be avoided if monoliths are used instead of rings and the particulates content in the fuel gas is carefully controlled. The main catalyst manufacturer and provider is BASF AG of Germany, while the two main research teams which have extensively studied Nickel-based monoliths are the University of Madrid and VTT.

There are two recent projects, which plan to use this approach in eliminating tar (42, 43). Both are based on bubbling fluidized bed gasifiers (*Fig. 5*) and are



addressing the small to medium scale for power applications (1-5 MWe). In both cases the fuel gas is burned in a gas engine to generate electricity while in one of the projects (42) the waste heat is recovered in a district heat application. The success of these two projects will be critical for this market segment as other tar removal options are uneconomic or unreliable.

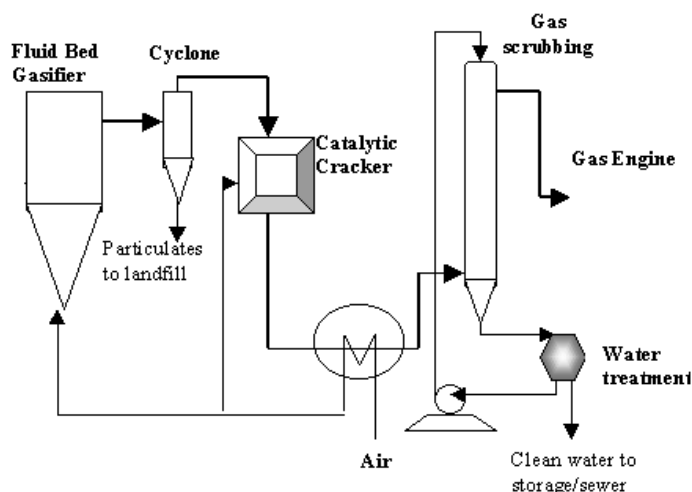


Figure 5 Schematic of catalytic reactor arrangement with monolith Ni-based catalyst

## TAR PROTOCOLS

A number of different sampling and analysis methods have been developed by manufacturers and various institutes working in this field to determine the level of particulates and tar in the gas exiting the gas cleaning system of a gasification installation. This diversity of methods makes the comparison of operating data from different sources very difficult and represent a significant barrier to the further development and commercialisation of the technology.

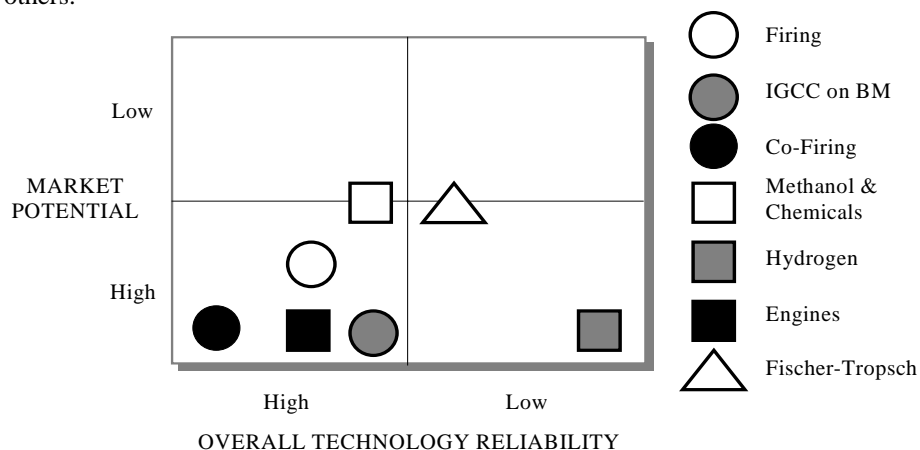
The members of the IEA Bioenergy Gasification Task, the European Commission and the US DoE have been aware of this barrier for some time. In order to address it they called a joint meeting in the Spring of 1998, where it was decided to draft two sampling and analysis protocols – one for small scale, fixed bed, engine based systems and the other for larger utility scale plants (44). These protocols were to describe the best available procedure for each scale of operation and should reflect as far as possible the collected experience and expertise of the international gasification community. It was intended that the procedures should be used as reference methods and would eventually be submitted as the bases of European and US standard methods. More specifically the objectives were to describe a procedure and set of apparatus that would allow a skilled technician to:

- Determine the concentration of particulate material in the fuel gas stream gravimetrically;
- Determine the concentration of higher hydrocarbons or tars gravimetrically.

The first results (45, 46) were reported in a dedicated workshop during the 10<sup>th</sup> European Conference on Biomass for Energy & Industry, Würzburg, 1998 and were published in a special issue of Biomass & Bioenergy, volume 38 (44). This work prompted a significant amount of high quality dedicated publications from several groups working on this problem (47-50). It also concentrated the European scientific resources in a collaborative effort to address the tar & particulate measurement during parallel tar measurements sponsored by the Danish Energy Agency, NOVEM, VTT & the Swiss Federal Office of Energy (51). In addition, an international concerted action was sponsored by the European Commission to continue the work initiated by the Gasification Task of IEA Bioenergy and complete the tar protocols (52). The first conclusions of the work was that the protocols should be integrated into one for sampling and analysis of tar from all biomass gasifiers under all relevant conditions (0-900 °C; 0.9-60 bar) and concentrations in the range of 1mg/Nm<sup>3</sup> to 100 g/Nm<sup>3</sup>. Compared to the Würzburg Protocols, another solvent will be used because dichloromethane is not considered to be suitable for reasons of safety and health.

## APPLICATIONS

The various gasification applications for power and or heat are shown in *Fig. 6* in terms of their market potential and overall technology reliability. Each of these applications will be discussed in the subsequent sections and the most advanced plants in each application will be presented in terms of their status and future prospects. It is of course beyond the scope of this overview to present all known activities, however, the most significant of these will be discussed as a means of presenting their achievements for the benefit of the other projects, which are still in the development stage. All demonstration projects had to overcome numerous technical and non-technical barriers as this is an emerging technology, however, many of these problems are common to all projects in the same application field and thus the projects still in the development face could learn from the experiences of the others.



*Figure 6* Status of applications for market potential and technology reliability

## ***FIRING IN BOILERS OR HEAT APPLICATIONS***

Firing the raw gas in boilers or heat applications such as kilns after removal of dust and particulates is the simplest application since the gas is kept hot and the tar problem is avoided. However, surprising enough, there are very few known successful applications, which have been operating in a commercial environment. This market is one where all types of gasifiers can compete and more concerted efforts have to be undertaken by the gasification industry to increase the number of successful cases.

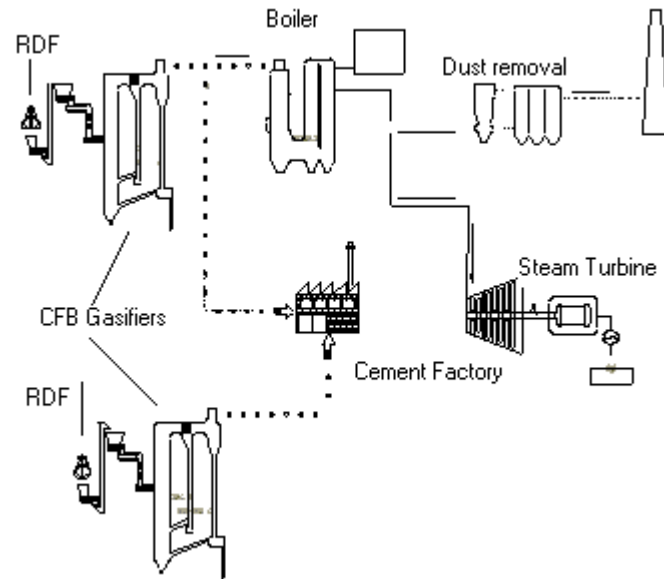
Between 1985 and 1986, when fuel oil prices were high, eight commercial BIONEER plants, with capacities ranging from 4 to 5 MWth, were commissioned: five in Finland and three in Sweden. Four plants are operated with wood or wood and peat mixtures while the rest are operated with peat only. Most of the gasifiers are still in operation at small district heating plants to provide circulating hot water. Ahlstrom Corporation bought the BIONEER company originally owned by YIT Corporation. After Foster Wheeler acquired Ahlstrom, in 1996 a 6.4 MWth plant was installed at Ilomantsi, in eastern Finland. The estimated investment cost for district heating applications is about 350 kECU/MWth, operating cost is about 17 ECU/MWh, and heat generation cost is about 20 ECU/kWh (53).

The first commercial Ahlstrom Pyroflow CFB gasifier was commissioned in 1983 at the present Wisa Forest Pulp and Paper Mill in Pietarsaari, Finland. The fuel for the 35 MWth (about 150 TPD of biomass) gasifier is primarily bark and saw dust. The biomass is fed from the side into the circulating sand of an air-blown CFB gasifier maintained at about 900 °C. The hot fuel gas at 700 °C, is fed directly to a lime kiln. The fuel gas replaces about 85% of the fuel oil for the lime kiln. Between 1985 and 1986, three more gasifiers, two in Sweden (25 MWth at Norrsundet Bruks, and 27 MWth at ASSI, Karlsborg) and one in Portugal (15 MWth at Portucel, Rodao Mill), were built and commissioned for firing lime kilns (53).

Corenso United Oy Ltd. is commissioning a new gasification plant for energy production and aluminium recovery at its core-board mill in Varkaus. The plant will enable the complete exploitation of used packages containing wood fibre, plastic, and aluminium. It will be the first plant in the world able to recycle the aluminium in used liquid packaging to create a raw material for foil for its original purpose, while simultaneously exploiting the plastic contained in the packages to produce energy. The fibre material in multi-layer packages (Tetra-Pack) can be recycled in core-board while the aluminium being recycled as raw material for foil. The remaining plastic will be gasified to generate 40 MWth, with an estimated annual total energy production of about 165 GWh. The estimated cost of the new plant being built is around EUR 17 million, with completion scheduled for the autumn of 2000. The investment includes the gasifier, an aluminium recovery unit and a new boiler designed specially for gasification gas (53).

The first commercial TPS CFB gasification process was built for Refuse Derived Fuel (RDF) gasification at Greve in Chianti and started commercial operation in 1993. RDF pellets, up to 150 mm long, are fed into the lower section of two 15 MWth capacity CFB gasifiers, at a rate of about 3 t/h. The air blown TPS gasifier operates at a temperature of about 875 °C. The fuel gas has a heating value of 8 MJ/Nm<sup>3</sup> (54). The raw gas from one of the gasifiers passes through two stages of solids separation before being fed to a furnace/boiler to generate steam for producing 2.3 MWe in a condensing steam turbine. The overall power generation efficiency is about 19 to 20%. The gas produced in second gasifier is supplied to the neighbouring cement

factory for a direct combustion in the cement kiln. The gas leaves the cyclone at a temperature of about 850°C and is sent to a oil-filled heat exchanger to be cooled to a temperature of about 450°C, before it is sent to the cement factory, (*Fig. 7*) (55). At present the owner of the plant is installing a modern second boiler and fuel gas cleaning equipment in order to generate electricity from the second gasifier as well to a total capacity of 6.7 MWe. The plant has been operated intermittently due to difficulty in obtaining continuous supply of RDF pellets.



*Figure 7* The Greve in Chianti process flowsheet

The Battelle/FERCO project in the US was built at the McNeil power plant in Burlington, Vermont. The 200 ton per day project employs the low pressure Battelle gasification process that consists of two reactors: (a) a gasification reactor in which the biomass is converted into a MCV gas and residual char at a temperature of 700-850°C, and (b) a combustion reactor that burns the residual char to provide heat for gasification. Heat transfer between reactors is accomplished by circulating sand between the gasifier and combustor (*Fig.8*). Since the gasification reactions are supported by indirect heating, the primary fuel gas is a medium calorific value fuel gas. The estimated HHV of this fuel gas is 17.75 MJ/Nm<sup>3</sup>. Full plant operation was achieved in mid 2000 using wood chips. It is envisaged that in subsequent phases, the fuel gas will be cooled for heat recovery, scrubbed, and recompressed prior to energy conversion and recovery in a 15MWe gas turbine system (13, 56).

### **IGCC PROJECTS**

Several project have been initiated for IGCC applications over the last decade, however, only two have been implemented, the SYDKRAFT plant at Värnamo based on FOSTER WHEELER technology (18) and the ARBRE plant based on TPS technology (41). The Vermont project based on Battelle/FERCO may be upgraded to an IGCC plant in the medium to long term, however, there are no concrete plans at

present. The Energy Farm project in Pisa with LURGI technology (57) and the Brazilian project with TPS technology (58) still face implementation problems and their future is uncertain. This indicates that such large scale projects still face barriers which are mainly related to high installation cost and high technical risks due to the emerging technology status of gasification. However, the successful operation of the ARBRE project, the first commercial IGCC, will provide reliability for the technology and a basis for scaling up with confidence so that the second generation ARBRE could be built with reduced costs indicated by learning effects. In addition there is a small scale IGCC plant based on an hot gas indirect fired gas turbine which is described below in the section concerning hot gas operations of gas turbines.

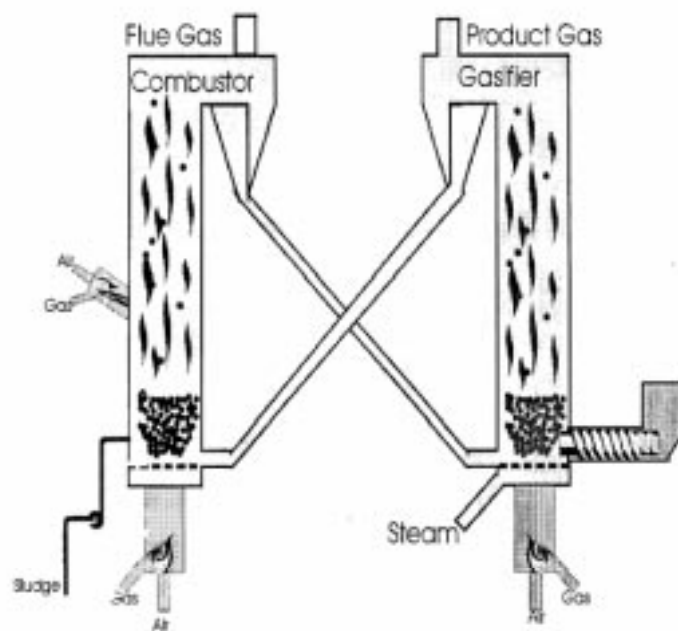


Figure 8 Schematic of the Battelle gasification technology

### ***The Värnamo Plant***

The plant in Värnamo (*Fig. 9*) produces about 6 MWe electricity to the grid as well as 9MWth to the district heating system of the city of Värnamo, from a total fuel input equivalent to 18 MW (18, 59). The accumulated operating experience amounts to about 8500 hours of gasification with more than 3600 hours of gas turbine operation on gas. A successful test programme was completed in 2000 addressing fuel flexibility and NO<sub>x</sub> emission problems. Fuels including wood, bark, forest residues, willow grown on energy crops, straw and RDF have been used without any major operating problem. However, some problems occurred in the hot gas filtration system, where some ceramic filter candles broke. The reason for the cracking was found to be mechanical fatigue due to micro cracking in the filter elements and since 1999 sintered metal filters are installed. No problem was experienced with this type of filter.

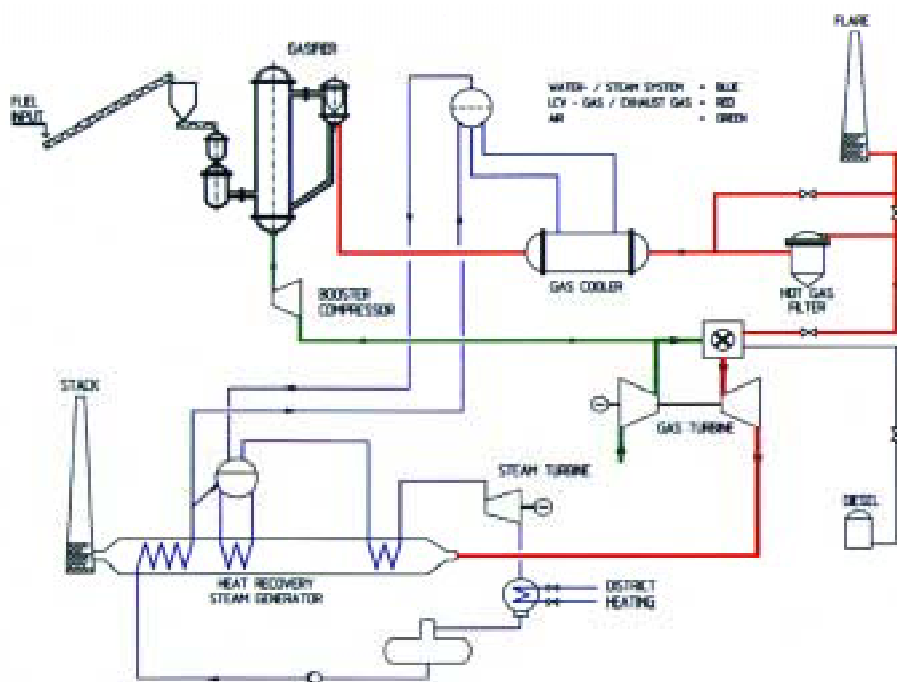


Figure 9 The process flow diagram of the Värnamo plant

In addition to the demonstration programme, development work aiming to substantially reduce the  $\text{NO}_x$  emissions from gasification plants originating from fuel-bound nitrogen compounds was carried out under the coordination of VTT Energy. The method is based on controlled and selective oxidation of fixed nitrogen species, primarily ammonia and hydrogen cyanide, of the gasification product gas to  $\text{N}_2$ . The central part of this research is the development of a new SCO (Selective Catalytic Oxidation) technology. Tests in reducing the bed material feed were also made in order to check the possibilities of reducing the operating costs for the IGCC-technology.

It has also been possible to make a drastic reduction of the bed material cost as the tests have proved that a significant amount of the bottom ash from the gasifier can be fed back into the process as bed material, thus reducing the required amount of “fresh” bed material to a minimum. The plant dynamics have been tested with load acceptance tests, change-over of gas turbine fuel during operation from diesel oil to bio-gas and vice versa. These tests have verified the calculated dynamic properties of the plant and fuel switch-over is now made as a fully automatic procedure, remote surveyed from the control room. The gas quality has been at the calculated levels during all sorts of operating conditions and the gas has a lower heating value in the range  $5.3 - 6.3 \text{ MJ/Nm}^3$ . Other gas components, such as tars, were not continuously monitored, but extensive measurement have been made during most of the tests, however tars have never caused any problems in the plant. An example of the influence of fuel composition on the amount of tars in the gas is given in Table 1.

Table 1 Effect of feedstock on tar

Fuel	Benzene (mg/nm <sup>3</sup> )	Light tars (mg/nm <sup>3</sup> )
Bark 60 % + Forest residue 40 %	5000 - 6300	1500 – 2200
Cellulose chips	7000 - 9000	2500 – 3700

### The ARBRE Plant

Construction of the ARBRE plant, situated just South of Selby, North Yorkshire, UK started in July of 1998. Construction is now been completed and all equipment has been installed. The plant will provide a net electrical output of 8 MWe with an efficiency of 30.6%. The sale of electricity to the grid is supported by the NNFO programme in the UK. The process flowsheet is given in Fig. 10.

The supply of the coppice will be undertaken by Yorkshire Environmental Ltd., which will try to maximise the utilisation of biomass fuels supplied by short rotation forestry. Slurry of domestic treated sewage sludge supplied by Yorkshire Water Services Ltd. will be applied to the coppice plantations as organic fertiliser to increase crop yield. The sludge will be low in heavy metal, pathogens and odour. Waste ash from both the gasifier and the catalytic cracker will be recycled to the coppice plantations as a soil conditioner and source of base cations and micronutrients to improve soil fertility.

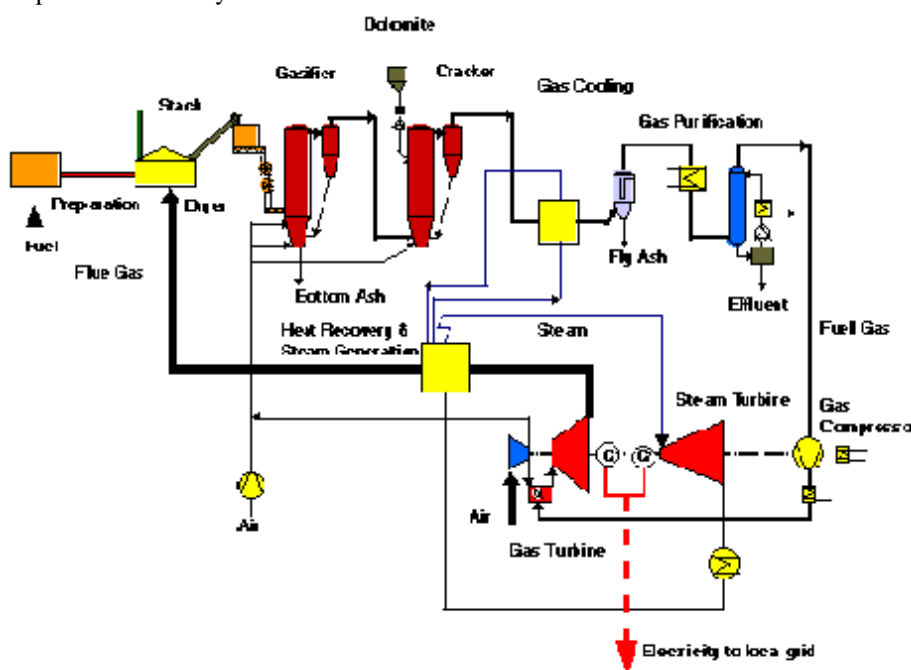


Figure 10. Process flowsheet of the ARBRE plant.

Coppice fuel will be used throughout the year, necessitating storage facilities. The chips will be in two covered warehouses adjacent to the site, and in clamps on local disused airfields. The chopped wood will be dried to 10-20 % moisture content by the low grade heat taken in the form of warm dry air from the air cooled

condensers downstream the waste heat boiler. This warm dry air will be led underneath a four day chipped wood store and will be blown upwards through the floor of the grain floor wood chip dryers. It is expected that drying will take up to two days to be completed.

A lock hopper system will feed the chips into the TPS circulating fluidized bed gasifier operating at between 850 - 900 °C. Sealing gas is introduced to the fuel feeding system at a flow rate sufficient to prevent backward gas leakage from the gasifier. In the TPS process the tars are cracked catalytically to simpler compounds in a second circulating fluidized bed reactor, which is built in the same way as the gasifier, is and has similar dimensions. The gas is introduced together with some air at the bottom of the catalytic reactor and is contacted with the bed material, which consists of dolomite at temperatures of about 900 °C. The gas is then cooled to 180°C in a cooler, which is used to generate high pressure saturated steam. The gas leaving the cooler enters a conventional high efficiency bag-house utilising needle fibre bags. The gas is then supplied to a combination cooler and scrubber where its temperature is lowered to 25 °C and any remaining alkalis, naphtha and ammonia are removed. Liquid effluent from the gas scrubber is treated in a wastewater treatment plant. Facilities will be provided for pelletisation of dolomite containing ash for use as slow release fertiliser to be applied in the energy plantations.

The gas after compression to about 20 bar is fired in an ABB Alstom Typhoon gas turbine (the same as in the Värnamo plant). The exhaust gas from the gas turbine exits at approximately 475 °C. The steam produced is used to generate 5.5 MWe in a steam turbine. Waste heat is used for drying the biomass fuel.

### ***CO-FIRING WITH COAL***

Co-firing application are perhaps the most interesting at present for an accelerated market penetration potential as the overall costs are relative low due to the existence of the power cycle in the coal fired power plant. In addition, co-firing has the advantage over co-combustion, where the biomass fuels are mixed with coal before or during the combustion process, that the biomass residual ash is not mixed with the coal ash, which has an existing market as a construction material. Also the technical risks are low as the gas is utilised hot and therefore there is no tar problem. In reburning applications, (when the fuel gas is introduced almost at the top of the coal boiler) it has been shown that the environmental performance of the power station is significantly improved in addition to the replacement of fossil fuels by renewable biomass fuels (60).

### ***The Lahti Plant***

The utility Lahden Lämpövoima Oy has built a FOSTER WHEELER CFB gasifier for its Kymijärvi Power Station in Lahti, Finland. The gasifier uses industrial waste wood, chips, fuel peat and recycled fuel (REF) as fuel. The gasifier-produced gas is burned in the Kymijärvi Power Station's steam boiler with a high flame temperature, guaranteeing the purity of the flue gases. The objective of the gasifier is to replace 50 MW of the Power station's steam boiler's 350 MW fuel effect by biofuels (*Fig. 11*). One third of the gasifier fuels is recycled fuel (REF), which is in-origin classified refuse from households and industry and the other two-thirds is composed of different kinds of biomasses. One possible fuel in the future is shredded tires, which has been tested during the past operating seasons. By using biofuels it is possible to



reduce the power station's emissions and diminish the environmental hazards. The decrease of carbon dioxide has been calculated to be 60 - 80 000 t/a.

The product gas for combustion is led directly from the gasifier through the air preheater to two burners that are located below the coal burners in the boiler. The gas is burned in the main boiler and it replaces part of the coal. When the fuel is wet, the heating value of the gas is very low. Typically, when the fuel moisture is about 50 % the heat value of the gas is only about 2.2 MJ/m<sup>3</sup>. The combustion air for the burners is extracted from the main boiler air supply. Air is divided into primary and secondary air to ensure optimum combustion conditions. With regard to the gasification plant itself, the problems faced were related mostly to the use of shredded tires as a fuel in the gasifier. In addition to that it has been observed that the light fuel fractions can occasionally cause some fluctuations in the fuel feed rate to the gasifier. On several occasions the wire content of the tires (there is no wire removal process, such as magnetic separation, after tire shredding) was so high that accumulated wires blocked the ash extraction system and the gasifier had to be shut down. However, in general the operation of the gasification process was good.

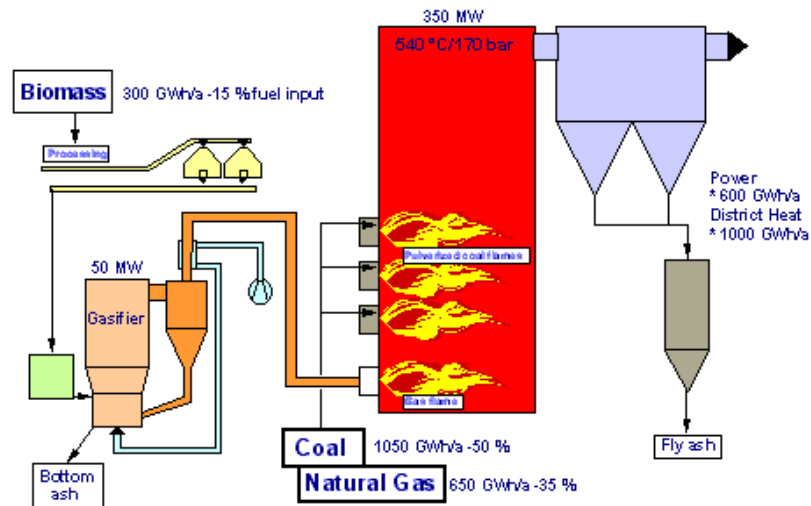


Figure 11 Schematic of the Lahti Co-Firing plant

Concerning the gasification process itself, the results have met expectations. The operating conditions as measured by temperatures, pressures and flow rates have been as designed and the process measurements of the product gas, bottom ash and fly ash compositions have been very close to the calculated values. The operating temperature of the gasifier has been typically 830 - 860°C and the feed flow rates of bed materials as designed. Typically the gasifier effect varied between 35 MW and 55 MW depending on the gasifier fuel moisture content and on the required gasifier load.

The stability of the main boiler steam cycle has been excellent. The large openings that were made for the low Btu gas burners have not caused any disturbances in the water/steam circulation system. Furthermore, as regards the operation of the product gas burners, the product gas combustion has been stable even though the moisture content of the solid fuel has been mostly high and the heating value of the gas very low. The stability of the main boiler coal burners has been normal despite the fact that the product gas burners were integrated very close to the

lowest level coal burners. The main boiler emissions were perhaps of the greatest interest as regards the measurement program of the monitoring phase. In summary, it can be stated that the changes in the emissions were rather low. As indicated earlier, the main boiler is not equipped with DeNOx or DeSOx plants and today the limit values for the emissions are as follows: NOx 240 mg/MJ (as NO<sub>2</sub>) and SOx 240 mg/MJ. Table 2 summarizes the effect of the co-combustion of the gasifier product gas on the main boiler emissions (60).

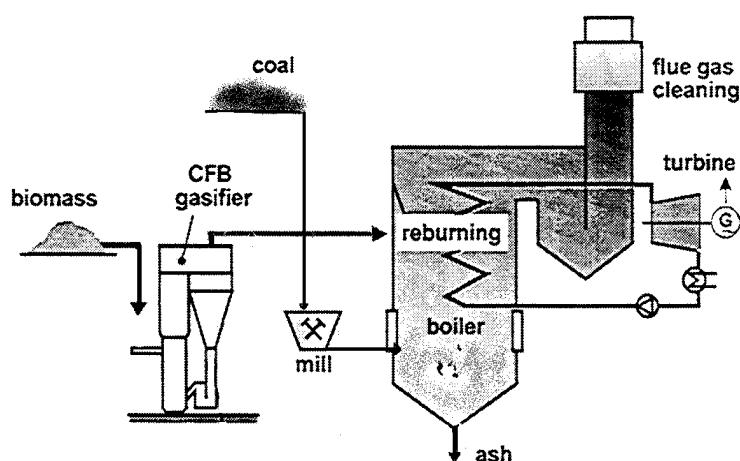
### ***The BioCoComb Plant in Zeltweg***

This demonstration plant has been installed at the Zeltweg power plant operated by DRAUKRAFT (15). The BIOCOMB process is designed for preparation of biofuels for co-combustion by partial gasification and attrition due to mechanical and thermal stress in a circulating fluidized bed reactor (CFB) (Fig. 12).

*Table 2* The effect of the Lahti gasifier to the main boiler emissions.

<b>Emission</b>	<b>Change caused by gasifier</b>
NO <sub>x</sub>	Decreased by 10 mg/MJ (= 5 to 10 %)
SO <sub>x</sub>	Decreased by 20 - 25 mg/MJ
HCl	Increased by 5 mg/MJ *
CO	No change
Particulate	Decreased by 15 mg/m <sup>3</sup> n
Heavy metals	Slight increase in some elements, base level low
Dioxins Furans PAH Benzenes Phenols	No change

\* When using low-chlorine coal in the main boiler and REF + tires in the gasifier.



*Figure 12* Schematic of the BioCoComb plant in Zeltweg

The product gas is fired in the furnace of a coal-fired power plant. The portion of biofuels reaches to about 3–5% of the total thermal input corresponding to 10 MWth. The fluidizing medium of the CFB is hot air, which is taken from the air preheater of the power plant. The CFB reactor operates at conditions where the biomass will be partly combusted and partly gasified at temperatures between 750 and 850 °C. The produced char is ground by mechanical attrition and thermal stress to a fine powder. The attrition is maximised by optimal operating conditions of the CFB. The cyclone of the CFB-reactor is designed in such a way that only char particles, which are small enough to burn completely in the coal furnace pass the cyclone. They are fed into the furnace together with the hot gas, which contains combustible components from the gasification. Larger char particles will stay together with the bed material - in the CFB process until they are small enough or gasified completely. The efficient combustion system of the boiler combined with the very efficient flue gas cleaning system of the plant guarantees a minimised impact on the environment. The substitution of part of the coal by biomass reduces CO<sub>2</sub> emission from fossil fuels, too. There is a high potential for the fuel gas to be used as a reducing gas in the reburning zone of the combustion chamber and thus reduce or even avoid other additional De-NO<sub>x</sub> measures (reduction of NH<sub>3</sub> consumption).

More than 5,000 tons of biomass and supplementary fuels have been gasified since start up. Main base fuel was spruce bark with moisture content of about 55% but also chopped wood and sawdust. Operating experiences are very positive with gasification as well as the combustion of the gas been according to design. The critical changeover from gasification to combustion and reverse is smooth with a slight and acceptable temperature increase. The power range of the gasifier was varied between 5 and 20 MWth, the maximum load depending on the moisture content of the biomass fuel. The quality of the fuel gas was similar to pre-calculated values while the burn out of carbon is excellent with almost no carbon found in the discharge bed material.

The reburning effects in the boiler have an astonishing good performance, where a decrease of 10-15 % of the ammonia water consumption was gained with only 3% of the total thermal input coming from biofuels (62).

### ***The AMER Project***

This wood gasification plant is located at the relatively new coal fired heat unit of EPZ, Amer 9 at Geertruidenberg in The Netherlands. The aim of the project is to achieve savings of 70,000 tons of coal (33,700 TOE) based on 150,000 tons of wood waste (construction & demolition waste) corresponding to 170,000 CO<sub>2</sub> t/y reduction in emissions. The equivalent electricity capacity is 29 MWe. The gasification plant has been supplied by LURGI.

Chipped demolition wood is transported to the plant by ship and by truck is stored in silos after passing a rotating disk separator (for separating off big parts) and a magnetic separator. From the storage silos the chips are continuously transported to two day silos, feeding two screw conveyor feeding system of the gasifier.

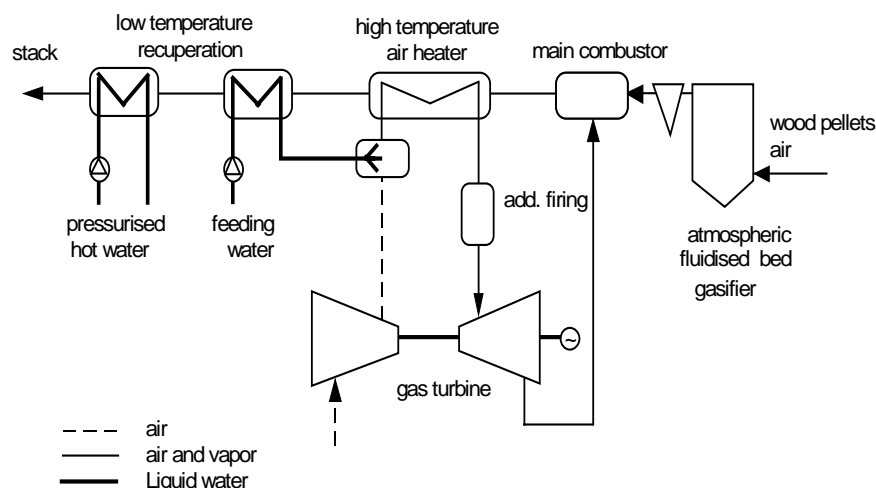
The gasifier is of the atmospheric circulating fluidized bed type, operating at temperatures of 800 - 950 °C with the addition of bed material and possible limestone or dolomite. After passing the cyclone, the raw product gas is cooled down in a gas cooler to a temperature of about 200 °C; in that cooler intermediate temperature steam is produced and slightly superheated. At the temperature of 200 - 250 °C, the gas is dedusted in a bag house filter. The dust-free gas is then washed with water in a scrubbing section, in order to remove mainly the ammonia. After this scrubber, the



### ***The Free University of Brussels project, BINAGAS***

The Binagas project is located at the campus of the VUB in Brussels. The gasification train consists of the feeding system, an atmospheric fluidized bed gasifier operating in the temperature range of 725 to 850 °C and a cyclone for the removal of particulates. The gas produced is fed to the combustion chamber of the heat exchanger through insulated lines and a high temperature valve, which isolates the gasification train (when the fuel gas is flared) and the metallic air heater/gas turbine system (*Fig. 14*). The operating procedure has been designed in order to avoid any condensation of tars with well defined starting up and shut down sequences (65).

The compressor of the Volvo gas turbine supplies the air through the heat exchanger where it is heated up to 850 °C, which is the limiting temperature dictated by the construction materials. Some natural gas topping combustion is included to raise the temperature to about 1,000 °C. Water injection in the air heater is included to enhance the power output and allow flexible power to heat ratios. The demonstration scale is 500 kWe, for production of power and heat for the University campus district heating. Targeted maximum performances are 24% electrical and 70% total. When injecting water at power mode, peak electrical efficiencies of 30% and power output of 700 kWe are expected.



*Figure 14* Process flowsheet of the VUB plant.

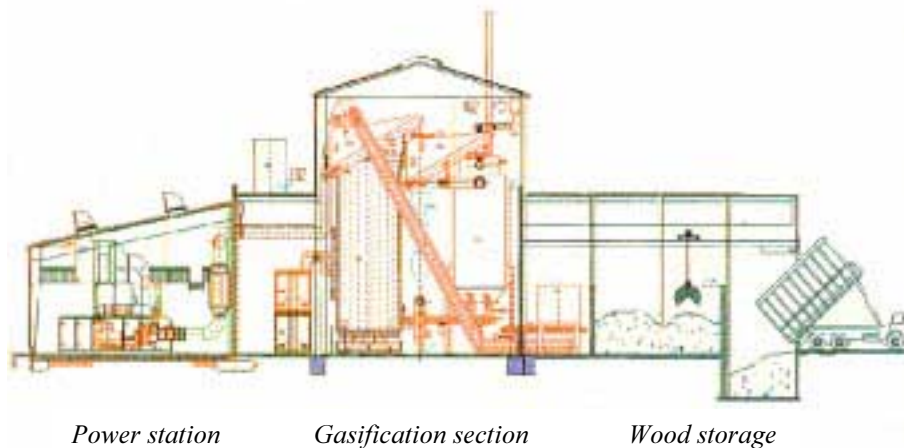
The complete plant has been operational for several hundred hours, but control problems were experienced with the gas turbine which was a prototype. Also the particulate accumulation in the heat exchanger has been higher than expected but no major problems have been encountered with this part of the plant. The gasification island operates efficiently and has met the design specifications, even though it is basically fed with sawdust instead of pellets. At present the modification to the gas turbine have been completed and the test program will restart. The VUB plans to use the installation as a test facility until all the problems have been overcome.

### ***The Freiberg Project***

Pipeline Systems GmbH (PPS) has constructed an IGCC indirect fired wood

gasification CHP plant at Siebenlehn in the Freiberg District, Saxony, Germany. PPS is the general constructor and works manager of the plant. The consumer of the process heat is an industrial user located 50 m from the CHP plant itself. The gas turbine nominal capacity is 1.3 MWe while the steam turbine's nominal capacity is 0.7 & 1.0 MWe, respectively for extraction or condensation operation mode. The primary energy carrier is a mixture of forest cut wood, industrial wood residue and forests residues.

In the co-current downdraft moving bed gasifier the fuel is fed from the top and the gasification medium is air supplied through a central blow-in pipe. The fuel gas is removed through an induced-draught fan. A small part of the fuel is burned in the oxidation zone in order to achieve the extremely high reaction temperatures, which characterise this gasifier. A rotating grate of conical shape and which is height-adjustable is built into the lower part to regulate the flow of the fuel. The firebox of the gasifier is made of a special high-temperature-resistant ceramic material. Through the special introduction of gasification air and the utilisation of high-temperature-resistant ceramic material, temperatures up to 2000 °C are generated in the oxidation zone of the gasifier. At these temperatures long-chained hydrocarbon compounds are cracked and transformed into combustible gases and the mineral and metallic components of the fuel are fused into an inert, glasslike slag (66), (Fig. 15).



*Figure 15* Schematic of the TU Bergakademie Freiberg plant

The fuel gas with a higher heating value of 5 MJ/Nm<sup>3</sup>, has a high concentration of H<sub>2</sub> (up to 20 Vol%). Formation of tar and contamination of the fuel gas is avoided to the greatest extent possible through the high temperatures in the reaction zone. This reduces the cost of any subsequent gas cleaning. The slag, which is formed corresponds to the storage regulations of mineral and/or inert material disposal sites. The gas cleaning consists of coarse dust removal by a cyclone and of a fine filter. The dust removed is made up of up to 99% carbon. Fine dust which passes through the gas cleaning devices is burned in the subsequent combustion chamber together with the fuel gas. The combustion of the wood-derived gas takes place at atmospheric pressure in an external combustion chamber. In a high-temperature heat exchanger, the combustion gas which arises raises the temperature of compressed air, which is to be the working medium of the gas turbine, up to the gas turbine entry temperature. The gas turbine aggregate consists mainly of an air compressor, the expansion unit

(turbine), reducing gear, a generator and the auxiliary systems required for operation.

The flue gas which emerges from the heat exchanger and a partial flow of the gas turbine exhaust are channelled to the heat recovery steam generator. The utilisation of this exhaust heat for steam generation corresponds to the state of technology of the conventional gas and steam turbine process. In the heat recovery steam generator, equipped with economiser, evaporator and superheater, the fresh steam is generated for the steam turbine. A flue gas heat exchanger for generation of hot water is attached in series to the heat recovery steam generator for extensive utilisation of the exhaust gas energy and for minimisation of the flue gas temperature at the stack.

Clean hot air suctioned by the compressor of the gas turbine and then compressed to the required turbine entry pressure serves as the working medium of the gas turbine. A high temperature heat exchanger is placed between compressor and gas turbine, in which the air is heated to the high gas turbine entry temperature. This heat is supplied by the combustion of the fuel gas in a combustion chamber. The exhaust of the gas turbines provides the combustion air for this, whereby an increase of the combustion chamber temperature is also achieved, due to the high energy potential. The gas turbine exhaust not needed for combustion is fed through a bypass to the heat recovery boiler for waste-heat recuperation, as is the cooled down combustion gas in the high temperature heat exchanger. The heat recovery steam generator produces fresh steam for the extraction-condensation steam turbine, the extraction steam of which serves to cover the process heat requirements of the industrial user through its transformation into hot water.

The plant has been commissioned and the first results on the performance are expected soon. Design data give an efficiency to power of 23 and 27 % respectively for extraction and condensation mode of operation while the overall plant efficiency is 73 and 39 % respectively.

## **ENGINES**

Work for running engines with producer gas has been continuing for decades now but with few breakthroughs if any. In the field of reciprocating engines there have been two engine manufacturers who are the key players - Jenbacher and Caterpillar (67). The main problem relates to efficient removal of tar, however, the engine manufacturers have not been able to design and construct more robust engines, which can tolerate some tar in the gas. In developing economies like China, where there is high demand for energy and cheap labour, there are examples where engines are carefully and continuously maintained and are operated with a relative dirty gas (68). This approach results however in significant quantities of condensate which accumulates and causes an environmental hazard. This is not acceptable for developed economies and overall there is little development to report on engines.

In recent configurations, the product gas is kept above its dew point ( $>75\text{ }^{\circ}\text{C}$ ) throughout the installation downstream of the cooling section in order to avoid condensation of any water and any remaining harmful tar components. This eliminates the need for an extensive water treatment plant. The engines proposed are lean-burn, high-speed, high-efficiency, turbo-charged gas engines. The turbo-charger is mounted before the engine in order to increase the gas pressure, and therefore the gas energy density, compensating for the loss in efficiency due to the lower density fuel gas caused by the relative high temperature of the fuel gas ( $> 75\text{ }^{\circ}\text{C}$ ). The electrical efficiency of such a configuration can reach 40%.

Work on gas turbines has proven successful with the operation of the TYPHOON

gas turbine at the Värnamo plant and the expected operation at the ARBRE plant in the first half of 2001 (59, 41). In addition, NUOVO PIGNONE has carried out a successful series of combustion chamber tests for a 10 MWe gas turbine for the Energy Farm project in Italy (57); however, the gas turbine has not been built yet and it is only planned to be commissioned in 2003 if this project proceeds to completion.

This is an area which presents a dilemma for the gasification community since the gas turbine manufacturers do not wish to develop more robust engines that could operate with some contamination in the gas as the market is still considered very small. Thus the main task falls on the gasification industry to deliver a 'clean' gas to the combustion chamber of the gas turbine. On the other hand this has prompted the gasification industry to develop gas cleaning technologies which, if proven reliable, will form the basis for synthesis gas from biomass. This will open new opportunities and markets for bioenergy and especially gasification technologies as discussed below.

### ***METHANOL, HYDROGEN & FISCHER-TROPSCH***

These chemicals as well as energy vectors can be used in several applications or can be further upgraded into other useful products. They can all be produced via synthesis gas ( $\text{CO} + \text{H}_2$ ) that has been the subject of extensive investigations and commercial industrial processes based on fossil based synthesis gas exist. The advantage of these vectors is that they can be either used in fuel cells for electricity or transport applications, or alternatively, they can be processed to liquid transport fuel additives such as dimethylether (DME) and dimethoxymethane (DMM).

Advanced biomass gasification processes can also produce synthesis gas as has been demonstrated in the 1980s by the "Methanol from Wood" programme of the European Commission (69). During that work four pilot plants were operated at design capacities ranging from 4.8 to 12 dry t/d (70). These plants were developed by Framatome, Lurgi, John Brown/Wellman & Italenergie while TPS developed the MINO process. All technologies were based on fluidized bed with various mixtures of  $\text{O}_2$ , steam and air while the John Brown/Wellman process used an innovative approach of chemically active solids as an  $\text{O}_2$  carrier. Similarly various groups have looked into the production of  $\text{H}_2$  from gasification by a slurry of hydrated metal alloys (70). The National Renewable Energy Laboratory in the USA has also investigated extensively the conversion of synthesis gas to energy fuels with positive results (71).

In principle, if a clean synthesis gas can be produced from biomass, there should not be any serious technical barrier for its subsequent conversion to methanol or Fischer-Tropsch liquid products as these processes have been demonstrated to some extent by the novel methanol to gasoline process in New Zealand or by SASOL in South Africa (72). Various Dutch research centres have proposed a once through configuration for methanol combined with an IGCC fuelled by the lignin by-product of an ethanol facility in order to improve the overall economics and process efficiency while simultaneously producing ethanol (73). However, such schemes are only potentially viable at large scale and require a concerted approach by several stakeholders. Others have looked into the methanol route specifically (74), but these studies are still in the laboratory scale and a significant amount of work is required before industrial scale processes could be developed. On the other hand the results are promising.

A recent extensive techno-economic analysis of the various transport fuel chains from biomass (75) concluded that the most promising chains were ethanol substitution



of gasoline followed by Fischer-Tropsch produced diesel. On the other hand a similar study in Sweden (76) resulted in DME as the most promising liquid biofuel. What is of importance is that the main car manufacturers are seriously considering these liquid biofuels and try to develop dedicated engines.

## A ROAD MAP FOR GASIFICATION

Gasification technologies offer huge potential as they can produce energy and chemical vectors from a variety of lignocellulosic materials. These vectors can be used in numerous applications directly or after further processing and upgrading and can be either in the gaseous state or liquid state depending on the processes and applications. This section attempts to provide a road map and benchmarking of the gasification technologies in relation to existing and possible future markets and as a whole it can form the basis of a strategy for the commercialisation and market penetration for gasification applications.

*Figure 16* shows the relationship between technology and markets. Each of the four quadrants relates new and existing technology to new and existing markets.

		EXISTING TECHNOLOGY	NEW TECHNOLOGY
EXISTING MARKETS			
	Market Penetration	Product Development	
	Co-Firing Firing Waste + BM	Methanol H2 Fischer-Tropsch	
NEW MARKETS			
	Market Development	Product Diversification	
	IGCC - 30-75 MWe Gasification 1-5 MWe Hot Air Gas Turbines	Chemicals from Biomass Monomer recovery Materials recovery	

*Figure 16* Developing growth strategies and market opportunities

At present the most reliable applications for biomass gasification are co-firing and direct firing of the fuel gas in a boiler for heat or steam cycle. These applications present the least technical risks as the problem of tar is avoided and therefore the main task of the industry is to increase their market penetration. It is important that more plants will be built and operated in existing markets in order to increase the degree of confidence for the users and especially the utilities as well as to improve the industrial capabilities with various problematic but cheap fuels.

The bottom left quadrant in *Figure 16* shows the applications for which new markets must be developed based on the expected success of a few key projects, which are now in the demonstration phase. Commercial IGCC, medium scale gasification and hot air gas turbines are expected to become commercially available in the short to medium term of about 4-6 years. If this happens, then the gasification technology will be able to address all basic requirements for energy applications

either as biomass dedicated plants or in combination with fossil fuels.

New technology development is needed for chemicals and liquid biofuels, which can have direct utilisation in existing structures of modern society and especially as transport fuels. Although bio-ethanol and biodiesel from grain and seed respectively are supposed to be more competitive, various studies indicate that Fischer-Tropsch diesel and DME can be competitive in the medium to long term of about 5-10 years. The progress achieved at Värnamo gives confidence that the gasification industry would be in position to deliver a clean gas for further processing to synthesis gas while gasifier operation with mixtures of oxygen and steam does not appear to create any serious technical barrier. Finally hydrogen will always remain the cleanest fuel of all and any process that can produce hydrogen from biofuels under economically competitive conditions will be an immediate market success.

The last quadrant in *Figure 16* shows the areas for eventual product diversification from energy and/or liquid biofuel vectors. Although these do not appear to offer great market potential they can address niche markets for the production of bio-chemicals and/or the recovery of the valuable products such as the monomer from waste polymers and aluminium from drink packaging.

Considering that financial resources are limited and there is very strong competitions with other bioenergy technologies such as fast pyrolysis and combustion, in addition to other renewable energy sources which may be more appealing to the general public and even utilities and authorities such as wind power, it is strongly advised that the finite financial resources available should be carefully targeted to address actual technical and market barriers. It is therefore recommended that the target areas would be those included in the bottom left and top right quadrants of *Figure 16*. It must be repeated once more that the main barrier remains the delivery of a clean gas.

## CONCLUSIONS

Biomass gasification technologies have reached the point where the first simple applications with minimal technical risks are becoming commercial. In addition the first biomass based IGCC plants are being demonstrated and are expected to reach commercial status within about 5 years. Future market opportunities exist for liquid biofuels production via synthesis gas, however, although these systems have been examined periodically since the 1980s, a significant amount of work has still to be done before such plants could be considered by the financial community. The development of the technology has moved beyond the element of the “gasifier” to the critical area of the supply of a “clean gas”, free of particulates and tar. If this will be achieved, then the power market will be slowly but steadily penetrated on condition that sufficient feedstocks can be secured. After this stage and on the basis of the various policies concerning liquid biofuels by the European Union, USA, Canada, China and India synthesis gas could become an important market. At this stage the technology will move from the supply of “clean gas” to the production of “synthesis gas”. This would necessitate a dedicated policy for the production of very large quantities of biomass fuels to satisfy the demand for power and liquid biofuels.

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