Thermal Gasification of Biomass

An overview of activities within the countries participating in Task 20 prepared by Task Leader, Suresh P. Babu and the collaborating members.

Introduction

Renewable biomass and biomass derived fuels could readily replace fossil fuels in many of the present energy utilization applications with concomitant environmental benefits. Gasification is a form of biomass energy conversion producing a fuel that could substitute for fossil fuels in high efficiency power generation and CHP applications. While fossil fuel resources are heavily concentrated in coal mines and oil and gas wells, biomass resources are dispersed and hence the fuels they produce are more expensive than fossil fuels. However, biomass is a renewable resource and may become a significant component in the global sustainable energy mix as fossil fuel resources begin to be depleted. For example, short rotation poplar crops as shown below. In addition, biomass utilization can expedite mitigation of greenhouse gas emissions and carbon sequestration cycles and promote 'green' industries with associated growth in rural economies. Biomass gasification fuels may be able to use the existing natural gas distribution network and, with minor equipment modifications, biomass fuel gases could be readily used in most of the present natural gas energy conversion devices.

Courtesy of NREL,USA

Air-blown gasification of biomass produces a clean burning fuel gas that could be used for direct combustion in boilers to produce heat and steam, or in gas and Stirling engines to produce electricity in the 20-30% efficiency range. Pressurized gasification with close-coupled gas turbines offers the capability to produce electricity at 40% or higher efficiency. Enriched-air or oxygen blown gasification produces a synthesis gas, suitable for conversion to hydrogen, chemicals, fertilizers, or substitute liquid fuels. Fuel gas, synthesis gas, and hydrogen could be used in fuel cells which could further raise the efficiency of power production to the 40-50% range. Recognizing these benefits, many countries are actively developing biomass gasification technologies for on-site power generation, for co-generation, and for the production of substitute fuel gases.

The Task activities are focused on information exchange, promoting cooperative RD&D among member countries, and interaction with industry to expedite commercialization of biomass gasification. The following sections highlight selected biomass gasification projects in the member countries of the Task. For more complete information, including principal contacts, please see Appendix 7 and visit Task 20 on the IEA Bioenergy website: www.forestresearch.co.nz/ieabioenergy.

Austria

There are two gasification demonstration projects in Austria: the first is at Zeltweg and the second is two new plants which are being designed around the FICFB Process. A third project, the bark gasification project at Pöls, is also described. Biomass gasification could become the second most important conversion process in Austria, especially for power production.

Zeltweg BioCoComb Project

Courtesy of Zeltweg BioCoComb Project, Austria

In a demonstration project supported by the EC Thermie Programme a biomass gasifier for bark, wood chips, sawdust, etc has been installed at the 137 MW_e pulverised coal fired power station of Verbund-Austrian Hydro Power AG in Zeltweg, Austria. The project title 'BioCoComb' is an abbreviation for 'Preparation of Biofuel for Co-Combustion' where co-combustion means combustion together with coal in existing power plants. The gas produced substitutes approximately 3% (~ $10MW_{th}$) of the coal fired in the boiler. The biomass fuel from plants is used in its raw form. Only the coarse fraction of the biomass has to pass a shredder and is then fed together with the fine fraction into the gasifier. Partial gasification of the biomass is carried out at a temperature of 820°C, in a circulating fluidised bed reactor, which maintains uniform temperatures throughout the gasifier. Temperatures are low to prevent slagging. The low calorific value (LCV) gas produced is directly led via hot gas duct into an existing pulverised coal fired boiler for combustion. The carryover char from partial gasification passes through a cyclone separator and is fully combusted in the coal boiler. The plant started its trial runs in November 1997 and has been in successful commercial operation since January 1998.

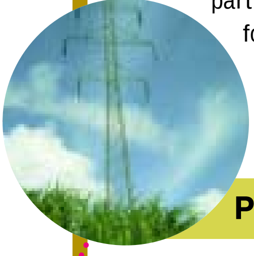
The main advantages of the BioCoComb concept are:

- drying of feed biomass is not required since the resulting LCV gas is acceptable for co-firing;
- partial gasification of biomass results in a smaller gasifier;
- no gas cleaning or cooling is required thus preventing tar condensation problems;
- the relatively low gasification temperatures prevents slagging;
- there are favourable effects on power plant emissions (CO_2, NOx);
- there were no substantial modifications to the existing coal fired boiler;
- there is high flexibility in arranging and integrating the main components into existing plants.

New plants based on the FICFB Process

At present there are two FICFB Process plants in the detailed design stage. An 8 MW_{th} gasification plant will be located in Güssing, Burgenland and a 2 MW_{th} plant will be located in Wiener Neustadt, Niederösterreich. In the bigger plant a gas turbine, and in the smaller plant a gas engine will be used to produce electricity from the gas. The plant in Güssing will begin operation in summer 2000 and the smaller plant will commence operation in winter 2000.

The FICFB Process consists of a fluidised bed reactor divided into two zones, a gasification zone and a combustion zone. The bed material is circulated between these two zones while the gaseous products are kept separated. The circulating bed material promotes heat transfer between the combustion and the gasification zones. The fuel is fed into the gasification zone and gasified with steam. The gas produced in this zone is therefore nearly free of nitrogen. The bed material, together with some carryover char, circulates to the combustion zone. This zone is fluidised with air to burn the char particles. The exothermic reaction in the combustion zone provides the energy for the endothermic steam gasification zone. With this concept it is possible to produce a medium calorific value product gas without the use of pure oxygen.



Pöls Bark Gasification Project

The Pöls bark gasification project employing the Lurgi circulating fluidised bed (CFB) gasifier was built in 1987 in Pöls, Austria by a large paper mill, The plant was designed to handle up to 6.6 TPH of dry bark, which is of approximately 35 MW_{th} capacity. Crushed and air dried bark is gasified in the air-blown CFB gasifier operating at about 1 bar pressure. The resulting LCV fuel gas was to be partially cooled and fired in the paper mill's lime kiln. However, because of the undesirable contamination of the lime with the ash contained in the fuel gas, the gasifier is not operated continuously and it is now used for testing and evaluation purposes only.

Brazil

Brazilian BIG-GT Demonstration Project

The Brazilian Wood Biomass Integrated Gasification-Gas Turbine (BIG-GT) demonstration project, is to be located in the state of Bahia, in northeast Brazil. The TPS low pressure, circulating fluidised bed (CFB) gasifier has been selected for the project which is supported by the Brazilian Government, UNDP, the World Bank, and the UN Global Environmental Facility. At present the project is being supported by MCT and a consortium made up of ELETROBRAS, and Companhia Hidro Eletrica do Sao Francisco. The proposed 32 MW_e project will use a GE LM2500 gas turbine. A description of the TPS process is given under some of the projects described below.

Canada

BIOSYN Gasification and Gas Conditioning Technologies

The BIOSYN gasification process was developed during the 1980s by BIOSYN Inc, a subsidiary of Nouveler Inc, and a division of Hydro-Quebec. The process is based on a bubbling fluidised bed gasifier containing a bed of silica or alumina capable of operating up to 1.6 MPa. Extensive oxygen-blown biomass gasification tests were conducted during 1984-88, in a 10 t/hour demonstration plant located at St-Juste de Bretennieres, Québec, to produce synthesis gas for methanol production. Air blown atmospheric gasification tests were also conducted for evaluating cogeneration. The BIOSYN process proved the technical feasibility of gasifying biomass from forest and agricultural residues. Subsequently, by using a 50 kg/h process development unit, the BIOSYN process has also proven the feasibility of gasifying primary sludges, refuse derived fuel (RDF), rubber residues (containing 5-15% Kevlar), and granulated polyethylene and propylene residues.

Courtesy of BIOSYN Inc, Canada

The process accepts feed particle sizes up to 5 cm, feed bulk densities higher than 0.2 kg/l and feed moisture content up to 20%. The thermal efficiency for biomass gasification varies from 70-80%. The fuel gas composition ranges from 30-55% N_2, 16-30% CO_2, 12-30% CO, and 2-10% H_2. Air blown gasification produces 2 Nm^3 fuel gas/kg of dry biomass. The gas yield reaches 4 Nm^3 of fuel gas/kg of polyethylene. With air as the gasifying agent the higher heating value (HHV) of the fuel gas is about 6 MJ/Nm^3. Enriched air, with 40% oxygen, can produce a fuel gas having a HHV of about 12 MJ/Nm^3 at half the gas yield. The raw gas cyclones remove 85-95% of entrained particulates.

The supporting research and development includes gas scrubbing for efficient tar removal with reduced water requirements, recycling the insoluble tars to the gasifier, wet oxidation and adsorption of dissolved organic compounds in the scrubbing water, and recycling carbon-rich ashes and carry over carbon with adsorbed organic compounds to the gasifier. This effort also includes hot-gas filtration of entrained dust using a static bed of perlite particles and a moving sand bed filter, and catalytic steam cracking of tar. Proprietary catalysts can decompose 99% of tars and 97% of naphthalene compounds. The BIOSYN technology is commercialized by Enerkem Technologies Inc, a subsidiary of the Kemestrie Group, a spin-off company of the University of Sherbrooke. A commercial installation to gasify 2.2 t/hour of granulated polypropylene residues is now under construction in Spain. The electricity output will be sold to the grid. Environmental International Engineering SL, a Spanish-based development and engineering group, in partnership with Enerkem, will erect and commission the plant in late 2000.

Denmark

Courtesy of Voeland Research Centre, Denmark

Harboøre Project

Between 1988 and 1992, the Danish boiler manufacturer Ansaldo Vølund Energy chose to build an updraft, counter current, moving bed gasifier for the Harboøre District Heating Project located on the west coast of Jutland. The updraft gasifier was selected to circumvent feed drying, to achieve 99% carbon conversion, and to produce a high heating value fuel gas with low dust content. The Vølund gasifier is based on a German design and it is now operated with woody biomass, at 4 MW_{th} capacity, to provide heat to about 550 homes. The raw gas containing condensible tar and other organic compounds is cooled and scrubbed to separate and recycle these combustible condensates back to the gasifier. Extensive research and technology development was conducted in support of this facility to test novel heat exchangers, tar cracking schemes, minimization and disposal of emissions and effluents, and operation of IC engines. The gasifier could be operated at higher capacity in the future for cogeneration applications. In January 2000, two 1.5 MW_e gas engines were installed to cogenerate electricity and district heat.

Høgild Project

This 0.5 MW_{th} capacity CHP project supplying heat and power for 120 homes and residences in Høgild near Herning, started with the French Martezo co-current downdraft moving bed gasifier. The project owner Herning Municipality, contracted the Hollesen Engineering Company to reconstruct the gasifier. Since December 1998, the gasifier has been operating satisfactorily. The feed stock for gasification is double screened dry wood residues (15% or less moisture content) and waste from woodworking factories. The raw gas from the gasifier is cooled and cleaned using a wet scrubber, a sawdust filter, and a filter type water separator. The fuel gas with a lower heating value of 4-4.8 MJ/Nm^3 is burnt and consumed in a Mercedes gas engine to produce heat and power. The efficiency of electricity production is about 24%.

Blære Project

The Department of Energy Engineering at the Technical University of Denmark (DTU) has developed a two-stage gasification process. Based on this technology a cogeneration plant producing 250 kW_{th} and 100 kW_e was built at Blære, Aars by the Danish REKA Maskinfabrikken company. Wood or straw is pyrolysed in a first stage screw-conveyed reactor by external heating at 600°C. The resulting volatiles react with preheated air/steam mixture to produce a low-tar-containing fuel gas which is used to gasify the residual char from the pyrolysis step. The resulting fuel gas is cooled and cleaned in a venturi scrubber and is fed to a 12 litre Perkins engine rated at 100-120 kW_e. The waste heat from the engine exhaust is used to heat the first stage pyrolysis reactor. The efficiency of electricity production is estimated to be 25%. Tests in the 50 kW_{th} DTU Pilot Plant showed that if the feed is dried to 30-35% moisture content the process may consume the entire condensate and there may not be any need to provide a waste water treatment facility. The pilot plant tests produced a fuel gas with a heating value of 6 MJ/Nm^3 at a thermal efficiency of about 90%.

Finland

Lahti Kymijärvi Project

In 1997-98, the Lahden LÄMPÖVOIMA Oy, installed a 60 MW_{th} capacity atmospheric pressure Foster Wheeler (formerly Ahlström) CFB biomass gasifier, at a cost of approximately US$15 million at its 200 MW_e fossil fuel fired power station. This power plant was originally built in 1976 to use fuel oil. In 1986 the burners in the boiler were converted to natural gas and a natural gas turbine cycle was added. The biomass gasification plant was installed primarily to use locally available fuels and waste materials including plastics. The gasifier is a single gasifier vessel with a cyclone and an air preheater for heating the gasification air to approximately 400°C. The LCV gas is cooled from approximately 830-850°C to 700°C before it is transported in a pipeline to the boiler. The raw gas has no adverse effect on the performance of the boiler. Emissions are reduced and the heating surfaces in the boiler stay relatively clean. The reported gas composition (in volume %) is: 12.9% CO_2; 4.6% CO; 5.9% H_2; 40.2% N_2; 33.0% H_2O; 3.4% C_xH_y. The heating value of the LCV gas is approximately 2.0-2.5 MJ/Nm^3. The NOx emissions were reduced by 5% (permitted level is 230 mg/MJ for both NOx and SO_2) and the dust emissions were reduced by half because of increased conductivity of dust. However HCl emission increased by a small quantity of 5 mg/Nm^3. The present breakdown of fuels in the boiler is approximately: 11% LCV fuel gas from the gasifier, 69% coal, 15% natural gas to boiler, and 5% natural gas to gas turbine. The annual average total efficiency is approximately 80%, the fuel to power efficiency with gas turbine in operation is 35%. The gas turbine has increased the efficiency by 4% points. The plant supplies 200 MW_e power to the national grid (110 kV line round the town) and 250 MW_{th} heat to the town (100,000 inhabitants) and surrounding houses (main pipe 700 mm). The district heating system was constructed in 1958.

Courtesy of Lahti Kymijärvi Project, Finland

BIONEER Process

The BIONEER gasifier is an updraft moving bed gasifier, producing tarry LCV fuel gas. The gasifier consists of a refractory lined vessel with a rotating cone-shaped grate. Biomass fuel is fed from the top, from where 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 amounts 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 close coupled boiler to generate steam and hot water for district heating. During the mid 80s, VTT and BIONEER conducted extensive tests with a variety of feed stocks (eg 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 Hämeenlina 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/Nm^3. The tar content of dry product gas is estimated to be in the range of 50-100 g/Nm^3. Between 1985 and 1986, when fuel oil prices were high, eight commercial BIONEER plants, with capacities ranging from 4-5 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. The BIONEER plants are completely automated and operated with minimal personnel costs.

Courtesy of Bioneer Kauhojoki, Finland

Ahlstrom Corporation bought the BIONEER company originally owned by YIT Corporation. After Foster Wheeler acquired Ahlstrom, a 6.4 MW_{th} plant was installed at Ilomantsi, in eastern Finland in 1996. The estimated investment cost for district heating applications is about 350 $kECU/MW_{th}$ and the operating cost is about 17 ECU/MWh.

Wisa Forest Pyroflow Gasifier

In 1981, Ahlstrom Corporation developed the first 3 MW_{th} capacity pilot CFB gasifier from its successful CFB pyroflow combustion technology at the Hans Ahlstrom Laboratory at Karhula. The first commercial Ahlstrom Pyroflow CFB gasifier was commissioned in 1983 at the Wisa Forest Pulp and Paper Mill in Pietarsaari, Finland. The fuel for the 35 MW_{th} (about 150 t/day of biomass) gasifier is primarily bark and sawdust, sized up to 5cm, and dried at 150°C to about 15% moisture content. 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 objective of replacing 85% of the fuel oil for the lime kiln was achieved within a few months of start up. Between 1985 and 1986, three more gasifiers, two in Sweden (25 MWth at Norrsundet Bruks, AB, Norrsundet and 27 MW_{th} at ASSI, Karlsborg Bruk, Karlsborg) and one in Portugal (15 MW_{th} at Portucel, Rodao Mill), were built and commissioned for firing lime kilns.

Italy

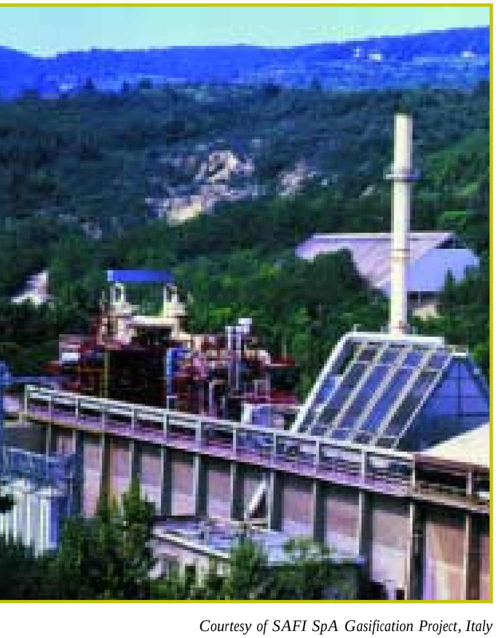
Thermie Energy Farm Project

The Thermie Energy Farm (TEF) Project by Bioelettrica SpA employing the atmospheric Lurgi CFB-gasifier is now under construction at Cascina, near Pisa. The 43 MW_{th} capacity plant will produce about 14 MW_e. The air-blown gasifier will gasify up to 3.5 cm biomass feedstocks (poplar and Robinia wood chips, olive residues, grape residues, and sawdust) with about 5% moisture (after drying at the plant by the flue gases from the heat-recovery steam generator) at a temperature of about 800°C and 1.5 bar(a) pressure. The raw LCV fuel gas is cleaned of most particulates in cyclones, cooled, scrubbed, and compressed prior to producing electricity in a gas turbine and heat-recovery steam generation and steam turbine plant. The project is owned by Bioelettrica SpA, whose shareholders are USF Italia, Electricidade de Portugal-EDP, Lurgi, Energia Verde, and Fumagalli, and receives financial contribution from the EC under the Thermie 1994 programme. The plant is expected to be operational in the middle of 2002.

Courtesy of Bioelettrica, Italy

SAFI SpA RDF Gasification Project

The first commercial TPS CFB gasification process was built for RDF gasification at Loc Testi, Passo dei Pecorai, Greve in Chianti. RDF pellets, up to 150 mm long, are fed into the lower section of a 15 MW_{th} capacity CFB gasifier, at a rate of about 3 t/hour. The TPS gasifier operates at low (2500 mm water) pressure and a temperature of about 875°C, employing air as the gasification/fluidizing agent. Part of the air is injected at the bottom of the gasifier and the remainder is injected part way up the vessel. This pattern of air distribution creates a high-density bed in the lower part of the vessel, which allows the gasifier to handle relatively large-sized fuel particles. The CFB of sand particles are maintained by a superficial gas velocity of about 3-10 m/s.



Courtesy of SAFI SpA Gasification Project, Italy

The pellets are gasified within the 2-2.2 seconds residence time producing an LCV fuel gas of about 8 MJ/Nm^3. The raw gas passes through two stages of solids separation before being fed to a furnace/boiler to generate steam for producing 6.7 MW$_e$ in a condensing steam turbine. The overall power generation efficiency is about 19-20%. Alternatively, part of the raw gas can be fired in a nearby cement kiln. The flue gas exiting the boiler is cleaned in a three-stage Research Cottrell scrubber before venting through the stack. The plant has been operated intermittently due to difficulty in obtaining a continuous supply of RDF pellets.

The Netherlands

KARA/BTG Co-current Downdraft Gasifier System

This 150 kW$_e$ system incorporates two special features:

- The use of a low-speed (750 rpm), low-cost, robust engine made in China. This marine diesel engine is re-designed for use in connection with rice husk gasifiers. The engine is less sensitive to impurities and its efficiency is lower than modern, lean-burn engines. Any loss due to the low engine efficiency is compensated by incorporation of a roots blower to compress the fuel gas to enhance its volumetric heating value.
- The fuel gas enters the engine at a temperature higher than the dew-point, thus avoiding any condensation.

The system consists of a fuel feeding conveyor, gasifier, two cyclones, baffle filter, gas cooler, bag-house filter, roots blower, and gas engine.The gasifier feed is either sized or briquetted block-sized wood. The fuel gas has a heating value of about 4.5 MJ/Nm^3, with tar and dust content below 100 mg/Nm^3.

A demonstration plant is scheduled for early 2000 at a briquetting plant near KARA. Power will be delivered to the grid while the heat will be used for the drying system of the briquetting plant. The developers include a consortium of KARA Energy Systems BV, BTG biomass technology group BV and CPS, CompackSys BV, with funding support from Shell International Renewables and Novem.

Stork Thermeq Co-current Downdraft Gasification System

This 400 kW$_e$ system consists of a double valve fuel feeder, a gasifier developed at Energy Research Centre Netherlands (ECN), thermal catalytic tar cracker developed and patented by BTG, and an IC engine for producing electricity. A 400 kW$_e$ demonstration plant will be constructed during 2000 in Goor. The gasifier will be fed partly with composted waste wood. The electricity will be supplied to the grid and sold to Essent as 'green' power and the heat will be used in the greenhouses in Goor. The main objective is to demonstrate and validate the technology for subsequent scale-up to a commercially viable, fully automated, turnkey biomass gasification installation producing 2 MW electrical and 4 MW thermal power. The developers include a consortium of Stork Thermeq, BTG and KARA.

Amergas BV Project

Courtesy of NOVEM, The Netherlands

This 30 MW_e project is under construction at the Amer powerstation at Geertruidenberg in southern Holland, to gasify low quality demolition wood (about 150,000 TPY) which cannot be recycled by the chipboard industry. The gasifier is an 83 MW_{th} low-pressure, Lurgi CFB gasifier. The product gas will be cooled for steam recovery, scrubbed to remove particulates and ammonia and burnt in the coal fired Amer 9 cogeneration unit. The unit has a net production capacity of 600 MW_e and 350 MW_{th}. The start up of the plant is planned for early 2000.

Norway

At present there are no demonstration or commercial biomass gasification projects in Norway. Potential applications for gasification may be to improve pulp and paper mill operations and for cogeneration in remote sites.

Sweden

Gotaverken Project (Varo)

The Gotaverken (Kvaerner) process employs a CFB gasification process developed in a 2 MW_{th} pilot plant at the Royal Institute of Technology. Sized and dried fuel is fed a few meters above the bottom of the gasifier to create two distinct zones. In the upper zone, biomass is flash pyrolyzed by coming in contact with hot circulating dolomite, at a temperature of 645°C, and produces fuel gas rich in C_2+ and some tars. In the lower zone the recycled residual char is combusted with air to produce the hot flue gases that promote flash pyrolysis in the upper zone. The circulating bed of dolomite promotes tar cracking and reduces the amount of heavy hydrocarbons produced in the gasifier.
The LCV fuel gas is partially cooled in a heat exchanger to preheat gasification air and then burnt in a lime kiln. The plant start up was in 1987 and turned over to the customer in 1988. A typical gas composition is 15% CO, 10% H_2, 5% CH_4, 3% C_2+, 16% CO_2, 8% H_2O, and 43% N_2. Gotaverken has not built any more such biomass gasification plants due to low oil prices.

Värnamo Project

This is the first demonstration of the pressurized Foster Wheeler-Ahlstrom CFB biomass gasification process, operating at 20 bar pressure and 950-1000°C. The 18 MW_{th} capacity IGCC demonstration cogeneration plant uses a feed stock consisting of 40% wood chips and 60% bark. The hot-gas filter employs high temperature ceramic Schumacher candle filters. The gas composition (in volume %) is reported as 10-12% H_2; 15.5-17.5% CO; 5-7% CH_4; 14-17% CO_2; 45-50% N_2. The fuel gas heating value is 5-6 MJ/Nm^3 (dry gas); tars <5g/Nm^3; alkalies <0.1 ppm; NH_3 <700 ppmv; dust <2 ppm by wt. The measured plant emissions include NOx 50-125 ppmv; SOx 5-10 ppmv; CO 50-200 ppmv; HC 0-4 ppmv; and dust approximately 5 mg/Nm^3 (dry gas).

Courtesy of Sydkraft, Sweden

The raw gas contains about 10-12% undecomposed steam and the hot gas filter is operated at 350-400°C. The raw gas LHV is about 5 MJ/Nm^3. The demonstration plant employs the EGT Ruston Typhoon gas turbine. To handle the LCV fuel gas, the natural gas turbine burners and their enclosing cans were enlarged in size. The exhaust from the gas turbine at 450°C passes through an Ahlstrom heat recovery steam generator to produce superheated steam. A Nadrowski steam turbine is used to generate electricity. The turbine air compressor produces 10-12 bar air, which is compressed further in a booster compressor to produce gasification air at 20 bar pressure. The demonstration plant was commissioned in March 1993 and over the last two to three years the plant has operated successfully in an integrated fashion for many thousands of hours.

Termiska Processor AB (TPS) Process

Since the mid 1980s TPS has been developing a low pressure, air-blown CFB gasification process. The initial applications were planned for fueling lime kilns. In the late 1980s TPS licensed the process to Ansaldo of Italy and provided the design for two pelletized RDF gasifiers for a commercial plant in Greve-in-Chianti, Italy. The plant was designed by Studio Ingenaria Ambientale and built by Ansaldo Aerimpianti. The plant owner is Servizi Ambientali Area Florentina (SAFI). Further details of the SAFI gasification project is given under the Italian gasification projects. The TPS process was also selected for the ARBRE project in UK and the BIG-GT project in Brazil.

Switzerland

Pyroforce Gasification Plant

A commercial 200 kW_e Pyroforce gasifier with a Jenbacher engine is currently under construction at a military research center near Interlaken. The plant employs a Pyroforce gasifier, based on the KHD (Kloeckner Humbolt Deutz) high temperature gasification process and a dry gas clean up system. The downdraft moving bed gasifier maintains a temperature of 1200-1300°C in the combustion zone. Plant commissioning is scheduled for the middle of 2000. Although pilot tests were conducted with demolition wood, uncontaminated wood chips will be used as the gasification feed material.

Courtesy of IISc, Switzerland

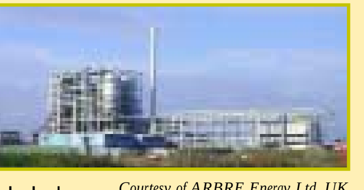
Indian Institute of Science-DASAG Gasifier

The Indian Institute of Science (IISc)-DASAG gasifier is an air-blown, low pressure, open-top, co-current, downdraft, moving bed system with a specially designed lateral air inlet to reduce tar production. The gasification feed material is uncontaminated woody biomass materials. A pilot demonstration plant designed for 330 kW_{th} and 100 kW_e capacity is in operation at Châtel-St-Denis. The plant is equipped with a Swiss gas cleaning system and a 6 cylinder Liebherr gas engine. The present electrical output is 55 kW_e. The electrical efficiency of the plant (from wood to electricity) is 24%. The plant had operated for about 700 hours by November 1999. Continuous tests lasting up to 1500 hours are expected to be complete by February 2000. Air-blown gasification tests with biomass feed up to 8 cm in particle size, produced a gas composition with 18% CO, 13% CO_2, 2% CH_4, 18% H_2, 15% H_2O, 34% N_2, 50 mg/Nm^3 tar, and 700 mg/Nm^3 particulates.

Courtesy of IISc, Switzerland

United Kingdom

ARBRE Project



Courtesy of ARBRE Energy Ltd, UK

The ARBRE project employs the low pressure TPS gasifier. The 8 MW_e capacity plant is currently under construction in Yorkshire. The project integrates the use of Yorkshire's municipal sludge for growing short rotation coppice plants for biomass gasification and includes recycling the gasifier ash back to the coppice plantations as a soil conditioner. The biomass feed stock is derived from 2000 hectares of willow and poplar short rotation coppice plantation. The air-blown TPS gasifier is close coupled to a CFB catalytic tar cracker to reduce tar in the LCV gas which is cooled and water scrubbed to produce a clean fuel gas. The fuel gas is compressed and combusted in a gas turbine heat recovery steam generation system to produce 8 MW_e employing a Typhoon European Gas Turbine. The projected overall electrical efficiency is 31%. Initial shakedown and startup of the gasifier is scheduled for early 2000. The project team consists of Yorkshire water, TPS, and AEP, part of Compagnie Generale des Eaux of France, who will provide operating and maintenance services.

Boughton Pumping Station CHP Project

This is the second installation by Rural Generation Ltd, the company that developed UK's first on-farm CHP biomass-fuelled plant in Londonderry. The new plant produces 100 kW_e and approximately 180 kW of heat. The plant includes a downdraft, moving bed gasifier based on the concept of Professor J. Martins of the University of Louvain in Belgium. The power is produced by a six cylinder, dual fuel, Iveco engine running on 80% wood and 20% diesel - although eventually it will run on 10% diesel. The ex-works price for such a unit, including the gasifier, gas clean-up system, engine and generator, and heat recovery unit, is about £80,000. However, local factors can influence the cost significantly.

Courtesy of Rural Generation Ltd, UK

The unit produces heat and electricity for a converted water pumping station in Ollerton, Nottinghamshire. The station was originally built in 1905, to house the steam operated pumps that supplied the city of Nottingham. It is now used as a workshop and office complex, with restaurant and conference facilities. The basement houses a popular 'hands on' sustainable energy exhibition. The project does not have a NFFO contract, although the plant puts electricity into the local grid at peak-price times of day, like its forerunner in Londonderry.

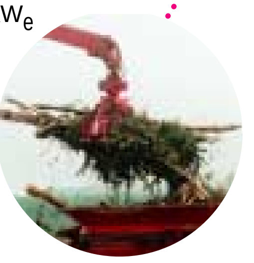
Blackwater Valley Museum Project

B9 Energy Biomass Ltd, undertook this project in 1995 to develop and operate a wood fuelled, combined heat and power unit to provide heating and clean electricity for 400 homes. The project team consists of B9 Biomass, Armagh City and District Council and the Blackwater Valley Museum, Benburb. The fuel used will be a mixture of wood from existing forests and coppiced willow from local farmers. However, to begin with, until grants are in place to encourage farmers to grow willow, the unit will use sawmill wood chips. The plant uses a downdraft, moving bed gasifier linked to a reciprocating engine to produce around 400 kW of heat and 200 kW of electricity at 415 volts. This is transformed to 11kV and carried away on the NIE grid. The plant is capable of 24 hours per day unmanned operation for a

Courtesy of B9 Energy Biomass Ltd, UK

period of six days after which the ash is removed. Over the 15 years of the electricity contract approximately £1,000,000 will be spent locally on fuel and labour. The installation is the first of its type in the world and was built in Northern Ireland at a cost of £250,000. The commercial demonstration project at Blackwater Valley has the potential to raise further orders for Northern Ireland.

Other UK gasification projects include: Rural Generation Ltd, Brook Hall Estate, Northern Ireland - Downdraft/Louvain gasifier, 100 kW_e - based on forest fuels; Shawton Engineering, Warrington, England - Downdraft/ Shawton gasifier, 100 kW_e - based on wood waste; Compact Power, Bristol - indirectly heated gasifier, 1 MW_{th} - based on industrial and other wastes; and Waste Gas Technology, South Wales - indirect/WGT rotating drum gasifier, 1 MW_{th} - based on sewage sludge.



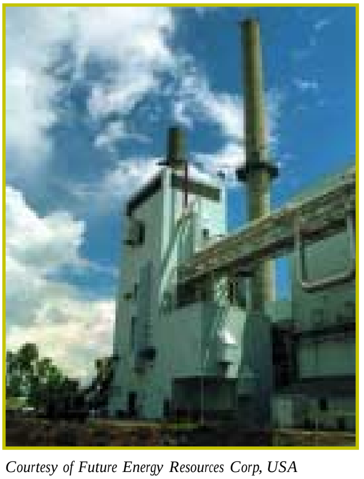
United States of America

Vermont Battelle/FERCO Project

The Battelle/FERCO project employs the low pressure Battelle gasification process which consists of two physically separate reactors:

- a gasification reactor in which the biomass is converted into a MCV gas and residual char at a temperature of 850°C, and
- 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. Since the gasification reactions are supported by indirect heating, the primary fuel gas is a medium calorific value fuel gas. A typical product gas composition obtained in pilot plant tests, at steam to biomass ratio of 0.45, is 21.22% H_2; 43.17% CO; 13.46% CO_2; 15.83% CH_4 and 5.47% C_2+. The estimated HHV of this fuel gas is 17.75 MJ/Nm^3. A 200 t/day capacity Battelle demonstration gasification plant was built at the McNiel Power Plant and plant shakedown and initial testing is now in progress with wood chips. During the first phase the fuel gas will be cofired in the existing McNeil boiler. In subsequent phases, the fuel gas will be cooled for heat recovery, scrubbed, recompressed prior to energy conversion and recovery in a 15 MW_e gas turbine system. The project participants include; US DOE Biomass Power Program, FERCO, Battelle Columbus Laboratory, Burlington Electric Department, Zurn Industries, OEC/Zurn, and NREL.



Courtesy of Future Energy Resources Corp, USA

MTCI Process

The MTCI gasification process also employs indirect heating to promote steam gasification of biomass to produce a MCV fuel gas. The gasifier combusts part of the fuel gas in pulsed combustion burners which promote heat transfer to the gasification section. Extensive pilot plant tests were conducted in a 20 t/day process development unit (PDU) at MTCI laboratories near Baltimore, Maryland. These tests also included an evaluation of black liquor gasification. Based on the PDU tests a 50 t/day capacity black liquor gasification demonstration unit was built at Weyerhaeuser's New Bern facility. The MTCI process group is currently designing and building a modular system and also seeking partnerships and support to demonstrate other gasification applications.

IGT RENUGAS Process

The IGT RENUGAS process employs a 20 bar pressurized bubbling fluidised bed process. The process was extensively tested with a variety of biomass materials, including bark-sludge mixtures, bagasse, and pelletized alfalfa stems in a 12 t/day process development unit (PDU) at IGT test facilities in Chicago. Subsequently USDOE selected the IGT process for scale-up and demonstration, using bagasse, at the HC&S sugar mill at Paia in Hawaii. Since this 100 t/day demonstration plant had limited success in handling the low-density, shredded bagasse, the project was terminated. A typical gas composition obtained in the IGT PDU with bagasse at 2.24 MPa, and 850°C is 19% H_2; 26% CO; 37% CO_2; 17% CH_4 and 1% C_2+. The heating value of this fuel gas is approximately 13 MJ/Nm^3. The project participants included: US DOE Biomass Power Program, IGT, Westinghouse Electric Corporation, State of Hawaii, PICHTR, and HC&S.

Courtesy of Institute of Gas Technology, USA

The pressurized RENUGAS process coupled with hot-gas particulate and alkali cleanup is ideally suited for IGCC applications and to generate electricity at efficiencies in the 40-42% range. IGT is currently seeking partnerships and support for further demonstration of the RENUGAS process.

Small Modular Biopower Projects

The objective of this program, sponsored and managed by DOE, NREL, and SNL, is to develop small modular biopower projects that are fuel flexible, efficient, simple to operate, have minimum negative impacts on the environment, provide power in the 5 kW - 5 MW range, and are useful for domestic and international markets. The ten projects selected for the Phase 1: Feasibility Studies are given below:

Company	Technology	Size, kW_e
Agrilectric	Fluid-bed Combustor/Steam Turbine	500-5000
Bechtel	Gasifier/Engines/Gas Turbine	500-1500
Bioten	Direct-fired Combustion Turbine	5000
Carbona	Gasification/Steam Turbine	1000-3000
CPC	Gasification/IC Engine	10-25
EERC	FBC/Steam Turbine	500-5000
NIMO	Gasification/IC Engine/Gas Turbine	500-5000
Reflective Energies	Gasification/Gas Turbine	100-1000
STM	Gasification/Stirling Engine	25-70
SunPower	Gasification/Stirling Engine	1-10

These projects are under evaluation to provide funds for Phase 2: Prototype Testing and Phase 3: Integrated Systems Demonstration.

Brightstar Synfuels

Brightstar Synfuels, Houston, Texas and Baton Rouge, Louisiana, employs a modular, skid-mounted, tubular entrained-flow steam gasification system. The estimated cold-gas efficiency with 40% moisture feed is about 80%, with no tar formation. Three 1.5 MW units are planned for East Texas, for natural gas replacement, and there is a potential project to couple the gasifier with an IC engine in Australia.

Thermal Technologies

Thermal Technologies, Inc. Camp Lejune, North Carolina employs a downdraft gasifier, operating at a maximum temperature of 982°C. Extensive tests were conducted in a 816 kg/hr pilot unit with 10% moisture feed. The resulting 0.49Nm^3/s fuel gas at 6.35 MJ/Nm^3 is fed to a Waukasha L7042 turbo-charged engine/generator to produce 700 kW_e.

Primenergy

Primenergy, Tulsa, Oklahoma employs an updraft gasifier in a 36 t/day capacity pilot unit. Sixteen different feed stocks have been tested, including switch grass, paper mill sludge, rice straw, bagasse, and poultry litter. So far sixteen commercial units ranging in size from 50-550 t/day of rice husk have been installed to produce heat (for hot air or steam) or electricity (up to 12 MW). A 600 t/day capacity rice husk gasification plant is now under construction at Riceland Foods, Stuttgart, Arkansas for producing 15 MW_e using an extraction steam turbine and a 150 t/day capacity rice husk gasification plant is under construction at Riceland Foods, Jonesboro, Arkansas coupled to a 7 t/hour steam boiler and three parboiled rice dryers.

Cratech

Cratech, Tahoka, Texas employs an air-blown, high pressure gasifier. A 2.2 t/hour capacity unit coupled to a 225 kW Solar Spartan Turbine is now under construction.