IEA Bioenergy Agreement
Task 33: Thermal Gasification of Biomass

Work Shop No. 1: Perspectives on Biomass Gasification

By
Suresh P. Babu, Task Leader
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Background

On May 3, 2004, Task 33 conducted the first workshop on "Short, Medium and Long Term Perspectives on Biomass Gasification" for the 2004-2006 triennium in Vienna, Austria. This report includes information from this workshop on national perspectives on biomass gasification (BMG) from all the participating member countries in Task 33.

Introduction

The present global effort to curb GHG emissions involve substituting fossil fuels with renewable fuels and improving efficiency of energy utilization, and plans to separate and sequester CO_2. Of the various renewable fuels, in many of the countries biomass is either the largest or second largest renewable resource next only to hydropower. Hence, there is increasing interest in developing and commercializing innovative biomass energy conversion technologies. Of the many biomass energy conversion methods, BMG offers several advantages. BMG converts a heterogeneous feed to produce either a uniform in composition fungible fuel gas or synthesis gas. The product gases can be cleaned and the clean gas can readily replace fossil fuels, in both conventional and advanced energy conversion devices.

Biomass Feedstock Availability and Suitability to BMG

The World Energy Council reports that wood fuels contribute 6% of the global energy requirement, which is larger than the combined contribution of hydropower and other renewables, but less than nuclear energy. Further, the Council recognizes that by efficient utilization of wood fuels, and biomass in general, the atmospheric CO2 emissions can be effectively reduced in comparison to carbon sequestration in trees[1]. In spite of such well recognized potential benefits, the extent of biomass utilization has not increased in the last two decades. Consequently, issues related to the development of the basic infrastructure for sustainable supply of biomass and global trading for energy production continues to be a topic for scholarly discussions[2]. It is anticipated that as more countries recognize that there is an imminent need to catch-up with set goals to contain GHG emissions and/or ensure security of energy supply, the said discussions should lead to tangible actions to develop the biomass feed stock supply infrastructure. An effective and expedient way could be to implement policies that would motivate the rural economies and existing forest product industries to play a lead role in sustainable production and distribution of biomass at a competitive price. Simultaneously with this effort, it is imperative that industrialized countries should commit resources to develop and promote biomass energy conversion processes that are more efficient than simply burning wood.

BMG is one such conversion process that can be at the core of 'green' energy conversion systems that could increase efficiency of power production by 50%, produce synthesis gas for fuels and chemical feed stocks, pave the way for ultimately building the ‘hydrogen economy’, enable recycling of plant nutrients in ash to energy plantations, and even offer the option to capture CO_2 produced during gasification.

Perspectives on Biomass Gasification

In the following sections, the member countries of Task 33 have provided a brief summary of their respective national perspectives on biomass and BMG in particular.

European Commission (EC): One of the main EU energy texts in the area of renewable energy sources (RES) is the White Paper for a Community Strategy and Action Plan [COM(97)599][3]. It has set the target to double the share of RES from around 5.4% in 1995 to 12% of gross consumption by 2010. The projected share of bioenergy by 2010 should be 135 million tons of oil equivalent (Mtoe).

In the recently issued Biomass Action Plan [COM(2005)628][4], the EC proposed measures that could lead to an increase in biomass use from 69 Mtoe in 2003 to about 150 Mtoe in 2010 or soon after. EC believes that this scenario can be achieved by increasing the use of biomass by 35 Mtoe to produce additional electricity, 27 Mtoe to produce additional heat, and 18 Mtoe to produce substitute transportation fuels over and above the 20, 48 and 1 Mtoe respectively, consumed in 2003.

In pursuit of these EU goals, and in some cases higher targets set by individual European countries, a variety of legislative actions have been developed to promote RES at the EC level as well as by national and regional administrations. The Directive 2001/77/EC[5], adopted in September 2001 has set a target to increase the share of green electricity to 22% of gross electricity consumption by 2010. Directive 2003/30/EC[6], adopted in May 2003, aims to raise the share of biofuels to 5.75% by 2010. In addition, Directive 2003/96/EC[7] authorizes a partial or total tax exemption for biofuels when used either exclusively or in combination with conventional fuels.

In support of this challenging mission, the Sixth Framework Programme for “Research and Technological Development (RTD): 2002-2006” is spearheading initiatives including renewable energy sources under the so-called “Sustainable Energy Systems”. Bio-energy research represents an important portion of the portfolio, and a number of ambitious bio-energy projects are being financed by the EC. The programme is divided into (1) actions having an impact in the medium to long term (MLT), which are managed at DG RTD and (2) demonstration activities, including actions, which have an impact in the short to medium term (SMT), managed at DG TREN. In addition, national and regional programmes also finance RTD actions to develop and deploy biomass energy technologies.

The following is a summary of the BMG projects (and project coordinators) selected under the MLT part of FP6:

1. Clean hydrogen-rich synthesis gas – CHRISGAS: To develop a large scale BMG process to produce clean hydrogen-rich gas that can be used for the production of transportation fuels. The key research facility is the pressurized BMG plant in Värnamo, Sweden; Coordinator: Växjö University, Sweden and EU support = € 9.5 million. Starting date: 01/09/2004. Duration: 60 months

2. Renewable fuels for advanced power trains - RENEW: To compare and (partially) demonstrate a range of fuel production chains for motor vehicles; Coordinator:

Volkswagen AG Group Research, Germany and EU support = €10 million. Starting date: 01/01/2004, Duration: 48 months

3. Overcoming barriers to bioenergy – NoE BIOENERGY: Covering all processes, components and methods necessary for establishing successful bioenergy chains to produce heat, electricity and fuels; Coordinator: VTT, Finland and EU support = € 8 million. Starting date: 01/01/2004. Duration: 60 months
4. Biomass fuel cell utility systems – BIOCELLUS: The project will study the performance characteristics of SOFC membranes for different syngas compositions and gasification operating conditions. An appropriate gas-cleaning concept will be developed and an innovative stack concept using heat pipes will be demonstrated. Coordinator: TU München, Germany and EU support = € 2.5 million. Starting date: 01/07/2004. Duration: 36 months
5. SOFC fuelled with BMG gas – GREENFUELCELLS: The project aims to develop a tar-decomposition and gas-cleaning system for integration into BMG enabling them to produce a gas suitable for use in SOFC; Coordinator: Cirad, France and EU support = € 3 million. Starting data: 01/09/2004, Duration: 36 months
6. Biomass Fluidized Bed Gasification with In-situ Hot Gas Cleaning – AREGAS II: The project aims to develop a low-cost gasification process with integrated in-situ gas cleaning for the conversion of biomass into a product gas with high hydrogen concentration, high heating value, low CO_2-content, no nitrogen and low tar, alkali, and sulphur concentrations in one process step for subsequent power production. Coordinator: ZSW, Germany, EC contribution: € 1.8 million. Starting date: 1/1/2006. Duration: 36 months
7. Advanced BMG for High Efficiency Power – BIGPOWER: Three promising European gasification technologies have been selected to form the basis for the development of the second generation processes: air-blown fixed-bed gasifier for the size range 0.5-5 MWe, steam gasification in a dual-fluidized-bed gasifier for 5-50 MWe, and air-blown pressurized fluidized-bed gasification technology for 5-100MWe. Coordinator: VTT, Finland, EC contribution: € 1.7 million. Starting date: 01/10/2005, Duration: 36 months.

Information concerning the EU funding demonstration projects will be provided as soon as the corresponding contracts have been signed (hopefully by Spring 2006).

In addition to the latter, the “Intelligent Energy for Europe” (IEE) Programme supports the European Union’s policies in the field of energy by providing funds for actions to remove market barriers to the increased use of energy efficiency and renewable energy sources. In this respect, the IEE programme is complementary to FP6.

Austria: While many European countries are actively pursuing measures and means to implement the European Directive, Austria has set higher goals than EU targets for introducing biofuels. To expedite the introduction of biofuels the existing infrastructure for fossil fuels are being employed for blending biofuels with conventional fossil fuels.

In 2003, Austria derived 21% of its energy from renewable resources while biomass contributed roughly 12% (or 168 PJ or 0.16 Quads) of the primary energy demand. Of the latter, 60% is used for heating applications, 21% for process heat, 11% for combined heat and power (CHP), and 8% for district heating. Thus, at present biomass is mostly used for heating applications.

Austria, considers that the 1st generation biofuels are available today, primarily as biodiesel from rape and other oil bearing crops, and bio-ethanol from starchy crops; the 2nd generation fuels (ex: synthesis gas) are now under development; further development of 1st and 2nd generation fuels should lead to 3rd generation fuels, such as H_2, which may build the bridge to the sustainable, carbon contained energy of the future[8].

In the short term, Austria will explore ways and means to introduce BMG CHP systems as an alternative to the widely deployed combustion based district heating operations. In support of this goal the Technical University of Vienna (TUV) has successfully developed the Fast Internal Circulating Fluidized Bed (FICFB) Process (Figure 1) which employs indirect-heating to gasify biomass with air to produce synthesis gas. The first application for the FICFB process is to service the CHP needs in Güssing.

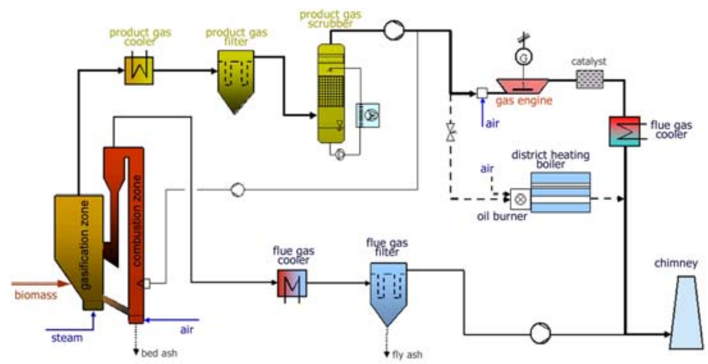

Figure 1: The TUV- FICFB Biomass Gasification Process: CHP Demonstration in Güssing (8 MWth capacity, 2.0 MWe + 4.5 MWth Heat, 50 tons/day of wood chips from forestry)

The gasifier including the gas cleaning units were commissioned at the end of 2001. The calorific value of the product synthesis gas is 12–14 MJ/Nm^3 and the tar content after gas cleaning is < 20 mg/Nm^3. R&D is continuing to further reduce the tar content. The scrubbed clean product gas was first used to generate electricity using GE-Jenbacher IC engines in April 2002. The entire CHP system is performing as per design specifications in a 3-year demonstration phase (2001 to 2003). At the end of January, 2006, the 8 MWth capacity demonstration plant has logged-in nearly 22,000 hours of gasifier operation which includes almost 18,000 hours of integrated operation with GE-Jenbacher engines, producing ~2 MWe and 4.5 MWth for district heating.

Since the primary product from the TUV FICFB BMG Process is a mixture of CO, H_2, and CH_4, the demonstration project has attracted attention from other European countries in jointly evaluating the production of substitute natural gas (SNG) and Fischer-Tropsch (F-T) biodiesel from steady supply of slip-stream gases at the demonstration plant. It is Austria's goal to continue with the development of the TUV FICFB Process for second and third generation biofuels mentioned above.

The next major demonstration gasification plant in Austria is the down-draft BMG CHP plant at Wr. Neustadt (Figure 2), with a fuel capacity of 2 MWth and producing 0.5 MWe and 0.7 MWth of district heat. The calorific value of the fuel gas is in the range of 4.5 to 5.5 MJ/Nm^3. The plant was commissioned in 2003 and research is continuing to clean the producer gas with biodiesel as well as a wet electrostatic precipitator, before feeding the fuel gas to a gas engine. The focus of the development effort is to optimize gasifier operations while minimizing the production of waste water. It is a national goal to use the experience from this demonstration plant to build compact and simple in design biomass gasifiers for on-site power generation with capacities ranging from 0.2 to 1 MWe.

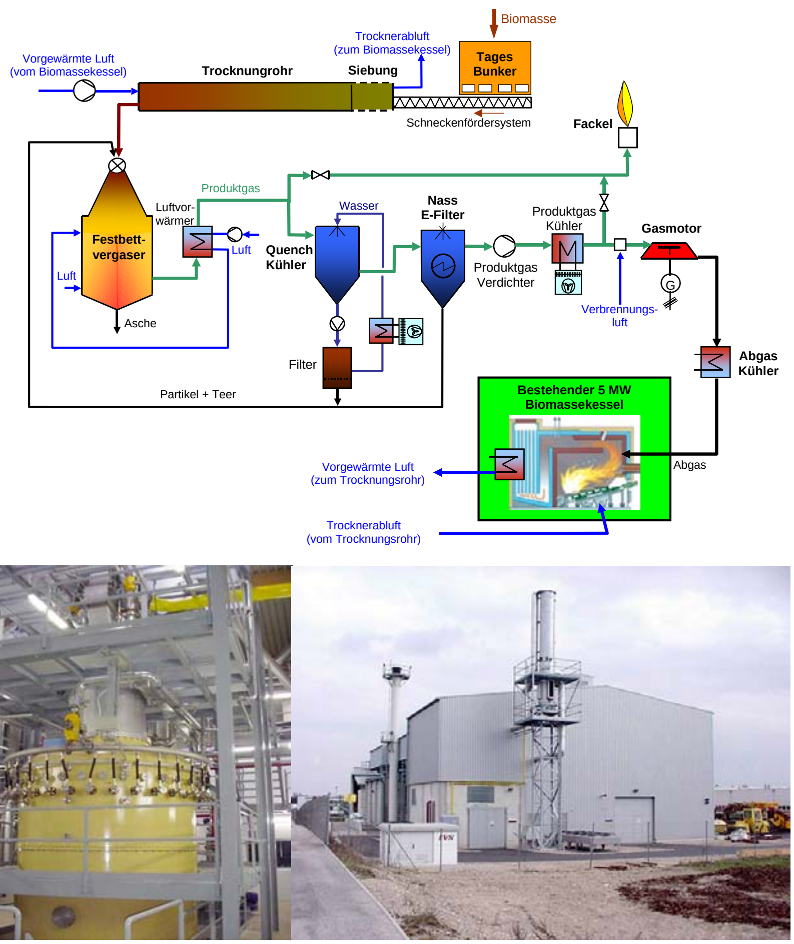

Figure 2: Wr. Neustadt Biomass Gasification CHP Demonstration Plant

(2 MWth capacity, 0.5 MWe + 0.7 MWth Heat, 12 tons/day of wood chips from forestry)

The TUV is also a participant in the EU sponsored RENEW project, coordinated by Volkswagen AG, focused on producing F-T biofuels, the AER – Gas II project for CO_2 removal with CaO in the gasifier, the Big Power project, the BioSNG project, to demonstrate Bio-SNG production, and a project for development of a pressurized (~10 atm) BMG process for SOFC applications. The Institute of Thermal Engineering at the Graz University of Technology is investigating the performance and optimization of a fixed-bed gasifier and gas engine system, similar to the Viking BMG power generation demonstration conducted in Denmark. Thus, Austria is well poised to deploy biomass gasification for a wide range of applications to meet present as well as the future energy needs, including the production of value-added fuels and H_2.

Denmark: The 1996, Energy 21 policy is the prevailing foundation for Danish Energy programs[9]. Under this program renewable energy is expected to increase by 1% per year until 2030. At this rate renewable energy is expected to contribute 12-14 % of the primary energy demand (or 100 PJ) by 2005 and 35% (or 235 PJ) by the year 2030. In Denmark, biomass is the largest renewable resource. Although co-firing with biomass is widely practiced to cut-back on coal consumption, there is considerable interest in pursuing the development of small-scale BMG plants for CHP applications. To further assist deployment of renewable energy, legislative measures are put in place to guarantee 'green' electricity sale price of about 60 ore or about 8 Eurocents/KWh. The population distribution and the demand for heat and electricity present a compelling case to build distributed, small-scale biomass CHP plants. In order to improve efficiency and reduce emissions from wood burning, Denmark has chosen to develop BMG in early 1990s. Denmark has also invested in the development of straw handling for energy conversion which could be applied in general to the utilization of crop residues.

The first large scale BMG (5 MWth Capacity) for CHP application was built and commissioned in December 1993, by Babcock & Wilcox Vølund for the municipality of Harboøre, in Kyndby, Jutland, Denmark. Since then considerable resources were invested by the Danish Energy Authority into the development of an updraft gasifier, gas cleaning and waste water treatment at the Harbøre Varmeværk CHP demonstration plant.

The plant was originally intended solely to provide heat to the village heating grid. It was built as such consisting of a gasifier fuelled by wood chips and burner/boiler where product gas was converted to heat. At that point the main objective was to prove that a full-scale up-draft gasifier could be operated continuously. This was done successfully and some years later, in the year 2000, the plant has added gas engines for CHP. The primary challenge in adding the gas engines was the requirements to produce a gas which should be clean of tar and dust. A range of technologies for removing tar, aerosols and dust from the product gas have been tested. Finally, it was decided to install a gas cleaning/conditioning system, using a gas-cooler system with heat recovery for district heating,followed by a wet electrostatic precipitator. This system has proved successful in supplying clean gas to gas engines, which are now in continuous operation. The condensate from the gas cleaning system consists of a mixture of tar, water, and water-soluble tarry compounds and water-soluble organic compounds, such as carboxylic acids with molecular weights below 200. Cleaning of this water has been the subject of extensive investigation which led to selecting a system based on micro-filtration and reverse osmosis. This system is now discharging a waste water that is environmentally safe. The water-insoluble tar is stored and used as an additional fuel source at the plant, substituting for fuel oil to deal with peak load demand.

The Harboore plant has a capacity up to 3.5 MWth fuel input and 1 MWe produced at the gas engine and 2 MWth supplied for district heating. The plantconsists of the following principal components:

- A 3.5 MWth updraft gasifier with fuel silo, fuel feed, ash system, and air humidifier
- A gas cleaning system with gas coolers and an electrostatic precipitator
- Two GE –Jenbacher gas engines with generators and exhaust boilers with capacities of 648 kWe and 768 kWe (with a turbocharger)
- A tar fired boiler with storage tank for the water-insoluble tar from the gas cleaning system
- A product gas fired boiler, which was mainly used before the gas engines were installed in 2000
- Common district heating components (pumps, deionised water pyrification facility, hot water tank etc.,)

Since year 2000, the Vølund, Harbøre Varmeværk updraft BMG CHP plant illustrated in Figure 3, has been in operation since 1996 and it has been producing power. The gasifier has now logged in more than 80,000 hours and the two GE-Jenbacher gas engines have logged in more than 20,000 hours of operation, delivering more than 10,000 MWh to the power grid. It has been observed that the plant has an excellent turn-down capability which is beneficial in the summer time when the heat-uptake in the district heating grid can be very low. The plant is now in commercial operation.

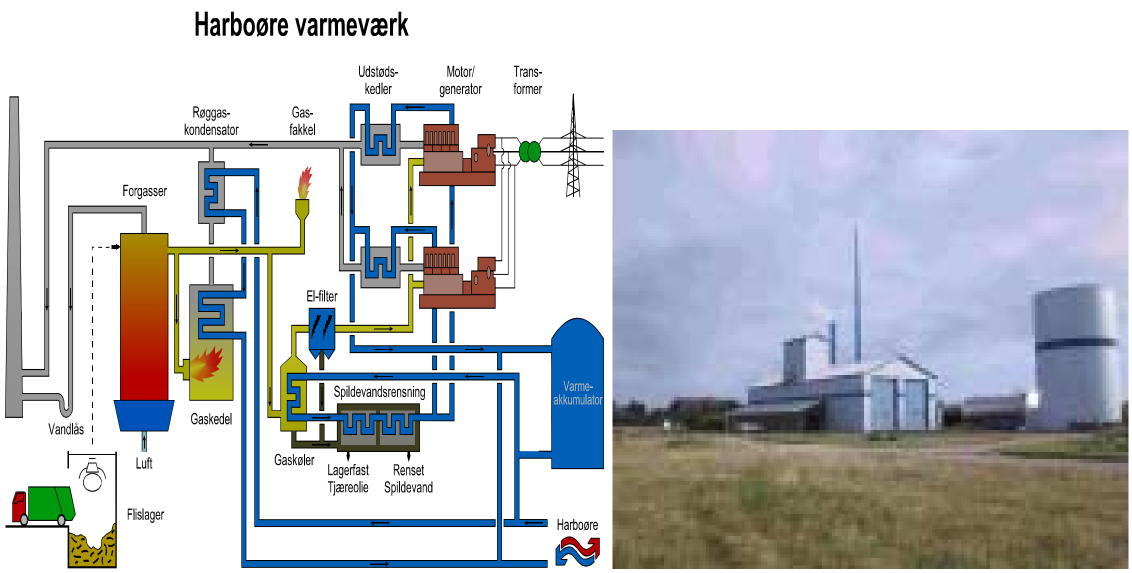

Figure 3: Harbøre Varmeværk CHP Demonstration Plant

(5 MWth Capacity, 1.5MWe + 2 MWth Heating)

Recently, Babcock & Wilcox Vølund has licensed the technology to a Japanese company, JFE, which was planning to build a similar plant in Japan, in 2005. The JFE Engineering and Babcock & Wilcox Vølund are now marketing the CHP system in Asia. The first plant will be owned by Yamagata Green Power Co. Ltd. and it will be located in Murayama City, in Yamagata Prefecture. The operation of the 2 MWe plant, processing 60 tons/day of cherry tree wood-chips is expected to begin in February 2007. The project has received support from the Japan Agency for Natural Resources and the Ministry of Economy, Trade and Industry.

The latest BMG initiative in Denmark is the construction and commissioning of the Carbona CHP Plant at Skive. This project is funded with Public Service Obligation of DK 130MM. The project also receives funding support from the DEA, EC and USDOE. The Skive plant which employs the RENUGAS bubbling fluidized bed gasification technology is illustrated in Figure 4. The 30 MWth capacity plant has been designed to produce 5.5 MWe and 11.5 MWth district heat. Ground breaking for the plant has begun in April 2005. Plant construction is now in progress and plant commissioning is scheduled for late 2006.

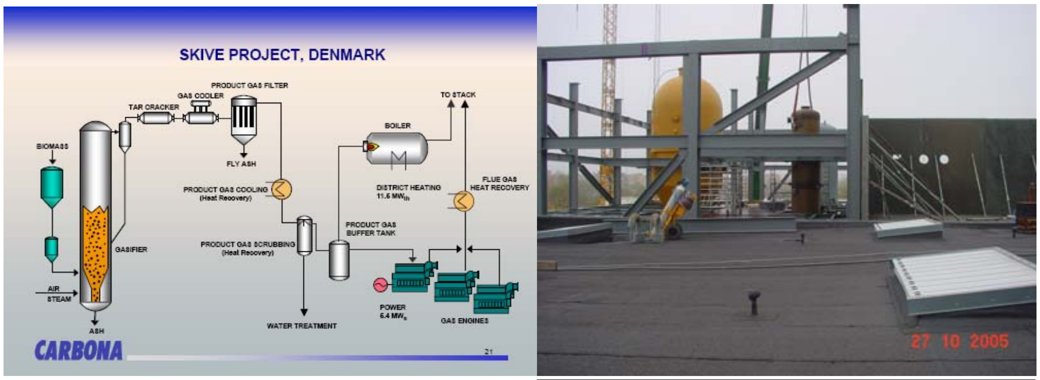

Figure 4. Carbona CHP Demonstration Plant in Skive, Denmark (30 MWth capacity, 5.5 MWe, and 11.5 MWth district heat)

In 2003, BioSynergi has erected a complete CHP gasification pilot plant, named The Castor Gasification CHP pilot plant at Græsted. The Danish Energy Authority provided financial support for the project. Graested Fjernvarme (a district heating plant) in Denmark has agreed to provide the site and purchase the produced heat while BioSynergi assumed the operational and maintenance responsibility. The electricity produced is sold to the local electric distribution network.

Figure 5: The Castor Gasification CHP Pilot Plant at Græsted
(Electricity = 23%, Heat = 53%, Heat Losses = 24%)

The producer gas from the gasifier is used as fuel in an internal combustion engine that produces both heat and electricity. The plant is designed for unmanned operation. Wet forest wood chips (~45-50 % moisture on wet basis) are dried with engine exhaust to about 15-20% in an integrated drying process prior to gasification.

The BioSynergi's staged air, open core down draft gasifier was developed in three test campaigns during 1994-1998. The overall erection of the pilot plant and supply lines to the heat and electricity networks were completed and commissioned at the end of 2003. Upon implementation of safety procedures, the plant was prepared for a 3000 hour integrated demonstration with heat and electricity production. The pilot plant is designed to produce 90 kWe and about 200 kJ/s of heat output. Plans are underway to scale-up the process to 250 - 1,000 kWe capacity, for a well-defined segment of the Danish commercial energy market.

Some plant details include:

- A 10 cubic meter wood chip storage bin
- A 5 meter long drum dryer heated by exhaust gas from the engine.
- Screw feeders to transport 15-20 % moisture wood chips into an intermediate storage bin at the top of the open core gasifier
- A rotary valve discharging wood chips into the center of the gasifier.
- A refractory lined gasifier with three air inlets (one after the pyrolysis zone to thermally decompose tars) to achieve the staged air operation.
- A mechanical movable grate made of high-temperature steel for discharging ash through a water seal
- A heat exchanger jacket around the gasifier to recover heat from upward flowing producer gas, entering the jacket at 550^o C
- A water-jacketed heat exchanger that cools down the raw gas to approximately 120° C before cleaning the gas in a bag house filter where char particles and tar are removed from the gas.
- A second water-jacketed heat exchanger that cools the product gas down to about 60° C. The heat recovered from the two heat exchangers is supplied to the district heating network
- An induced draft centrifugal blower is installed ahead of the gas engine to draw air into the gasifier while maintaining below atmospheric pressure in the system
- A bypass line that circumvents the cleaning process and to an outdoor gas flare during start-up and shut-down
- An 8-cylinder Deutz MWM IC engine, attached to a 1500 rpm, 90 kW electrical generator

Thomas Koch of TK Energi, Denmark has developed a 3-stage, down-draft gasifier which includes pyrolysis and partial oxidation zones, and a reformer based char gasification zone with a rocking grate for ash discharge (Figure 6) [11]. The internally heated pyrolysis reactor has no mechanical parts that could be exposed to the high temperatures. Two gasifiers were designed for 833 kWth (for Japan) and 3.125 MWth (for Denmark) capacities, at a cost of € 1 and € 3.1 million, respectively. The thermal efficiencies are 60 and 56% while the electrical efficiencies are estimated to be 24 and 32%, respectively. The gasifiers are designed for 7000 hours of continuous operation before shutting down for maintenance check and servicing.

So far, the Japanese gasifier has been operated for about 200 hours and the Danish gasifier for a total of 1200 hours. Performance observations include about 3-10% of char-loss, throughputs up to 2 MWth/m^2 grate area (250 kWth gas is approximately equivalent to 1.2 MWth/m^2), and an overall thermal efficiency of 70 to 80%.

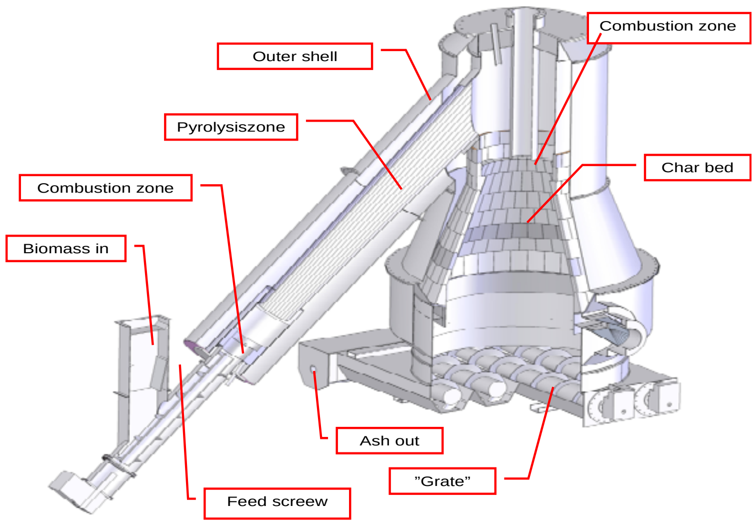

Figure 6. Three-Stage TKE Gasifier

The district heating company in Gjøl has received national and European funding to build the wood chip fired, three-stage TKE gasification unit. The gasifier is designed for 2.3 MWth (dry wood input) capacity and the gas will be used in an existing natural gas fired Jenbacher engine, which will be modified and updated to accommodate the gasification gas with minimal derating. By incorporating a partial oxidation zone that separates the pyrolysis and gasification zone, the gasifier produces clean gas that can be filtrated in a dry, low temperature bag filter. Since the existing Jenbacher engine is located 300 meters from the gasifier the gas will be transported in an underground gas pipe. The gas will be cooled to below 40° C before it enters the gas pipe. The resulting condensate water will be re-evaporated and applied as steam to the gasifier. To ensure high cold gas efficiency the hot gas from the gasifier will be used to preheat the air for the gasifier and to dry the wood chips. The drying system also designed and built by TKE, is a closed loop type with no exhaust and a near 100 % heat recovery. The plant is estimated to operate at a cold gas efficiency of over 80 % and an electric efficiency of about 30 %.

Located next to the gasifier is a 1500 kW wood chip boiler which will operate as a base load unit during summer (when the gasifier is not operated) and as peak load unit in the winter time when there is not enough heat from the engine and the gasifier. The gasification plant is currently being erected and hot tests should commence in June 2006.

The gasification technology is currently marketed in Austria, Italy and Germany for 1-10 MWth capacity BMG/CHP applications.

Denmark's two-stage biomass gasification process was developed at the Technical University of Denmark (DTU). In the two-stage gasification process, pyrolysis and gasification take place in two separate reactors. Between the two reactors the 600° C pyrolysis products are partial oxidized by preheated air to thermally decompose oils and tars at about 1100° C. The pyrolysis reactor is heated by waste heat from engine flue gas or hot product gases to improve thermal efficiency. The process was demonstrated in fully automated operation, as the Viking Process (Figure 7) with high cold-gas efficiency (above 95%) and low tar content in the gas (<5 mg/Nm3). With the use of modern gas engines, the electrical efficiency could exceed 35%. The clean fuel gas can also be used for other purposes (ex. fuel cells, biofuels, or gas turbines).

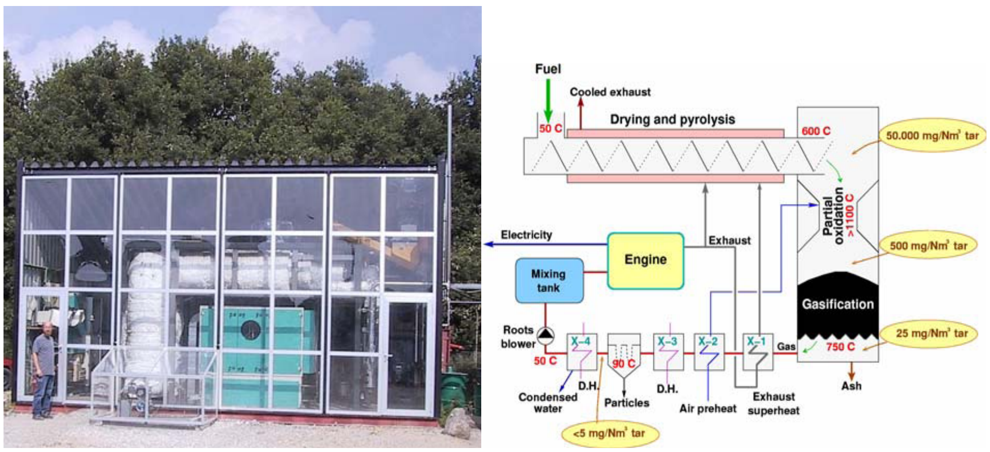

Figure 7. The Viking Plant and the Two-Stage BMG Process diagram
(Capacity: 80 kWth/20 kWe)

In the process, the product gas passes through heat exchangers and cooled to 90° C, thus delivering heat for the process and district heating. At this temperature the soot particles are removed dry in a bag house filter. By further cooling of the gas, the steam is condensed and the cooled gas is fuelled to a gas engine coupled to a generator, producing power and district heat. The gas engine is an integral part of the whole gasification plant. The excess heat from the exhaust gas is utilized for drying and pyrolysis of the biomass in the gasification system, and the engine directly controls the load of the gasifier. Some key operational data from the Viking demonstration tests are given in the following table.

Key data from the Viking Plant tests	
Thermal input	68 kW
Fuel:	Wood chips
Moisture content	35-45 %
Gasifier efficiency	93%
Engine efficiency	32%
Electric efficiency	27%

Overall elect. eff.	25%
Tar level	<1 mg/Nm^3
Dust level	<5 mg/Nm^3

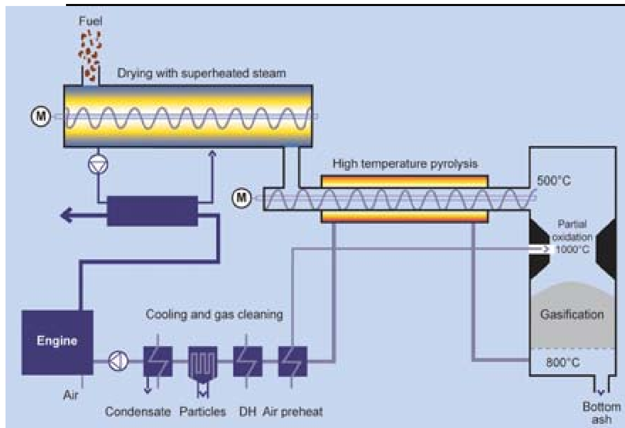

Figure 8. Schematic Layout of the Scaled-up Two-stage BMG Process

It is anticipated that the two-stage Process could be scaled-up to 0.2 to 2 MWe capacity with certain modifications (Figure 8). These include the installation of a separate wood dryer and heating the pyrolysis reactor with hot product gases from the gasifier. In addition to improving the over-all thermal efficiency, the feed retention time in the process should also be reduced. At present, a 600 kWth/200kWe two-stage gasification plant is being built in Denmark by biomass boiler manufacturer, Weiss A/S, in corporation with DTU and COWI, with economic support from PSO funds for R&D in power production. Weiss A/S will build future commercial plants.

DTU is also developing a Low-Tar BIG (Biomass Integrated Gasification) or LT-CFB Process in which both pyrolysis and gasification chamber are bubbling fluidized bed reactors and fluidized with steam. For moist fuels, the gasifier can be integrated with a steam drying process, where the produced steam could be used in the pyrolysis/gasification chamber.

The LT-CFB Process is designed especially for difficult to feed low grade biomass and waste fuels including agricultural biomass such as cereal straw, energy crops and animal manure. The main application is expected to be for medium to large scale (indirect) co-firing of fuel gas in existing and new power plant boilers. The fuel flexibility is achieved through a novel but simple combination of fast pyrolysis in a fast fluidized bed chamber with char gasification in a slow bubbling fluidized bed gasifier (Figure 9).

The LT-CFB gasifier allows for efficient gasification at a very well controlled maximum process temperature which is usually below 750° C to prevent ash melting. Due to low gas exit temperature (usually around 650° C), the volatile ash components such as potassium and phosphorous will be almost entirely in the solid state and can therefore simply be separated along with the biomass ash.

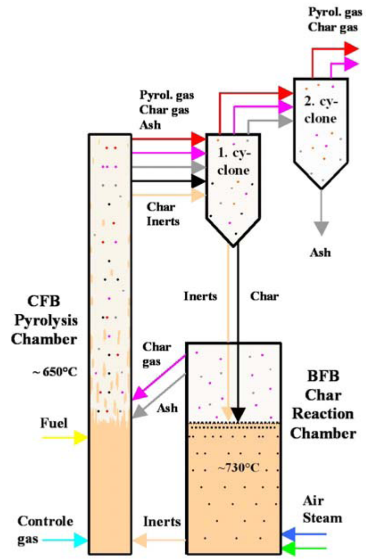

Figure 9. LT-CFB Process flow diagram

Following initial tests in a 50 kW (fuel input) laboratory unit, the process has been scaled-up to a 500 kW plant. The list of fuels tested in the LT-CFB test unit include wood pellets, two different types of high ash and high alkaline wheat straw, dry chicken manure, dry pig manure (11% ash), and dry pig manure sludge from a biogas plant

In all cases the bed-material has been ordinary silica sand with no additives and in several cases the bed-material has either been re-used between test runs or the tests have been made long enough to ensure that the concentration of low melting components in the bed-materiel would not increase any further, for example more than 5 % of potassium content.

Plant designs are developed for 6 MWth co-firing applications that could be further scaled-up to 100 MWth capacity. The aim is to expand services to process other difficult to handle fuels (ex. rice straw and cotton waste) and to market the technology in foreign countries.

The five partners who are developing the LT-CFB gasifier include, Danish Fluid Bed Technology, Biomass Gasification Group (BGG) at the Technical University of Denmark, Force Technology, Anhydro and Elsam Engineering. DEA and the Danish PSO R&D program provide funding for the work.

FINLAND: As it is the case with Denmark, Biomass is the largest renewable resource in Finland. In 2001, Finland derived 20% of its energy (approximately, 280 PJ or 6.7 MTOE) from wood fuels. The government policies are designed to raise the contribution of renewable energy to 30% by 2010. The opportunities for biomass utilization exist in supplying the thermal energy needs of industry and CHP. Hence, the government is focused on implementing measures to increase the supply of biomass while reducing its cost.

With approximately five million population, a large forest products industry, and the absence of a nation-wide natural gas distribution system, Finland has come to rely on biomass based CHP plants. The nine Bioneer BMG Plants, ranging in capacity from 4 to 5MWth that are in operation (eight in Finland and one in Sweden) for over 20 years, is a testimony to the important role played by biomass gasification. The Foster Wheeler Energy Oy has responded to Finland's need for biomass gasification by developing circulating fluidized bed gasification (CFBG) process that was successfully deployed at a paper mill in Pietersaari and for co-firing at Lahti (Figure 10), and a Bubbling Fluidized Bed (BFB) gasifier for aluminium and energy recovery in Varkaus (Figure 11).

The 60 MWth Foster Wheeler CFB BMG in Lahti has been in successful operation since 1998. At present the plant is operating with gasifier availability in excess of 95 %. In this process, the gas is fed directly to a PC boiler without gas cleaning. By co-firing with BMG fuel gas, the coal fired boiler emissions have decreased. A completely new, 160 MWth CFB BMG plant is now in the design phase. The design includes gasifiers, hot gas cleaning based on gas filtration, and a new gas fired boiler. Fuel gas and flue gas cleaning facilities have been designed to fulfil all WID regulations.

In May 2003, Foster Wheeler has started operating a CFB BMG plant in Ruien, Belgium for cofiring the fuel gas in a pulverized coal boiler. The gasifier capacity is reported to be 50 MWth with biomass containing 50% moisture and it can be increased to 86 MWth when the biomass is dried to 20% moisture content.

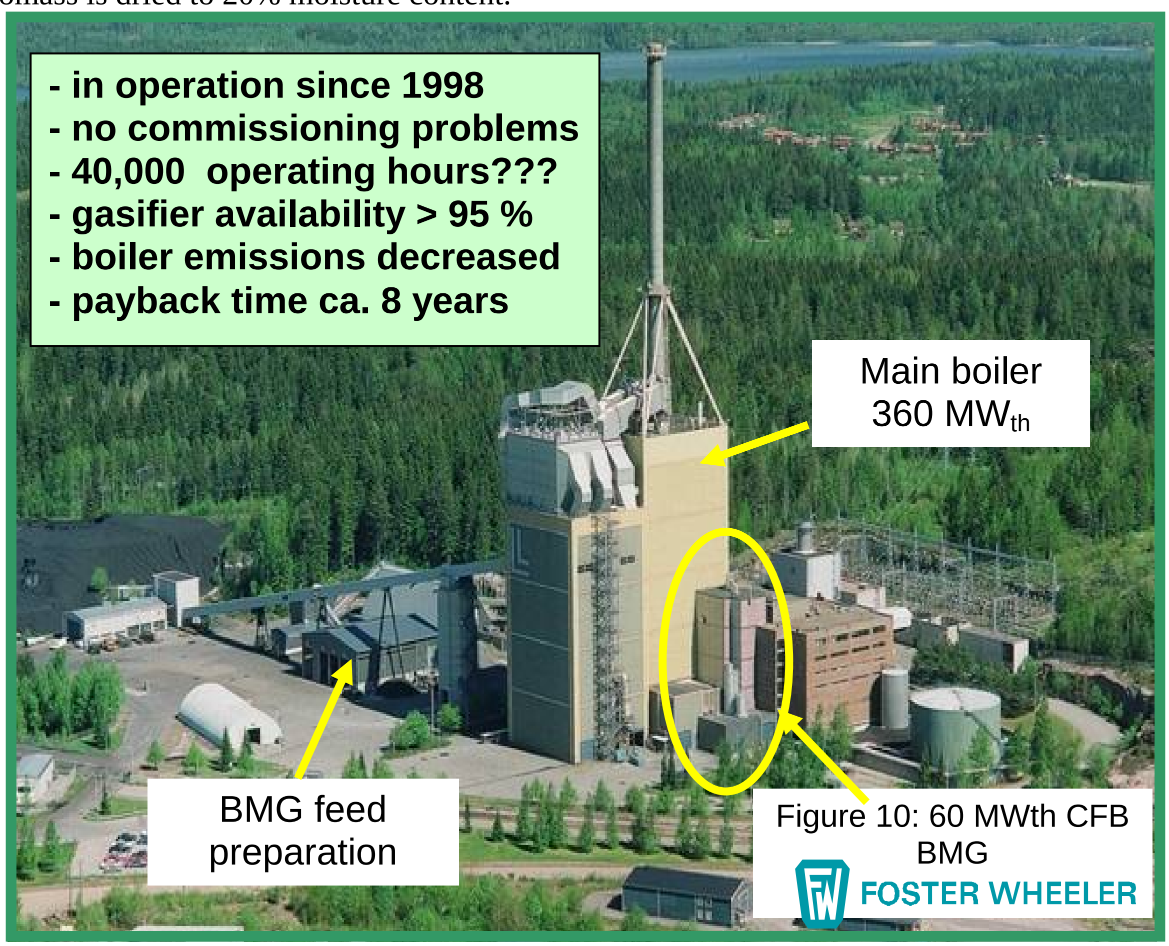

Figure 10: 60 MWth CFB BMG

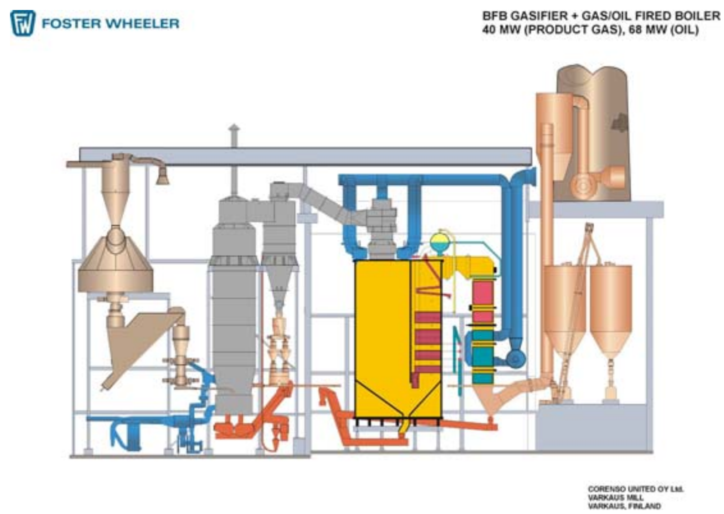

Figure 11: The 40 MWth Corenso plastic waste Foster Wheeler Energia BFB BMG Process

In addition to Foster Wheeler Energia's ability to build and operate large-scale fluidized bed BMG processes, there is considerable interest in Finland in developing the next generation small-scale gasifiers for CHP applications. The original developers of the Bioneer process (Condense Oy and VTT BMG experts) are now embarked on demonstration of a 7 MWth NOVEL updraft gasifier at Kokemäki. This CHP facility (Figure 12) employs low-temperature waste heat from the plant to dry wood fuels to about 20 % moisture. The design power output is 1.8 MWe and the district heat output is 4.3 MWth (3.1 MWth without boiler). The overall investment cost is €4.5 to 5 million. The plant construction was completed in April 2005 and plant commissioning is now in progress. While initial start-up employs a single JMS 316 Jenbacher gas engine (600 KWe); two more engines will be brought on stream by the end of 2006. The estimated electrical efficiency of the waste to power is 30 to 35 % which can be improved further at the CHP plant to 35 to 40 % by recovering heat from condensing flue gases.

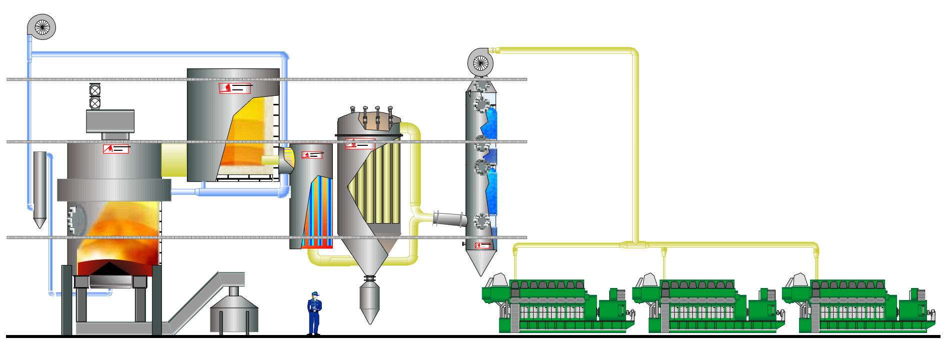

Figure 12: The NOVEL BMG CHP System (Capacity: 1.8 MWe + 4.3 MWth)

The other notable BMG suppliers in Finland include the Entimos and the Puhdas Energia Oy (Figure 13) downdraft gasification systems. The former has been shut down due to unsuccessful operation while the latter has been deployed and it is being commissioned in Connecticut, USA.

Figure 13: Puhdas Energia Oy Downdraft Gasifier

Finland has been actively conducting research at its national research labs, VTT to develop advanced BMG processes. With increasing interest in biomass gasification, and the absence of state-of-the-art test facilities in many European countries, organizations have sought the services of VTT to evaluate gasification feed stocks and gasification processes. VTT has successfully maintained continuity in biomass gasification R&D while many countries suffered cut-backs in funding to retain focus on resolving the technical hurdles to BMG. Other BMG, biomass and waste gasification RD&D activities at VTT include:

- PDU gasification tests with auto shredder residues
- CFB gasification of plastics and fuel gas utilization in industrial kilns
- Evaluation of gasification of contaminated (CCA) wood in the NOVEL process
- Catalyst development and design for gas cleaning (e.g. evaluating Zirconia as a substitute for Ni for tar cracking) at the Novel demonstration plant
- Integrated process concepts for producing liquid biofuels and/or green electricity at pulp and paper mills
- Construction of a 10 bar, 500 kWth pressurized BMG PDU at VTT for testing and evaluation of producing ultra clean syngas. This project is financed by Tekes, VTT, Foster Wheeler, Neste Oil, Andritz, and Vapo with a budget of €4 million. When the construction is completed in 2006, a variety of synthesis gas conversion tests will be evaluated for producing liquid biofuels, process optimization, and integration with pulp and paper and refinery industries.
- Improvement of the economics of fluidized bed BMG processes by advanced ash management involving integrated oxidiser tests with wood derived and waste derived solid recovered fuel (SRF) filter dust.

The EC sponsored BiGPower project (duration: Oct. 2005 to Sept. 2008) is aiming for high-efficiency electricity production based on advanced gasifier-engine, gasifier-fuel cell and IGCC concepts. In this project VTT cooperates with Finnish and Austrian gasification developers, gas cleaning equipment manufactures and with engine and MCFC suppliers. VTT's own work in this project is focused mainly on further development of NOVEL gasifier, catalytic gas cleaning and pressurised gasification for IGCC.

VTT provided the following illustration of techno-economic analysis of a biosyngas production and conversion:

Plant Capacity: 300 MWth of feedstock (LHV basis)
Annual operating time: 8000 hrs
Interest on capital: 10 % for 20 years
O&M costs: 4 % of investment

Base values for purchased/sold energy (other values applied in sensitivity case studies):

Feedstock: € 10 /MWth (LHV)
Electricity: € 30/MWhe
HP steam: € 16/MWth of transferred heat
MP and LP Steam: € 13/MWth of transferred heat
Fuel gas: € 14/MWth (LHV)

The estimated investment costs are:

Fischer-Tropsch (F-T) primary liquids; once-through synthesis: € 210 million
F-T primary liquids with reforming loop: € 230 million
Methanol: € 220 million
Synthetic (Substitute) Natural Gas (SNG): € 200 million
Hydrogen, either via traditional method or via PSA separation: € 195 million

Note: Steam refers to HP and LP steam produced in synthesis gas cooling and MP/LP steam produced in synthesis and water-gas shift. The overall efficiency of F-T is exceptionally high (by recovering heat of condensation of product liquids and heat of condensation of part of product H_2O recovered as LP steam) by implementing several process integration methods. In comparison, the overall efficiency of methanol synthesis is low.

VTT's 25 year BMG RD&D program vision includes:

1) Production of synthesis gas from biomass to produce liquid biofuels, hydrogen, SNG and chemicals in medium-to-large scale plants (150-400 MWth)
2) New waste recycling power plants with high-efficiency power production integrated with efficient material recovery
3) Medium scale (1-100 MWe) BMG CHP plants with advanced gas engines, MCFC/SOFC or combined-cycles (electric efficiency > 40-50 %).

The information given above and in the following Table, compiled by VTT, is indicative of Finland's long-term goals for employing a wide spectrum in capacity BMG processes for heat, CHP, industrial applications, and for producing liquid fuels and chemicals.

Features of Finland's BMG Processes

Gasification method	Potential size, MW_{fuel}	Application	Required gas cleaning
Circulating Fluidised-Bed = CFB	20 - 150	boilers, kilns	cyclone: clean biomass filtration: waste-derived fuels, agrobiofules
Bubbling Fluidised-bed = BFB	10 - 50	boilers, kilns	same as CFB
BFB	10 - 50	engines	catalytic reforming + filtration + wet scrubbing
Novel Fixed-bed	1 - 10 … 20	boilers, kilns	no cleaning: clean biofuels filtration: agrobiofuels, wastes
Novel Fixed-bed	1 - 10	engines	catalytic reforming + filtration + wet scrubbing
Pressurised BFB or CFB	50 - 300	gas turbines	filtration at 400-550 °C
O_2-blown or steam gasification	100 - 500	chemicals, H2, fuel cells	catalytic reforming + filtration + wet scrubbing + gas conditioning

Germany: Germany's energy policies are directed to ensure energy security with coal and nuclear energy while aggressively pursuing the use of renewable energy to cut back on fossil fuels. Germany's commitment to international GHG treaties and to develop advanced technologies includes a significant role for deriving energy from biomass and renewable wastes. BMG is an essential part of Germany's plans to convert biomass and waste for both polygeneration of power, heat and cold, production of synthesis gas for biofuels, and hydrogen-rich gases for fuel cells.

At present, Germany's primary interest is in developing BMG for CHP and for producing organic chemicals and fuels. The CHP plants are usually small scale units, many of these are in early stages of commercialization. A good overview of the CHP systems was prepared by Fördergesellschaft Erneuerbare Energien e.V., Berlin [14] (FEE, e-mail: FEE-eV@t-online.de (fee-ev). The largest renewable waste gasification plant in the world has been built and operated for nearly 20 years at Schwarze Pumpe employing a variety of gasification processes and synthesis gas conversion processes. Many features of this plant are also useful and applicable to BMG processes.

Lurgi, one of the largest fixed or moving bed coal gasification process developers, has chosen to adopt CFBG for gasification of biomass. A general process flow diagram for the CFB BMG is illustrated in Figure 14. The first successful commercial Lurgi BMG plant was built in Pöls, Austria for firing lime calciners. At present, the plant is not in operation for non-technical reasons. The successful Lurgi CFBGs are the 100 MWth waste gasification plant to fire cement

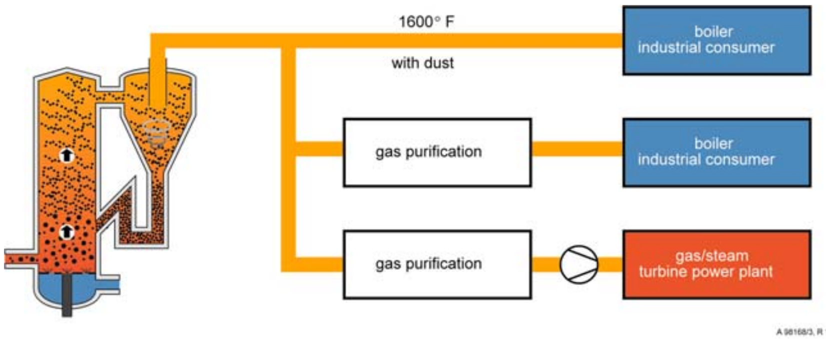

Figure 14: LURGI CFB BMG Process

kilns in Rüdersdorf, Germany (Figure 15) and the 80 MWth Essent co-firing plant in The Netherlands. Due to inadequate market pull and other related considerations, Lurgi has halted its BMG marketing efforts.

Figure 15: Lurgi Waste Gasification Plant in Rüdersdorf

Since 1996, the Fraunhofer Institute UMSICHT in Oberhausen, has also been developing a CFBG BMG process, in a 0.5 MWth pilot plant (Figure 16). Based on tests conducted at feed rates of 70 to 120 kg/h of wood and for over 1600 hours, developments are underway to build a 1-5 MWth CHP and a 5 MWth demonstration BMG plant.

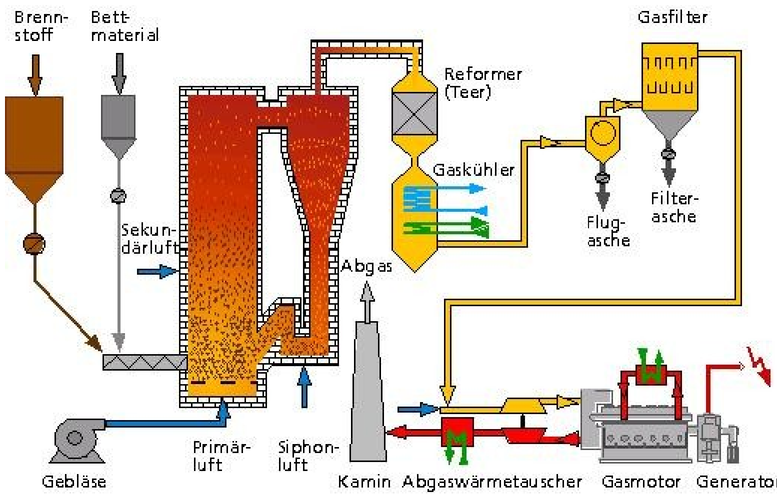

Figure 16: Fraunhofer Institute UMSICHT CFBG Process

With an impressive legacy in developing a wide variety of applications for coal conversion, Germany is now formulating the technology development strategy for advanced biomass energy conversion. These include the CHOREN and Future Energy’s pressurized BMG processes to produce and convert synthesis gas into liquid fuels.

The CHOREN Carbo-V process (Figure 17) involves first subjecting biomass to low temperature partial oxidation at 500°C,, followed by high temperature gasification of partial oxidation products (i.e., gas and tars) at about 1400°C and entrained flow gasification of the remaining pulverized char and other components at about 800°C. The resulting tar-free synthesis gas from the 1 MWth capacity pilot plant tests has been converted to fuels by F-T and methanol synthesis. At present, a 15,000 TPY fuels and chemicals demonstration plant is being planned for installation in Freiberg with start-up scheduled for 2007. Subject to successful demonstration, Shell may play a major role in commercializing CHOREN’s liquid fuels production processes.

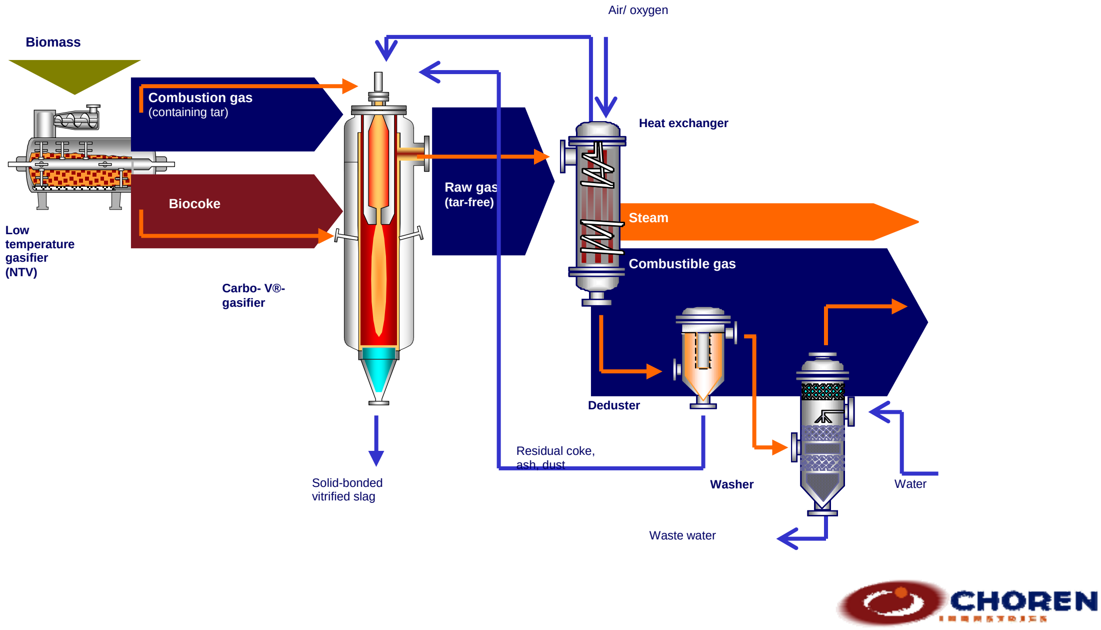

Figure 17: The CHOREN Carbo-V® Process

Future Energy has developed an entrained flow gasifier at 3-5 MWth capacity (Figure 18), which produces a tar- and CH4-free raw gas, with C-conversion > 99 %, at very short residence times (seconds) and at high throughput rates. This GSP-type (Gaskombinat Schwarze Pumpe) entrained flow gasifier, with fast start and shut-off capabilities is suitable for feeding any type of pulverized or pumpable fluid biomass feed. Since 1988, the GSP entrained gasifier has been in operation at Schwarze Pumpe processing solid waste streams. The pressurized water-cooling screen (maintained at ~ 250° C), which protects the high-temperature gasifier with a condensed layer of slag has been visually inspected after 10 years of operation and found to be in satisfactory condition. The cooling screen has also been demonstrated to successfully handle ash- and salt rich fuels for extended periods of operation.

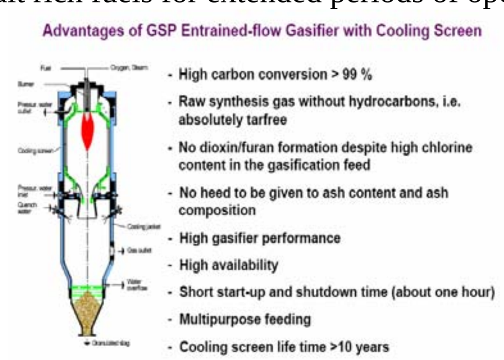

Figure 18: Future Energy's 3-5 MWth, GSP pressurized entrained flow gasifier

In other biomass R&D activities, Forschungszentrum Karlsruhe, Institut für Technische Chemie, CPV (FZK), is developing the "Karlsruher Biomass to Liquids (BtL) Process" concept, which is supported by the EU's RENEW project and Baden-Württemberg state ministry of agriculture. The concept involves first pyrolyzing biomass, such as straw, with an energy density of 2 GJ/m3, in pyrolyzers processing crop residues from a radius of 25 km, and transporting the pyrolysis liquids (with an energy density of around 16 GJ/m3) to a central gasification and synthesis gas conversion plant, similar to a typical oil refinery with a capacity of about 1 MTOE/yr.

So far, FZK has conducted four gasification test campaigns using the GSP-gasifier at Future Energy in Freiberg at 1200-1600°C and 26 bar, and at slurry throughput rates of 0.35 – 0.6 TPH. These included gasification of bioslurries from pyrolysis oils mixed with char, derived from wood and straw. The pyrolysis products were derived from slow pyrolysis of wood and straw as well as the fast pyrolysis from the Canadian Dynamotive bioslurries (LHV 10-24 MJ/kg, 20–40 % wt solids content). The tar-free synthesis gas was also low in CH_4 content, typically < 0.2 % by volume.

FZK is also testing a hydrothermal BMG process, operating at about 600°C and 350 bar, in the 100 kg/h Verena pilot test unit. The tar-free product gas consists of mostly H_2 and CH_4; the CO_2 contained in these gases can be easily separated.

Lists of the present German waste and BMG projects are given the following Tables.

List of Key Waste Gasification Projects

Company/ Process	Type	Capacity	Feed stock	Status
Rüdersdorf cement plant	Circulating fluidized bed	100 MWth	Wood waste	com. Op**.
SVZ Schwarze Pumpe	5 Fixed bed Fixed bed (BGL) + Entrained flow (GSP)	≈ 3 MWth	Brown coal + urban waste mix	com. op.
Thermoselect EnBW	fixed bed	≈ 100 MWth	Urban waste	com. op. shut down
Noell Conversion pilot plant	Entrained flow	3-5 MWth	Hazardous waste, flexible	Pilot

**- com. op.: commercial operation

List of BMG Projects

Company/ Process	Type	Capacity	Feed materials	Pressure	Status
SVZ Schwarze Pumpe commerical methanol	Fixed bed + Pressurized GSP entrained flow	130 MWth entrained flow	Waste mix brown coal	25 bar	see Table 2 com. op.
Choren Carbo-V	atmospheric CGT entrained flow	1 MWth (45 MW_{th})	Wood	4 bar (30 bar)	Pilot

		(pressurized)			
Future Energy + FZK BtL-process	Pressurized GSP entrained flow	5 MWth (2 MW_{th})	Straw, wood	26 bar (80 bar)	pilot in progress
CUTEC	Circulating fluidized bed	0.4 MWth	Wood, straw	atm.	Pilot
UMSICHT	Circulating fluidized bed	0.5 MWth	Wood, straw	atm.	Pilot
D.M.2 Blue Tower	Fixed bed + heat carrier	1 MWth	Wood, straw, waste	atm.	Pilot

The information contained in these tables is illustrative of Germany's goal to develop high-efficiency BMG processes, operating at high-pressure and high-temperature, for producing liquid fuels and chemicals.

Italy: Italy, which depends on foreign sources for nearly 80% of its energy needs is one of the largest importer of fuel and energy (about 46 TWh), in Europe. To meet this challenge, concrete steps have already been taken to define national policies to develop both domestic energy sources and diversification of energy sources. A set target of 76 TWh/yr from renewable energy sources (RES) for the period 2008-2012 has been confirmed through Legislative Decree No. 387, dated December 2003. Among different RES, biomass is expected to play an important role in power production. Biomass gasification can play a critical role in converting biomass residues, particularly the large resource of crop residues into cheap and 'green' electricity. In addition to wood and crop residues (17-24 million dry TPY), Italy produces about 500,000 TPY of olive cake residue.

The current National Program, developed in October 1998, drives the current biomass R&D programs on Renewable Energies from Biomass. These programs include investigations on variation of feed types and the related feed handling and gasification issues. This explains why in spite of the huge potential of biomass (about 21-23 Mtep) so far only around 2.5% of these resources are used effectively (well under the European average).

To promote RES and energy efficiency in a cost effective manner, special attention has been given to the introduction of two market based instruments, namely the Green Certificates (Legislative Decree No. 79 of 16 March 1999) and the White Certificates. With re-organization of the energy sector vide Law No. 239, issued in August 2004, activities and the general objectives of energy policy were established. The specific objective is to improve the environmental sustainability of energy use through RES.

TPS of Sweden has built the first large scale TPS CFB BMG plants in Greve, in the Chianti district (Figure 19). The plant has operated intermittently with RDF pellets and it is currently shutdown with an indefinite future.

Figure 19: TPS CFB BMG Plant in Greve, Chianti
(2x15 MWth Gasifiers)

The notable Italian BMG process developers are listed below. Gasifiers are downdraft and updraft systems integrated with gas cleaning and power producing reciprocating engines. These processes are in early stages of demonstration:
1. Ansaldo Ricerche, Genova,
2. ENEA
3. Marcegaglia Group, Taranto
4. Rossano Energia, Rossano
5. Ecoengineering Impianti S.r.l.

The following is a summary of key BMG RD&D projects, which involve some of the BMG process developers listed above:

- Clean Energy (Hydrogen) from Biomass: TUV's Fast Internal Circulation Fluidized bed (FICFB) Gasification in a 500 KWth pilot plant (Figure 20): Coordinated by University of L'Aquila, with participation from ENEA and TUV, Austria.

Figure 20: TUV's Fast Internal Circulation Fluidized bed Gasifier at ENEA Trisaia Centre
(Capacity: 500 KWth)

- 1 MWe (2 x 500 KWe) Updraft BMG with Power Generation: Coordinated by CCT, Legnano (VA), with participation by Guascor.
- 4.5 MWe, downdraft gasification with olive cake using Prime Energy System: Coordinated by Rossano Energy and Rossano (CS), with participation from Guascor.
- 3 MWth, updraft BMG (including coal, wood and RDF) which is now undergoing tests: Coordinated by Ansaldo Ricerche, Genova.
- 3 MWth, updraft BMG which is now undergoing tests: Coordinated by Marcegaglia Group in Taranto.
- 15 KW_e downdraft fixed bed, 80 KW_e downdraft fixed bed, and a multi-fuel 160 KW_e CFB BMG systems. The first two are on stand-by and the third plant is now undergoing experimental tests in China (Figure 21): Coordinated by ENEA, Trisaia.

Figure 21: 160 kW_e (CFB) Gasification Plant Developed by ENEA and installed in China

- 1 MWth HT, horizontal fixed bed experimental plant in Tempio Pausania (Sardinia) fed with sized MSW (Figure 22), in operation since May 20005.

Figure 22: Horizontal Fixed Bed gasifier in Tempio Pausania (Sardinia); capacity 1.5 KWth

- 1.5 MWth LT, vertical fixed bed gasifier fed with medium to high density briquetted RDF; in operation since October 2005. Presently, Ecoingineering S.r.l. is planning to supply the RDF feedstock RDF and the plant is expected to become operational by the beginning of 2007, in Catanzaro (South Italy).

Based on the results achieved so far, plans are underway to develop steam-oxygen gasification for gas turbine power generation for plants with around 1.3 MW_{th} capacity. The goal is to produce a high hydrogen content gas that could also be tested in a 125 KWe molten carbonate fuel cell (MCFC).

Some of the recent process development activities at this plant include:
- installation of a propane burner in the gasifier to expedite plant start-up
- improvement of gasifier and piping insulation to deliver high temperature gas to the fuel cell;
- design and construction of the gas storage system fuelling the MCFC.

ENEA has selected BMG as a high priority technology, which should be developed for multiple uses together with many applications in the energy sector. Consequently, many technologies and equipment related to bioenergy have either already been developed or under development. Some of these technology development efforts are carried out in the framework of European projects and/or in cooperation with national and international partners.

The Italian government agencies and industries realize the importance of implementing a well-coordinated national BMG RD&D program as a part of the overall bioenergy program. In the near term, such a coordinated program should provide efficient and environmentally sound, preferably indigenous BMG technologies to meet the demand from the industry and public administrations.

The Netherlands: In 2005, biomass contributed 1.7% to the energy mix in the Netherlands. This comes mainly from electricity production by waste incineration and from co-firing biomass in coal-fired power plants. Although the goal for utilizing renewable energy for 2010 are expected to be met, achieving the ambitious longer term goals, namely producing 10% renewable energy by 2020 and 30% of total energy from biomass in 2040, require significant new policies and developments. The EOS long-term R&D programme has been set up by the Dutch government to generate the necessary innovations to facilitate energy transitions and reach the 2040 goals. Five areas for development have been selected, which may not only pave the way to achieve the 2040 goals but also can strengthen the Dutch technical expertise and capabilities. These include the production of clean fuel or synthesis gas from fossil fuels and biomass, energy generation and efficient use of energy. BMG and gas cleaning are identified to play a crucial role in the future of biomass energy supply in the Netherlands.

It is anticipated that specific biofuels targets in the Netherlands could be reached by the obligation to mix 2% biofuels in 2007 and 5.75% in 2010 in transportation fuels. Although most biofuels in the coming years shall be first generation fuels (biodiesel and ethanol from fermentable feedstock), second generation biofuels (F-T diesel, ligno-cellulosic ethanol, SNG, etc.,) are expected to play an important role in the long term. Thus, BMG will be at the core of producing second generation biofuels.

The Netherlands is introducing liquid biofuels to its pool of liquid fuels. In 2007, there will be mandatory addition of 2% liquid biofuels without any tax incentive, which will be raised to 5.75% in 2010. From 2006-10, the government will provide an additional €12 million/yr to support RD&D for developing next generation biofuels.

In addition to initiating a significant national biomass RD&D program to support the future goals, Netherlands has invested resources to build the 85 MWth Lurgi CFB BMG plant for Essent/AMER in Geertruidenberg (Figure 23). The gasification feed stock for this plant is demolition wood and the resulting fuel gas is co-fired in a 600 MWe pulverised coal boiler. In 2004, Lurgi handed over the gasifier to Essent, and the plant is now in commercial operation.

Figure 23: Essent/AMER Lurgi CFB BMG Plant (Capacity : 85 MWth biomass)

One of the most interesting BMG demonstrations is the large-scale commercial co-gasification of biomass with coal in the 250 MWe, Willem-Alexander Centrale Shell IGCC plant in Buggenum (Figure 24). In mid-2005, successful co-gasification tests were conducted at this facility in the Shell entrained coal gasifier with up to 30% by weight of biomass (185,000 tonnes/yr or equivalent to 35 MWe). The biomass materials included sewage sludge, chicken manure, & wood. Netherlands provides 7.0 €cents/kWh over normal electricity commodity price as an incentive for using renewable feed stocks.

Figure 24: The Shell Entrained Coal Gasification Plant at Willem-Alexander Centrale

The leading small-scale gasification system supplier in Netherlands, HoST also has built a 3MWth chicken litter gasifier in Tzum NL, which is currently being commissioned.

The BMG R&D projects at the Netherland's national research laboratories, ECN include: Torrefaction, a 5 kg/h allothermal gasifier, testing and evaluation of the TREC granular bed filter, development of lab-scale integrated BMG system for SNG production, and the OLGA gas clean-up process which has recently completed 700 hrs of operation during a long-duration test at 0.5 MW_{th} scale.

The ECN Biomass R&D program is divided into three parts: 1) gasification, gas cleaning and gas conditioning, 2) production of electricity and heat, and 3) development of biorefineries for next generation biofuels. ECN leads the first part and ECN and KEMA are involved in the second part. SenterNovem is trying to set up ERANET bioenergy programme involving NL, AT, FI, DE, SE, and UK to develop the biorefinery of the future .

New Zealand: New Zealand's total annual energy consumption is equal to 765 PJ in 2004 and the country produced about 237 PJ from renewable resources. Of the renewable energy used, woody biomass make up 35 PJ in 2004. With the availability of wood increasing by 50% in the next 5 years and with increasing use of woody biomass in wood industry, the woody biomass contribution to energy could double by 2010. With the depleting natural gas resources and abundance of woody biomass, New Zealand is positioned to develop bioenergy to improve security of energy supply.

The leading small-scale BMG manufacturer, Fluidyne (www.fluidynenz.250n.com), has scaled up the downdraft moving bed technology to a 2 MWe plant that is undergoing tests in Canada. The second manufacturer, AB Powerhearth Ltd. (www.3alternativepower.com) has developed a 3 MWe downdraft BMG system for commercialization in U.S.A. The third, PowerGen Ltd.

(formerly AB Power Systems) has built a downdraft gasifier with a 170kWe Caterpillar engine which has been operated on 80% BMG fuel gas and 20% diesel. The fourth, Page MaCrae Engineering Ltd is operating a 2 MWth commercial, updraft co-firing BMG plant, using the wood residues generated in a plywood mill to supply heat for manufacturing plywood. Based on the same technology, Page MaCrae is planning to manufacture an 8 MWth BMG plant. The fifth company, AES (Alternative Energy Solutions) plans to install a 200 KWe demonstration downdraft BMG system in NZ timber industry, using the Ankur (India) gasifier.

The University of Canterbury has recently built a laboratory-scale TUV-FICFB gasifier for testing and evaluation of the process for power generation, synthesis gas production, and other applications. The University is also leading a large R&D programme with three industry partners including Page MaCrae Ltd. The ultimate objective is to build a commercial BMG CHP plant using wood processing and forest logging residues.

Sweden: In the past, Biomass programs were driven by the Energy Policy Act of 1997, with the objective to ensure, in both the short and long terms, a reliable supply of electricity and other forms of alternative energy on competitive terms. The strategy for restructuring the country’s energy system includes implementing short-term programs (replacing the loss in production resulting from the closure of Barsebäck nuclear plant), providing investment subsidies (approximately 25% for biomass CHP, 15% for wind and micro-hydroelectric power), initiating long-term RD&D programs, implementing politically justified measures to counter climate change, and imposing landfill tax to ultimately comply with the EC directive prohibiting the land-filling of organic materials.

The objective of the Energy Policy Act of 2002 is to create the right conditions for efficient use and cost-efficient supply of energy in Sweden, with minimum adverse effects on health, the environment and climate, while at the same time supporting the move towards an ecologically sustainable society. The strategy includes, increasing the thrust of the guide measures in the shorter term and increase taxes on energy, emissions etc., reduce direct labor requirement, incentives for ‘renewable’ electricity, and the efficient use of energy with innovative co-generation applications.

The trading of renewable energy (RE) certificates has been in progress since 2003. The RE quota of 7% in 2003 will increase to 17 % in 2010. The target is to build 10 TWh of additional RE capacity by 2010. These are the main driving forces for the exploitation and use of biomass in Sweden. In 2002, biomass contributed a total of 50 TWh towards 600 TWh of annual national energy demand. Majority of biomass along with peat was employed for district heating.

In 2005, The Prime Minister of Sweden has established a Commission, involving industrial, economical and institutional stakeholders from both the private and public sector, with the objective to establish policies and strategies for eliminating or drastically reducing the dependence on and the consumption of fossil fuels by 2020. It was anticipated then that the Commission recommendations should be supportive of exploiting the abundant biomass resources of Sweden.

State-of-the-Art of Swedish BMG: Some of the early BMG plants were built in Sweden. These include a Bioneer and the FWE/Ahlstrom CFB BMG processes from Finland and the CFB BMG processes developed in Sweden. The 20 MWth FWE/Ahlstrom CFB plant at Norrsundet and the 30 MWth plant at Karlsborg are still in operation. In 1987, at the Södracell Värö pulp mill, Götaverken (now a part of Kvaerner Pulping AB) has commissioned the 30 MWth CFB Gasifier (Figure 25), which is fuelled by bark and wood wastes. The fuel gas is used in a limekiln. In 2003, enriched air was used to increase the limekiln capacity. At present, Kvaerner Pulping is not in the business of building BMG plants.

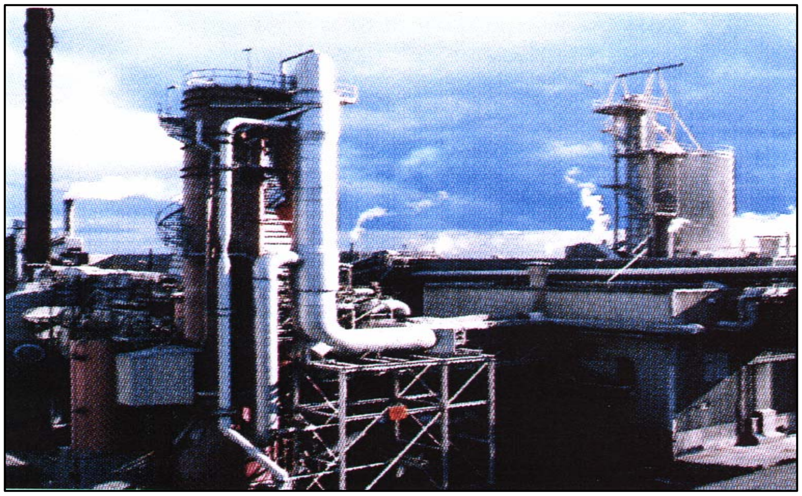

Figure 25: Götaverken CFB Gasifier at Värö pulp mill

TPS, Termiska Processer in Nykoping has been active in the development of its own CFB gasification process (Figure 26) with emphasis on tar cracking using dolomite and certain thermal decomposition methods. Based on extensive pilot plant research, Two TPS/Studsvik CFB gasifiers, each with 15 MWth capacities, were built and operated intermittently by Ansaldo Aerimpianti with RDF pellets near Florence, Italy. The future of this plant remains uncertain. The TPS process was also selected for demonstration as the ARBRE project in Eggborough, UK. The project has been prematurely terminated when project owners withdrew their commitment before plant shakedown was completed.

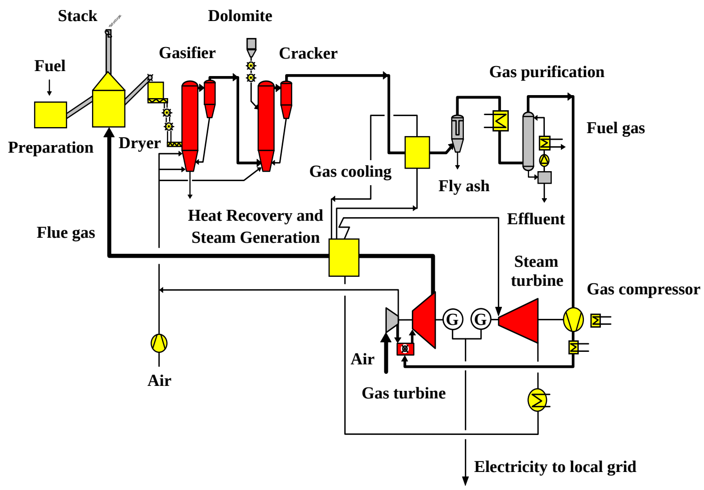

Figure 26: TPS Termiska Processer BMG Process Flow Diagram

The most significant technical accomplishment in BMG is the successful demonstration of the pressurized, CFB Bioflow BMG in Värnamo, supplied by Ahlstrom/FWE and Sydkraft (Figure 27). The 18 MWth capacity plant was operated at 18 bar pressure. The raw gases were cleaned without condensation employing candle filters and successfully combusted in a closely integrated Typhoon gas turbine to generate 6 MWe and 9 MWth heat for district heating.

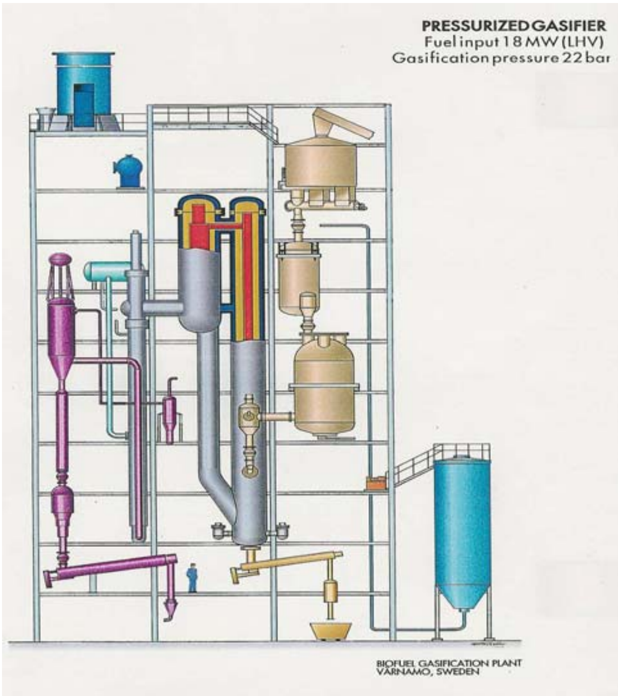

Figure 27: The Bioflow Pressurized CHP Gasifier in Värnamo

The Värnamo plant was mothballed in 2000, after more than 8,000 hours of gasifier and 3,600 hours of integrated operation with the gas turbine. The plant emissions were low in CO and

THC. The facility was reactivated in October 2005, as the Växjö Värnamo Biomass Gasification Center AB, as one of the prominent European center piece for R&D of the CHRISGAS project. One of the primary missions of this project is to start production, within 3-4 years, a clean hydrogen-rich gas from biomass fuels at a rate of 3,500 Nm3/hr.

The R&TD Deliverables for the CHRISGAS project are:

- Test new drying and feeder systems,
- Conduct BMG tests and obtain operational data at 3-4 TPH, and
- Evaluation of catalysts, filters, gas cleaning systems etc. used in the Bioflow process.

The ultimate goal of the CHRISGAS Project is to produce bio-fuels at a price competitive with current fuel prices. Other deliverables include development of a web based educational package involving academic research organizations.

The multinational CHRISGAS Project partners are listed below:

Sweden: Växjö University (co-ordinator), Växjö Värnamo Biomass Gasification Centre (VVBGC), AGA-Linde, Catator, KS Ducente, Royal Institute of Technology (KTH), S.E.P. Scandinavian Energy Project, TPS Termiska Processer, (Valutec), and Växjö Energi

Denmark: TK Energi

Finland: Valutec

Germany: FZ Jülich, Linde, and Pall Schumacher

Italy: University of Bologna

Netherlands: Technical University Delft, and

Spain: CIEMAT.

The project is financed by € 9.5 million EC grant, € 1.5 million STEM grant, and € 7 million grant from other team members.

The on-going Värnamo Plant modifications will include installing a new steam/oxygen distributor, a new hot gas filter system, and the installation of a catalytic high temperature reformer.

Chemrec AB, Stockholm and Piteå, is committed to the development of an advanced black liquor gasification (BLG) process. With more than SEK 100 million, cost-shared by pulp and paper companies, the power company Vattenfall AB, and national research funding from STEM, and the Swedish Energy Administration, BLG RD&D tests are now being conducted at Piteå. The development under the EC sponsored RENEW project will also involve evaluation of synthesis gas production and its subsequent conversion to liquid transportation fuels at the Södracell Mörrum pulp mill.

The Universities currently involved in BMG R&D include:

1. KTH - active in the CHRISGAS project
2. Luleå, Umeå and Chalmers - working on black liquor gasification
3. Växjö University and MittUniversitetet, Mitthögskolan, Härnösand - in early stages of BMG R&D

Future for BMG: Sweden being one of the larger countries within the European Union, and with a tradition of extensive use of forestry biomass for pulping and more recently for energy, BMG is seen as one key technology for sustainable energy supply. BMG should play an important role in the energy-intensive industrial sector, the transport sector, the biofuel production sector as well as the fuel based energy conversion sectors. The crosscutting nature of BMG has been acknowledged by the creation of a Swedish Technical Advisory Committee for the coordination of future R&D programs in each of the sectors mentioned before. The government budget planning also specifically refers to BMG R&D and demonstration activities. It provides the necessity of the government to support R&D with commitment to success, i.e. to extend support for more costly demonstration activities, to reach the policy objectives of commercially exploitable maturity for these technologies. For this purpose, the budget is increased by SEK 370 million (~USD 50 million) per fiscal year, for 2006, 2007 and 2008.

Switzerland: In Switzerland, biomass contributes approximately 5 % to the total energy consumption. The aim of the Swiss energy policy is to fully exploit the national biomass potential to increase its contribution by nearly 100 %.

The main source of bioenergy in Switzerland is wood. At present, it contributes approximately 2.5 % of the total energy. All other biomass beside wood includes biomass contained in municipal solid waste, sewage sludge, paper sludge, agricultural residues, and organic residues from the production of biogas, which is used for electricity production and as fuel for cars.

In Switzerland, energy production from biomass is supported in different programmes by the government (Energie Schweiz / Swiss Energy) and the cantonments.

BMG activities: The notable commercial BMG activities include the demonstration of a small-scale gasifiers for on-site power generation applications. The operation of the Xylowatt BMG plant was suspended because of the frequent need for gas cleaning and the inability to continuously operate the gas engine. Besides tar additional problems were encountered with particulates. As a consequence, Xylowatt has now stopped all BMG activities.

A 200 kWe Pyroforce gasifier with an Jenbacher engine is installed at Spiez near Interlaken (Figure 28). The plant employs a Pyroforce gasifier, based on the KHD (Kloeckner Humbolt Deutz) high temperature gasification process and a dry gas cleaning system. By spring 2006 the plant has reached 10, 000 operating hours with an Jenbacher engine.

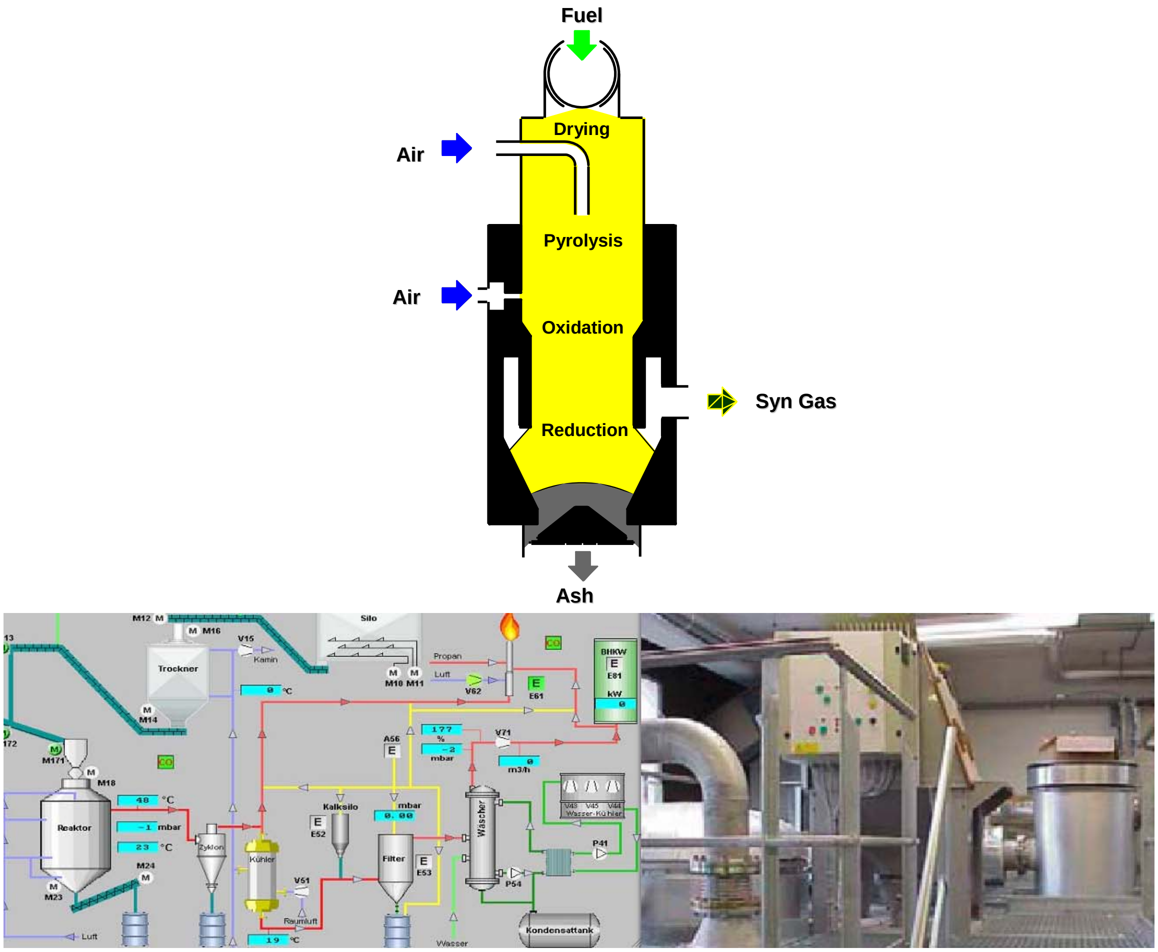

Figure 28: Pyroforce Plant at Spiez (Capacity: 200KWe)

In spring 2006, two Pyroforce gasifier plants were sold; one 300 KWe plant at Güssing, Austria, and a 1 MWe plant at Ferlach, Austria. The construction of these plants is expected to begin in 2006. For both plants, commissioning is planned for January 2007.

Dasagren offers gasifier plants based on the open top technology, of the Indian Institute of Science. Netpro in India constructs the gasifier island, including gas cleaning, according to European standards. Dasagren has sold a 350 kWel BMG plant and an Jenbacher engine to a company at Wila, a village in the cantonment of Zurich. Plant commissioning is planned for the end of 2006.

The Paul Scherrer Institute is working on biomass utilization for producing synthesis gas and SNG. In phase 1, synthesis gas and SNG research is conducted on a slip-stream of the product gas at the the TUV CHP plant in Güssing in Austria. The raw gas stream is scrubbed to remove Cl and passed through a ZnO bed to remove sulfur. These tests are conducted at 10 bar pressure. A single-step, combined water-gas shift and methanation catalyst has been tested for over 200 hours (Figure 29). The raw product gas contains 45% CH_4, 6% H_2, 1% CO, and the rest is mostly CO2 and 2% N2. Phase 2 will entail the construction of a ~ 1 MW pilot plant Phase 3 will build on experience gained from Phases 1 and 2.

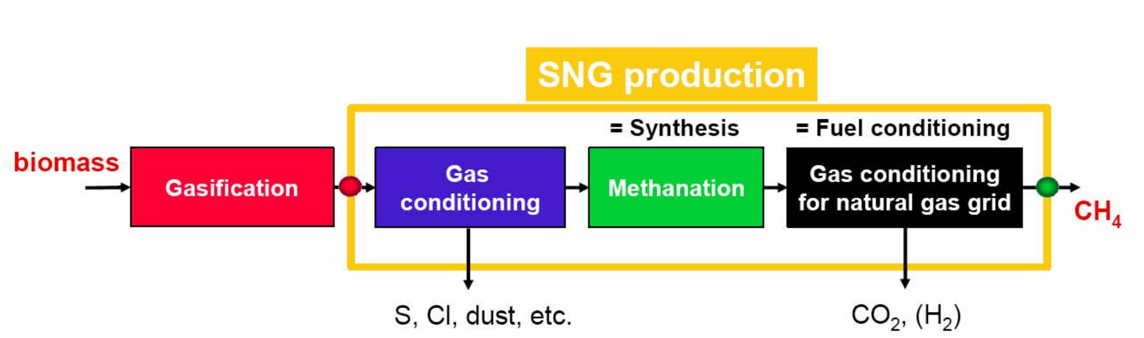

Figure 29. SNG production from biomass

United Kingdom: The Government has set itself a target of securing 10% of electricity supplies from eligible, renewable sources by 2010.

There are four elements to the new national strategy in support of renewable energy.

- The Renewables Obligations
- Climate Change Levy Exemption
- Capital Grants and Planting Grants for Energy Crops
- Research and Development Programme. The Government increased the amount available to support industrially led research and development through the DTI to £19 million per year.

More recently the following have been announced:

- The Renewables Obligation target has been increased to 15% of the UK electricity supply, using eligible renewable sources by 2015.
- The Royal Commission on Environmental Pollution has issued a special report "Biomass as a Renewable Energy Source" (http://www.rcep.org.uk/bioreport.htm). This supports the use of biomass fuels for both heat and power and makes recommendations to Government for policies that will encourage its use.
- In October 2005, a new Biomass Study, The Biomass Task Force, reaffirmed the potential of biomass, particularly for heat and CHP, and making recommendations to Government for measures to encourage its deployment.
- The European Commission has issued a directive to all member states to source 5.7% of their road fuels from biofuels by 2010.

The present market drivers for bioenergy include the enhanced electricity price available under the Renewables Obligation – currently at approximately 10.8 €cents/KWh, rising oil and gas prices, and the landfill directive and taxes, increasing wood and other biomass disposal costs.

The projected near-term growth in renewable energy is dominated by on- and off-shore wind energy, co-firing and landfill gas. Developers report that the barriers for biomass energy outside of co-firing are: high investment costs, requirement for long term power purchase agreement, the need for long term fuel supply contracts, and lack of general familiarity with biomass technologies. The additional barriers for BMG include poor reputation of the technology (from ARBRE demonstration), poor evidence of reliability, high purchase cost, lack of mass market to support volume production for smaller units, up-front engineering costs where each project is unique, environmental concerns, and the high cost and institutional difficulty in establishing grid connections.

Basic Research: The most important vehicle for basic research in this area is the Supergen Consortium (Web site http://www.supergen-bioenergy.net). This is a programme of basic research that involves the assembly of research consortia from a range of scientific disciplines to tackle the larger challenges of sustainable power generation and supply. Biomass, biofuels and energy crop utilization is one of four themes for this Programme. Within this theme the research will investigate the potential for power generation systems using energy crops and agricultural crops whilst striving for a carbon neutral cycle. Aston University is the lead contractor with five other Universities and research institutes and five industrial partners. The work programme comprises of six work packages:

1. Process and techno-economic assessment
2. Fuel specification and matching to conversion
3. Thermal reactor modelling
4. Minimisation of engineering risk
5. Co-firing and co-processing biomass
6. Network of British Biomass and Bio-energy Forum

Industrial and applied research: Biomass Engineering Ltd is a company specializing in small scale combined heat and power using downdraft gasification and pyrolysis. Three BMG power generation systems are in successful operation. The following four projects have been recently undertaken and completed successfully:

1. Ceramic filter investigation
2. Integration of BMG and micro-turbine
3. Operational and environmental impact of fuel types in Downdraft gasifiers
4. Process scale-up to a 250KWe CHP units

Exus Energy has successfully carried out two projects; commissioning of Blackwater Valley, and catalytic clean up of IC engine exhaust.

Siemens Industrial Turbines, Lincoln are developing gas turbines for BMG applications the work programme addresses combustion issues plus high mass flow power turbine technology. The focus is currently on MCV fuel gas applications due to increasing interest from waste pyrolysis sector.

Rural Generation and Queens University at Belfast are carrying out a project to investigate the integration of a downdraft gasifier with a micro-turbine and a catalytic burner.

Current and proposed BMG installations:

Biomass Engineering: The Biomass Engineering gasification plant is shown in Figure 30.

A 250kWe plant at Lancashire farm, has logged in 4,000 hours of operation. Biomass Engineering continues progress with manufacturing six small (250kWe) commercial CHP units while three other units are in operation or commissioning. The Ecos Millenium Centre, Balymena, 75 kWe net gasification system, with wood preparation and modified diesel engine, has been in operation since 2000.

Figure 30: Biomass Engineering gasifier

Rural Generation: The 100kWe Brook hall plant (Figure 31) has exceeded 15,000 hours of operation.

Figure 31: Brook Hall Estate Gasifier (Capacity: 100KWe)

Compact Power, Bristol: This plant has completed three years of commercial operation on wastes with excellent emissions performance. The process illustrated in Figure 32, is fully licensed for commercial use by the UK Environment Agency and was included in their annual report as an example of excellence. A new 2MWe demonstration is planned for next year.

Following the successful development of its waste gasification unit, Compact Power is planning to extend the technology to clean biomass and also to increase gasifier throughput. The related research efforts will investigate the effect of preheat on gas production in pyrolysis gasification processes by installing a preconditioning stage ahead of the indirect gasification step.

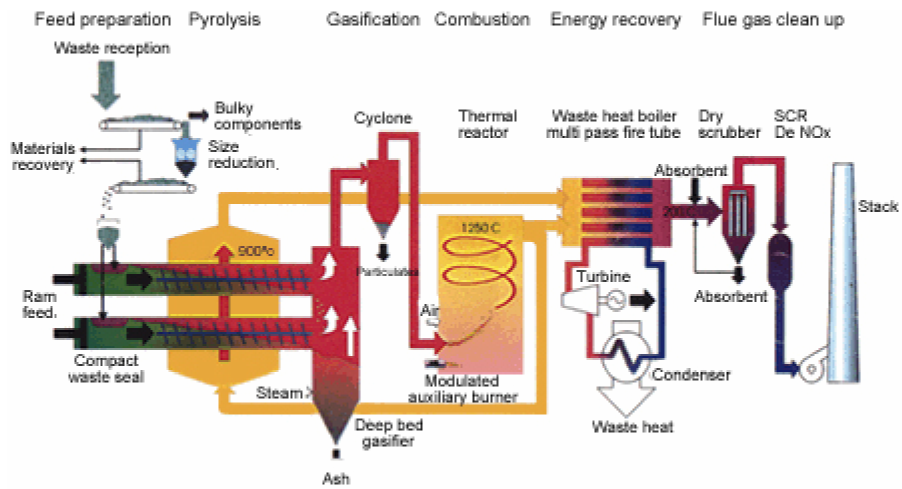

Figure 32: Compact Power Process

Winbeg 1: A 22MWe, FERCO combined cycle gasification plant is proposed for installation in Devon. The fuel is a mix of energy crops, agricultural and forestry residues. Support comes from Capital Grant plus Renewable Obligation. The expected start date of 2006 has been set back by 2 years due to delays in permitting.

Charlton Energy: A 7 MWe, rotary kiln gasifier CHP plant is operating in Gloucestershire. The plant will include Eco-tran equipment, reciprocating engines and it will use agricultural and forestry biomass as feed materials. Support comes from Capital Grant plus Renewable Obligation. Revenues will be derived from heat sale to nearby sawmill for drying wood. The anticipated start date is in 2006/7.

Exus Energy. BEDZED a 100kWe CHP installation (Figure 33) has completed 5,000 hours of operation in total, but problems have been reported recently. A 300kWe CHP plant is to be installed in a limekiln operation. The Blackwater Valley plant will be a redesigned for a 200 kWe CHP plant. The company is reportedly restructuring and the status of these projects is unclear at this time.

Figure 33: Exus Energy 300kWe module.

Further information on the research reports can be found at:
http://www.dti.gov.uk/publications. Click on “Browse” then Energy - New and Renewable: biomass

USA: A case in point regarding the challenges of resource development is the present and projected role for biomass in US. The US Energy Information Aadministration (EIA Monthly Energy Review, March 2004) lists the contribution of biomass and related feedstocks to total energy consumption in 2003 as follows:

Biomass (Wood, black liquor, & other waste wood)	= 2.09 Quads (Q)
Renewable waste (MSW, LFG, & other biomass)	= 0.56
Ethanol	= 0.24
SUM	= 2.89 Q
Total US Energy Consumption	**= 98.11 Q**

Thus, in 2003 US has derived little less than 3% (2.95 % to be more precise) of its energy from biomass resources. At a heating value of 8600 Btu/lb (dry) biomass, 2.89 Q translates to 168 million dry tons of biomass. EIA estimates that the maximum available biomass is about 482 million dry tons. The reported US DOE’s Biomass Feedstock Roadmap, which could change given the emphasis given to biomass in President Bush’s State of the Union message on January 31, 2006, has set the following goals for biomass contributions by the year 2030:

- 5% of the nations power
- 20% of transportation fuels, and
- 25% of chemicals

In order to meet these targets US is estimated to require sustainable supply of one billion dry tons/year of biomass. The following table summarizes the components of the 2003 resource and the DOE’s road map requirement:

Biomass type	**Avail. Quantity Million dry tons/yr**	**Roadmap Requirement Million dry tons/yr**
Agricultural Residue	136	150
Energy Crops	155	159
Forestry Residues	162	304
Urban wood waste/ Mill Residue	29	387
TOTAL	**482**	**1000**

The projected significant increase in the collection of forestry residues and urban wood waste and mill residues presents many issues, primarily those related to competing uses, implementation of forest residue collection methods, and the impact of increasing quantities of recycling wood wastes.

The USDOE, EERE, Office of Biomass Program (OBP)'s mission is "… significantly increasing America's use of fuels, chemicals, materials, and power made from domestic biomass on a sustainable basis." In support of this mission, OBP has two primary objectives:

1. To reduce dependence on foreign oil by developing biomass based liquid fuels
2. To foster the domestic biomass industry

In DOE's perspective, thermal gasification has an important role to play in the integrated biological and thermal conversion processes. Gasification produces synthesis gas from biomass or residual solids from biological conversion schemes, which could be converted to a variety of fuels and chemicals. In addition the sensible heat in raw gases that may amount to about 25% or more could be used to support the endothermic reaction steps in an integrated process. At present, there is also the hope that downstream processing of raw products may not be much of an issue as the biomass-derived products could be upgraded to specification fuels and chemicals simply by blending with raw materials in current commercial plants. Given the high price of oil and a global interest in developing indigenous fuels to improve security of energy supply, particularly in countries with sustainable biomass resources, conceptual scenarios are being evaluated to integrate biomass gasification and/or pyrolysis plants with existing refinery or chemical process industry operations to minimize investment in downstream processing.

<u>BMG Technologies:</u> The notable biomass gasification processes that have been scaled up to near commercial scale and operated with varying degrees of success are the Battelle/FERCO dual CFB SilvaGas process (Figure 34) and the Renugas® Process, developed by IGT/GTI and Carbona (Figure 35). It is anticipated that these processes and others may play an important role in the evolving concepts for biorefineries of the future.

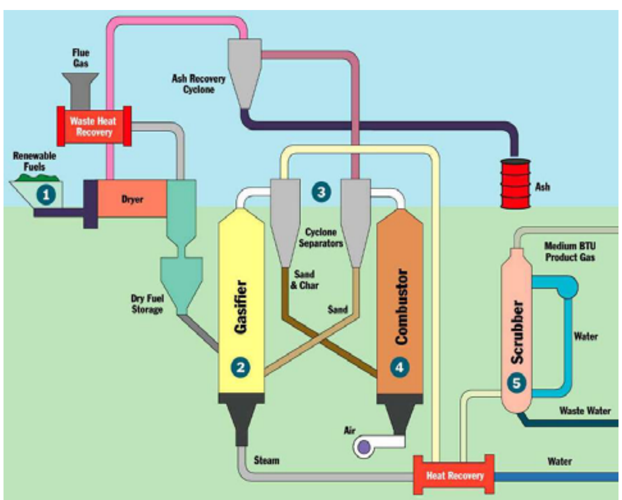

Figure 34: Silvagas Process

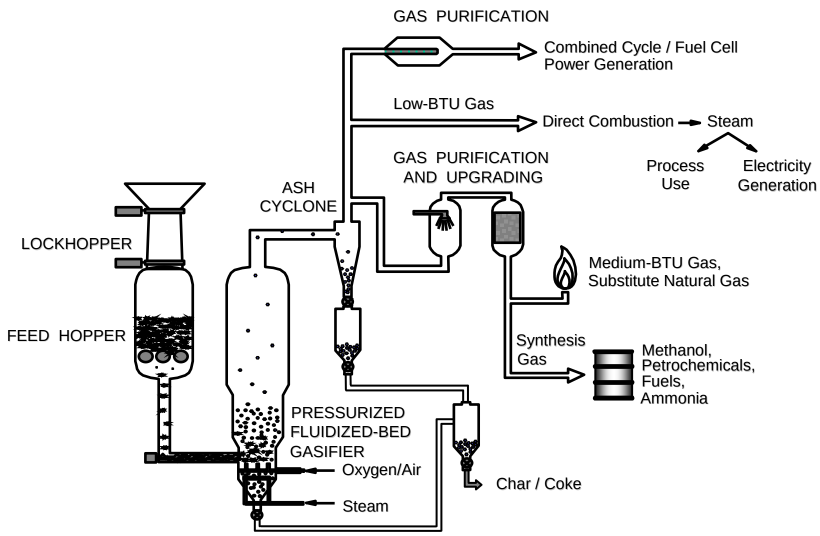

Figure 35: RENUGAS Process

The Community Power Corporation developed small-scale portable open-top downdraft moving bed gasifiers (Figure36). A 22 kWe gasification gas engine system has been demonstrated at Aliminos in the Philippines with coconut shells.[15] Similar units were also tested and being demonstrated in the USA for a variety of heating applications.

Figure 36: Community Power Corporation Portable BMG System

SUMMARY

Global biomass energy use has remained steady at about 5 to 6% of total energy consumption for decades. The basic infrastructure for biomass growth, transportation, feed preparation, and supply should be aggressively promoted to develop the bioenergy industry-of-the-future. Of the biomass energy conversion processes, BMG (using biomass or pyrolyzed biomass) offers many benefits and it could very well evolve as the core technology to convert different types of biomass feed stocks and wastes to produce a fairly uniform and environmentally preferable products that can readily displace fossil fuels.

The member countries of Task 33, have set a variety of environmental targets and targets to secure sustained supply of renewable energy. The plans to attain these targets include utilization of biomass in general, and BMG in particular. A variety of national action plans, directives, and multi-year RD&D programs are being implemented to expedite the development and commercialization of efficient and environmentally sound biomass energy conversion technologies.

The notable BMG technology development and demonstration projects and commercial plants in the member countries of Task 33 are given below:

Austria -	8 MWth TUV FICFB BMG CHP demonstration at Güssing 2 MWth down-draft BMG CHP at demonstration at Wr. Neustadt
Denmark -	5 MWth Vølund up-draft CHP demonstration at Harbøre 70 KWth, Viking 2-stage gasification and power generation at Lyngby 3+MWth, TKEnergi 3-stage, gasification process demonstration at Gjøl (an 833 KWth plant is demonstrated in Japan) 30 MWth Carbona Renugas fluidized bed CHP demonstration at Skive
Finland -	4 to 5 MWth Bioneer up-draft gasifiers (8 in Finland and one in Sweden) 60 MWth, Foster Wheeler Energy CFB co-firing plant at Lahti (50 to 86 MWth co-firing plant in Ruien, Belgium) 40 MWth Foster Wheeler Energy fluidized bed metal recovery gasifier in Varkaus 7 MWth NOVEL Updraft demonstration at Kokemäki
Germany -	130 MWth commercial waste to methanol plant at Schwarze Pumpe 100 MWth Lurgi CFB gasifier firing cement kiln at Rüdersdorf 0.5 MWth Fraunhofer Umsicht CFB pilot plant at Oberhausen 1.0 MWth CHOREN Carbo-V 2-stage entrained pilot plant in Freiberg 3-5 MWth Future Energy pyrolysis/entrained flow GSP gasifier in Freiberg
Italy -	15 MWth TPS CFB RDF plant at Greve in Chianti 500 KWth ENEA CFBG pilot plant at Trisaia (similar plant in operation in China)
Netherlands -	85 MWth AMER/Essent/Lurgi CFB gasification co-firing plant at Geertruidenberg Biomass co-gasification at the 250 MWe (35 MWe from biomass) Shell entrained coal gasification plat at Willem-Alexander Centrale 3MWth CFBG Plant in Tzum NL Several pilot plants at ECN, Petten

New Zealand – Fluidyne commercial down-draft gasification plants (2 MWe plant in Canada)
AB Powerhearth Ltd down-draft BMG (3MWe plant in Maine, USA)
2 MWth Page Macrae updraft BMG plant at Tauranga

Sweden - Bioneer up-draft BMG plant
30 MWth Foster Wheeler Energy CFBG at Karlsborg paper mill
20 MWth Foster Wheeler Energy CFBG at Norrsundet paper mill
30 MWth Gotaverken CFBG at Södracell paper mill
18 MWth Bioflow/Sydkraft/ Foster Wheeler Energy CHP demonstration at Värnamo

Switzerland - 200 KWe Pyroforce down draft BMG system at Spiez (scale-up to 1 MWe plant in Austria)

UK - 100 KWe Rural Generation downdraft BMG system in Northern Ireland
Upto 250 KWe Biomass Engineering Ltd., down draft BMG CHP systems in Northern Ireland
Upto 300 KWe Exus Energy down draft BMG CHP systems in Northern Ireland
Charlton Energy rotary kiln waste gasification in Gloucestershire
Compact Power two-stage waste gasification plant in Bristol

USA- Upto 120 MWth Primenergy gasification/combustion systems (6 in USA and 1 in Italy)
Upto 22 KWe Community Power Corporation small modular down-draft gasification systems
FERCo SilvaGas dual CFBG Process
RENUGAS fluidized bed BMG Process

The amount of investment made in developing these BMG technologies and the know-how accumulated, from this impressive list, of nearly 50 BMG systems, just from the Task 33 member countries, should play an important role in the evolving global bioenergy industry. These BMG technologies can produce heat, power, CHP, and synthesis gas and they could be designed for a variety of value-added co-production applications. The BMG processes suitable for scale-up to 1000 MWth capacity or higher, should be able to find early entry niche applications for producing biomass derived liquid fuels and chemicals. Supported by a mature fuel supply infrastructure that should become available in the near future in many countries, the BMG plants of the future could pave the way for producing significant quantities of sustainable 'green' energy from indigenous sources.

In recognition of this potential, the Task 33 member countries are providing various forms of support including RD&D funds, policies and incentives, to promote bioenergy RD&D and commercialization efforts. When fully implemented, the success of these efforts should be attributable to BMG as the central energy conversion technology.

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