Status of Gasification in countries participating in the IEA and GasNet activity August 2004

Compiled and edited by:
Kees W. Kwant, Novem, Netherlands
Harrie Knoef, BTG, Netherlands

Note:

The following countries have been updated from the previous report, September 2002
Austria
Denmark
Italy
Netherlands
New Zealand (new)
Spain
Switzerland
USA
UK
Germany
Sweden

June, 2004

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Gasification Survey Country (alphabetic order)

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Status of Gasification in countries participating in the IEA Bioenergy and GasNet activity, June 2004

Compiled and edited by:
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This report presents the results and status of the development of gasification systems in the 10 countries that participate in the IEA Bioenergy Thermal Gasification of Biomass Task 33 and the 16 countries within the European Gasification Network, GasNet. The report shows considerable activity to develop and demonstrate biomass gasification for efficient and environmentally acceptable energy conversion applications.
Good technical progress has been made in the field of biomass gasification, but at a commercial level the achievements still have to be attained. Heat gasifiers are commercial available. A few power gasifiers can be considered commercial like the Harboøre plant. A new market area is the application of gasifiers for pretreatment of biomass fuels, for cofiring in existing power plants (coal-fired or natural gas-fired). This is commercially demonstrated in, Finland (Lahti), Austria (Zeltweg) and Belgium (Ruien). Application of gasifiers in this market area could open up the market for the future in applications in integrated gasification combined cycle systems (IGCC). This was demonstrated with technical success in Värnamo, Sweden while Vermont is going into the same direction but closed in 2003. National policy and programmes exists in many countries stimulating RES like biomass. Other countries have still too low electricity prices for commercial operation of biomass gasifiers. At present the main focus is on the application of gasifiers to produce syngas for liquid biofuel production.

Introduction

At the turn of the century, the development of biomass gasification has seen a revival. There are several reasons for this. First, the world has become aware of its dependence of fossil fuels and the subsequent threat to the climate; as a result, there is greater demand for renewable energies. However the application of biomass should be shifted from its traditional low-efficiency applications for heating to high-efficiency applications for combined heat and power production.
Gasification of biomass converts a solid renewable fuel to a gas that can be used in a modern conversion device, such as a gas turbine or engine, for electricity and heat production. This opens the possibility of moving from the traditional, small-scale, low-efficiency steam cycle to combined steam and gas turbine with higher efficiency. Many studies have revealed the advantages of gasification over combustion for power and heat production.
The advantages can be summarized as follows:

- high efficiency for electricity production with a gas turbine or engine, even at a small scale
- good prospects for use in CHP, because of the small scale
- cost-effective reduction of emission because of the small gas flows, compared to combustion.

Many projects at both small and larger scales have been developed over the past decade and this report will summarise the results and offer a view of the field at present. The report focuses on the countries participating in the IEA bioenergy agreement, Thermal gasification of Biomass Task 33 and the countries participating in the European Gasification Network. Some recommendations for future work are also presented. Information of both Networks can be found at the following internet sites: www.gasnet.uk.net and www.gastechnology.org/iea

Policy and support for renewables
Several countries have developed policies to support the market for energy from renewables, including biomass1. It is especially in these countries, where these instruments are available, and the countries where wood cellulose, for paper production, that the development of biomass gasification is common practice. Traditionally Finland, Sweden and the USA have a paper industry and the developments for black liquor gasification. Denmark traditionally has a strong support for renewables, and more recently countries such as the Germany, Belgium, Netherlands, Austria, Italy and UK have shown such support as well. This additional support opens up new markets and thus the scope for more efficient and innovative technologies, such as biomass gasification. In some countries the situation is changing to the worse due to new elected government. On the other hand, the European Directives, especially on liquid biofuels are a real push to develop the gasification technology further.

Research and development focuses on gas cleaning
A number of universities, research institutes and industries are active in the development of gasification technologies. The research focus is on the development of the gasifier itself (2- and 3 stages), a better understanding of the gasification process for different kind of fuels, and the cleaning of the gas coming out of the gasifier. The gasification process can result in different qualities of gases, with low or medium heating value compared to natural gas. Different types of gas-cleaning processes have been developed and tested; conversion or removal of the tars in the gas is required for application in gas turbines and engines. Ammonia has to be removed, due to NOx emission constraints. Many countries are undertaking active R&D to overcome these hurdles – for instance, in Sweden (TPS) and in the Netherlands (ECN and BTG) have developed specific tar conversion units. Almost ten years of intensive R&D work in Harboore has ultimately resulted in a successful demonstration plant. At present, the wet gas cleaning has proven its effectiveness, and research is conducted on cleaning of the wastewater. A great number of pilot plants are sited around at the world, usually at universities and industries.

Implementation and demonstration
Biomass gasification sees several applications in several market segments, the results of which are discussed in more detail below

1. Heat gasifiers
Heat gasifiers are commercially available. The most well-known technologies are those of **Bioneer** (fixed-bed, updraft), **PRM Energy** (fixed-bed, updraft), Ahlstrom (now **Foster Wheeler**) and **Lurgi Umwelt** (both CFB). Less well-known are the small scale heat gasifiers installed in several developing countries supplying heat for lime kilns, tea drying.
About ten Bioneer gasifiers are in operation successfully for a number of years in Finland and Sweden. In most cases the gas is used for combustion in boilers and district heating purposes. Bioneer is now market by Condens Oy, Finland.
PRM Energy Systems has eighteen (18) units operating on four (soon to be five) continents gasifying 500,000 tons annually of biomass, mostly rice husk. Usually, the heat is used for industrial drying applications or low pressure saturated steam for an industrial process.
The first commercial fluid bed gasifiers were installed by Ahlstrom, Finland in the mid 1980's. Those 'Pyroflow' circulating fluid bed gasifiers had a capacity of 15 – 35 MW_t. The product gas from these gasifiers is used for fueling lime-reburning kilns of pulp factories. Four are still in operation.

1 Not all EU countries have national programs yet, like Portugal, but new legislation is being prepared

The first Lurgi circulating fluidised bed (CFB) gasifier was built in 1987 in Pöls, Austria by a large paper mill; heat was used in the limekiln. Since 1996 a CFB gasifier plant of Lurgi Umwelt is in operation at the Rüderdorfer Zement GmbH, Germany.
In autumn 2001 a 40 MWt heat gasifier was taken in commercial operation for energy production and aluminium recovery in Varkaus, Finland, based on Foster Wheeler technology

2. Cofiring gas from a gasifier in existing power plants

The first gasifier was installed in Zeltweg, Austria, followed by others in Lahti, Finland, Amer, the Netherlands, Vermont, in the USA and Ruien, Belgium. Despite successful operation, the plant in Austria was closed because the power station was shut-down. The Vermont demonstration project is successfully completed, but not in operation at present because of the low availability of the powerplant. The tests have shown that the gas quality was good enough to operate an gasturbine. The Lahti gasifier is in full operation. A new similar type gasifier became operational in Ruien, Belgium. The gas cleaning section of the Amer plant is modified and tested and will become operational late 2004. The *Danish Fluid Bed Technology Aps is* testing and developing the Low Temperature Circulating Fluid bed (LT-CFB) for cofiring. The designed allows using not only woody fuels, but also very difficult agricultural and waste fuels. The 2nd generation 10 times up-scaled test plant has been built at DTU and commissioning is planned for autumn 2004.

Table 1. Cofiring gasifiers

Location	**Plant**	**Capacity MWth**	**Status**
Zeltweg, Austria	CFB, directly fed into Pulverised Coal boiler	10	Operational since 1998 and shut-down in 2001
Lahti, Finland	CFB, Foster Wheeler, directly fed into Pcoal boiler	60	Operational since 1998, upgrading gas cleaning
Amer, Netherlands	CFB, Lurgi, with gas cleaning and ammonia removal, into PC boiler	80	Start-up since 2000, gas cleaning modified in 2004
Vermont, USA	Ferco Silvagas (Batelle) gasifier, planned to install CC	60	First test runs in 2000, demonstration project finished
Ruien, Belgium	CFB, Foster Wheeler, directly fed into Pcoal boiler	50	Operational since May 2003
Energi E2 A/S	CFB on straw	100	Not realised yet
Lyngby, DTU, Denmark	*Danish Fluid Bed Technology*. Low Temperature Circulating Fluid bed" (LT-CFB) on woody, agricultural and waste fuels	0.5	Commissioning is planned for autumn 2004

3. IGCC: integrated gasification and combined cycle

IGCC is seen as the total final concept of a biomass-to-electricity system. The development and implementation, however, is complex, as it involves all components, from fuel to power, in the gasification system. The European Commission has identified the potential of this technology, and called for proposals for Targeted Projects on this subject in 1993. Three projects were

selected, Arbre, Bioflow and Bioelettrica. Arbre is being realized and the CC has been in operation. However, the owner (Kelda group) has sold the plant to EPRI for unknown reasons in 2002. Negotiations are on-going about the future of Arbre. The Bioelettrica project has faced many technical and non-technical problems. The selected atmospheric gasification technology of Lurgi was changed to the pressurized gasification technology of Carbona, but the project was terminated definitely in 2003.
The cofiring project in Vermont is seen as a development towards an IGCC plant. Ferco is in negotiation with different clients to demonstrate the IGCC technology. Previously Sydkraft, a private company in Sweden, started a similar development in 1992 and has tested it successfully, but did not see commercial potential due to the low electricity prices in Sweden and mothballed the plant in 2000. The Värnamo pressurized gasifier of Foster Wheeler (formerly Ahlström) was also mothballed after positive results of the demonstration project. The capacity was too small for commercial operation. Within the sixth EU framework program, a new project is approved recently for syngas production using the Värnamo gasifier. It an integrated project called CHRISGAS.

Table 2. IGCC plants

Location	**Plant**	**Capacity MWe**	**Status**
Vänamo, Sweden	Pressurized CFB, with hot gas cleaning	7	Mothballed
Chianti, Italy	CFB gasifier, TPS technology, RDF fuel	6.7	1 10 thousand tons RDF treated in 2000
Arbre, Yorkshire, UK	CFB, with tar cracker, TPS technology	9	EPRI is new owner, uncertain status
Bioelettrica, Italy	Pressurized CFB, FLS Miljo, Carbona technology	8	Cancelled
SVZ, Schwarze Pumpe	Fixed bed, BGL, entrained flow		Operational, CC and methanol production from waste

4. CFB with gas engine

A relatively new application is the combination of circulating fluid bed technology coupled with gas engines. Table 3 shows 2 examples of this combination

Table 3: CFB gasifiers with gas engines

Location	**Plant**	**Capacity MWe**	**Status**
Güssing, Austria	Fast internal circulating fluidized bed	2	Operational on gas engine, more than x hrs
Skive, Denmark	Carbona CFB, catalysis gas cleaning and engine	4	Under commissioning

5. Fixed bed gasification for power production

A great number of small-scale, fixed bed gasifiers are either in operation or under development around the world. Some of these are based on old technologies (N-Ireland, Harboore) but also recent successful R&D results has being implemented (ESP, tar crackers, 2-stage gasifiers, etc.). Most of the units are CHP plants were heat is used for district heating. In India and China alone, hundreds gasifiers are in operation at farms and small industries, to produce heat or electricity at a local level. Other countries have successful demonstrations of small fixed bed gasifiers, with success defined here as at least 1000 hours of operation a year for power production.

Since the previous overview in September 2002, several new industries entered the market with limited success; some of them stopped the business after a few month. It is expected that, in particularly in those countries with favourable feed-in tariffs for electricity and "green-heat" regulations, several new installations will be implemented in the coming years.

However, despite the great number of developments at different industries and pilot plants available around the world, there are only a few that have achieved commercial operation in OECD countries. Table 4 tries to give an overview of operational systems.

Table 4. Status of fixed bed gasifiers for power production (anno June 2004)

Location	**System, supplier**	**Power MWe**	**Status**
Harboore, Denmark	Babcock & Wilcox, Volund updraft, CHP with gascleaning and 2 gas engines	1.5	Commercial
Seco-Bois, Belgium	Xylowatt sa, downdraft CHP	0.6	Under commissioning
Gedinne, Belgium	Xylowatt sa, downdraft CHP, wood chips	0.6	Under commissioning
Greasted, Denmark	BioSynergi, open core, wood chips	0.075	Under commissioning
Viking gasifier, DTU, Denmark	2-stage developed at DTU used for long-term testing	0.017	Operational since June 2002, scaling-up foreseen
Eckenförde, EVN, Domsland, Germany	Downdraft AHT technology	0.18	Discontinu operation since 2001
Austria	Grübl, wood gasifiers	0.05	Two in operation at farms
Londonderry, Northern Ireland, UK	Rural Generation, downdraft on farm, runs partially on energy crops	0.1	In operation, 16.000 hrs operating
Blackwater Valley Museum, N-Ireland	Exus Energy, downdraft on farm, runs partially on energy crops	0.2	In operation, 1.000 hrs operating
Ballymena ECOS Centre	Biomass Engineering, downdraft	0.075	In operation, 2.500 hrs
Spiez, Switzerland	Pyroforce gasifier, high-temperature gasification	0.2	Operational since 2002 > 1400 hrs
Bulle, Switzerland	Xylowatt,, open-top	0.2	Operational since June
Beddington Zed, UK	Exus Energy, downdraft	0.13	Under commissioning
Legnano, Italy	CCT, downdraft and updraft	0.5	Under commissioning
Rossano, Italy	PRM, updraft, olive pits	4.5	Under commissioning

5. Entrained flow gasification for syngas production

The European Directive on liquid biofuels for the transportation sector has been an important driver to develop new technologies for syngas production using entrained flow gasification. In Freiberg, Germany, three entrained flow gasifiers are in operation for syngas, methanol, hydrogen and Fisher Trops diesel production from biomass. Pyrolysis oil gasification is also considered as an alternative route for this purpose.

Carbo-V is operating a 1 MWt entrained flow gasifier at atmospheric conditions. Choren is marketing the technology. Engine operated for > 500 hours and in May 2003 the first methanol was produced and Fischer Trops diesel. Recent a 35 MW entrained flow gasifier is constructed in Freiberg.

Future Energy GmbH is a new company which bought the knowledge from BBP, Backcock Borsig Power (ex. Noell-KRC, ex-Deutsches Brennstoff-Institut). They operate a 5 MWt pressurised entrained flow gasifier. Future Energy is conducting the basic engineering for a new plant in Czech Republic.

A third entrained flow gasifier is in operation at the Freiberg Technical University.

Other commercially operated entrained flow gasifiers are installed at SVZ Schwarze Pumpe, Germany and BASF, Seal Sands, UK.

Evaluation and conclusion

A review of what has been achieved in the area of biomass gasification over the past 10 years shows that there is still R&D work needed on the gasification process and gas cleaning. Nevertheless several developments have resulted in successful pilot plants, and working demonstrations! However only a very few projects have achieved a commercial status, that is, where the technology has a competitive advantage on the market; in particular for heat applications.

Cofiring of fuel gas is on the competitive edge, as proven by several demonstrations, because of the fuel flexibility and the avoidance of emissions. Zeltweg and Amer has proven that for this type of application the operation of the gasifier is very dependent on the status of the power plant itself.

On a small scale, fixed bed gasifiers will have such advantages as high electric efficiency, and the possibility of using waste heat on-site. Highest reported efficiency is 36% and longest test run of 1000 hours. Harboore gasifiere have run about 70.000 hours and the engine about 10.000 hours, i.e. this plant can be seen as a commercial unit. Most demonstrations, however, show practical problems with the system, or the effluents (ashes or wastewater).

Many think that the IGCC concept is the potential future star of all the applications, and tests and verification will be needed to prepare it for this role. Recent developments show the high technical and financial risks associated with large scale concepts. Co-firing in coal/oil or natural gas boiler with advance steam condition is also promising since it almost reach the same level of efficiency. For small scale application fixed bed can be attractive in CHP mode to a total height efficient at small scale.

Most recent trend is syngas production for methanol, Fischer Trops diesel and/or hydrogen production.

Recommendations

1. Focus on the development of gasifiers for:
- cofiring in existing coal/oil/gas-fired power plants
- syngas production.
2. Seek niche markets for small-scale systems, and launch proven, reliable systems that are competitive with the existing steam cycle systems
3. Prepare overview of all achievements, all technical and non-technical barriers and recommendations to national and international donor agencies for future promotion of biomass gasification
4. Establish a good database on the existing knowledge about gasification available around the world
5. Exchange information on various technologies and projects within international Networks.

Gasification Survey Country: **Austria**

By: Hermann Hofbauer, Reinhard Rauch, Vienna University of Technology
Date: 18-04-2004

1. Policy

For the last years the part of biomass at the total energy production was about 11%. Austria has a strong policy on promotion and implementation of renewable energy. Austria has obligated a reduction of CO_2 emissions of 13 % until 2010. Biomass has to play an important role for this reduction. The Ministry of Economic Affairs has defined to increase the production of electric power from renewables (hydro power not included) to 4 % (at present 2.9 %) until 2008.
Since 1st January 2003 a new law for feed-in rates of renewable electricity is valid. Before 2003 each federal state of Austria had its own feed in rates.
The feed-in rate for solid biomass is shown in the following table (price in Eurocent/kWh). The feed-in rate is different for capacity and type of biomass, which is used.

	Biomass from forestry	Waste wood type 1	Waste wood type 2	Waste wood	combinations
up to 2 MW_{el}	16,00	12,80	10,40	2,70	Proportional to the fuel input
from 2 MW_{el} to 5 MW_{el}	15,00	12,00	9,75	2,70	
from 5 MW_{el} to10 MW_{el}	13,00	10,40	8,45	2,70	
over 10 MW_{el}	10,20	8,16	6,63	2,70	
Co-combustion	6,50	5,00	4,00	3,00	

2. Programs

R&D is funded by EU programs and national programs:

AT:SD

Program for sustainable development research including renewable energy (also for biomass) funded by the Ministry of Transport, Innovation and Technology

K_{PLUS}

Program for founding Centre of Competence (Austrian Bioenergy Centre was established in 2002) funded by the Ministry of Transport, Innovation and Technology

K_{NET}

Program for funding Networks of competence (RENET Austria was established 1999) funded by the Ministry of Economic Affairs

CLUSTER „BIOENERGY AUSTRIA“

Export promotion for bioenergy companies

3. R&D Institutes

Graz University of Technology, A-8010 Graz
Department of Heat Processes
Institute for Apparatus Design, Particle Technology and Combustion Technology

Joanneum Research, A-8010 Graz
Department of Energy Research

Vienna University of Technology, A-1060 Vienna
Institute of Chemical Engineering

4. Industries

Austrian Energy – AE Energietechnik,
A-1211 Vienna; A-8010 Graz
Energy and environmental systems, Fluidised bed gasifiers

GE Jenbacher Energiesysteme AG, A-6200 Jenbach
Gas engines

Elin EBG, A-4020 Linz
Gas turbines

Gruebl Automatisationtechnik
A-4223 Stubenberg am See 213
Fixed bed gasifiers

Repotec Umwelttechnik GmbH
A-7540 Guessing, Europastrasse 1
Biomass Power Plants

Urbas GmbH
A-9100 Völkermarkt, Billrothstraße 7
Fixed bed gasifiers

5. Projects

Graz University of Technology – Institute of Thermal Engineering
- Evaluation and optimisation of a fixed bed gasifier, gas cleaning system and gas engine
- Scientific Partner in Austrian Bioenergy Centre
- Health, Safety and environmental issues for gasification systems

Graz University of Technology - Institute for Apparatus Design, Particle Technology and Combustion Technology
- Fundamental research on biomass particles under gasification conditions
- Gasification and co-combustion in pulverised coal power stations

Joanneum Research Graz - Department of Energy Research
- Study on waste wood gasification

Vienna University of Technology, Department of Chemical Engineering
- Scientific Partner in RENET Austria (Network of Competence for Energy from Biomass)
- EC-Project “Clean Energy from Biomass” ENK5-CT2000-00314
- EC-Project “A New Approach for the Production of a Hydrogen-Rich Gas from Biomass - An Absorption Enhanced Reforming Process” NNE5-2001-00139
- EC-Project “Renewable Fuels for Advanced Power Trains” (RENEW)
- Scientific Partner in Austrian Bioenergy Centre

6. Implementations

Location	Type, Capacity	Biomass feed	Subsidy	Status
Guessing	FICFB 8 MW_{th}	wood chips	EC, 1a area	in operation
Civitas Nova	Fixed bed 2 MW_{th}	wood chips	EC, 5b area	in operation
Gruebl	Fixed bed downdraft 5-100 kW_{el}	wood chips	Local Government	2 gasifier in operation

CFB ... Circulating fluidised bed
FICFB ... Fast internal circulating fluidised bed

GUESSING:

In Guessing a Biomass CHP with the concept of the FICFB gasification system was realised.
The basic idea of the FICFB concept is to divide the fluidised bed into two zones, a gasification zone and a combustion zone. Between these two zones a circulation loop of bed material is created but the gases should remain separated. The circulating bed material acts as heat carrier from the combustion to the gasification zone. 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 charcoal, circulates to the combustion zone. This zone is fluidised with air and the charcoal is burned. The exothermic reaction in the combustion zone provides the energy for the endothermic gasification with steam. With this concept it is possible to get a high-grade product gas without the use of pure oxygen. The construction of the demonstration plant started in July 2000 and it started operation in November 2001. After first tests of the gasifier, the gas engine was started in April 2002. The total operation hours till end of March 2004 of the gasifier including the gas cleaning line are 9700 hours and of the gas engine 7100 hours. With this demonstration plant the scale up of the FICFB gasification process was realised and now the R&D on the gasifier and all ancillary units is going on, that the turn key contractor Repotec can bring an economical and commercially viable biomass driven power station to the market. The developmental aim is for a current-led heat power combination with high electrical efficiency for larger capacity applications.

CIVITAS NOVA:

In Wr. Neustadt/Civitas Nova a small Biomass CHP demonstration unit has been built. This system is a demonstration plant for marketable, economical and modularised installation systems for small capacity applications such as local heat supply systems or the woodworking trade and industry. As gasification system, a co current gasifier was realised. Electricity is produced using a gas engine. The biomass input is 2MW and the electric output is 0.6 MW. As gas treatment system a scrubber with a wet electrostatic precipitator is installed. The plant went into operation in February 2003, the first electricity was produced March 1st. At the moment the optimisation work is going on.

GRUEBL:

The company Gruebl Automationtechnic produces woodgasifiers for production of heat and electric power in the size from 5-100kWel.
This system consists of the following components: a sluice system to feed the wood chips into the gasifier, a fixed bed downdraft gasifier is used to produce a gas from the wood, the product gas cleaning system consists of a cyclone, a heat exchanger and a scrubber, after this gas treatment the gas is feed into a spark ignition engine to produce electricity and heat.
At the moment 2 gasifiers with a size from 5 to 50 kW_{el} are in operation. The main market for this type of gasifier will be farmers and small industry.

Gasification Survey Country: **Belgium**

By: Pépin Tchouate Héteu, Université catholique de Louvain
Date: September 2002

1. Policies and Programs

The Federal Belgian Government has adopted 1994 a master plan for Greenhouse gases emissions reduction. This national plan aims at reinforcing actions for the Ratiola Use of Energy and the valorisation of Renewable Energy Sources. This includes mainly the promotion of cogeneration and the support of emerging technologies and Renewable Energy Technologies. Renewable energy should contribute by 2010 to about 5% of the total energy production. Priority will be given to biomass, small hydroelectric plants and solar thermal technology.

In Belgium, the subsidy aimed at commercial scale energy production is limited to that supporting the generation of electricity from renewable energy sources. Up to the implementation of the new electricity law of 29.04.1999, green electricity generation was subsidised according to a formula established by the Control Committee of Electricity and Gas (CCEG). The formula distinguished a basic feed-in tariff and a premium for green electricity. The basic feed-in tariff was calculated on an "avoided cost basis" and varied according to the reliability of the supply. The premium for green electricity was established at 1BEF/kWh (2.479 Euro-Cents/kWh) for installations <10 MW and connected to the distribution grid operating at 15 kV (or lower) voltages. The subsidy was guaranteed for 10years. Subsequently, the amount was increased to 2 BEF/kWh (4.958 Euro-Cents/kWh) in certain cases i.e. small hydro and wind energy.
In article 7 of the new electricity law of 29.04.1999 a new price support measure is foreseen the implementation of which will modify or replace the former subsidy system. The price support mechanism will be based on establishing a minimum price to be paid to the producer(s) of green electricity, but details are not known as yet. The funds necessary to cover the related costs are -most likely-to be raised from within the electricity market.
Regional authorities can grant subsidies for R.E.S. development projects in various forms. Projects may be undertaken by statutory research organisations and by higher educational institutions within the framework of their annual budgets, thus supported 100% by the state.
Private companies are encouraged to invest in R&D aimed at product and/or technology development. Regional governments may provide financial assistance (e.g. loans partially convertible into grants) for implementing approved projects especially for those having an export potential. Special provisions are applicable where private companies are executing projects in collaboration with universities/research organisations.
Technology demonstration projects may qualify for 50% regional government subsidy.
Regional governments may also co-finance multinational R&D projects qualifying for C.E.C. funding.
For example, the Walloon Regional Government has launched a program "Programme Mobilisateur Cogénération-énergie totale" to finance R&D in implementing renewable energy sources and cogeneration. In the framework of this program, the first 4 projects here under are being presently financed. http://mrw.wallonie.be/dgtre

2. R&D Institutes

- Part of the Faculty of Applied Sciences of the Université catholique de Louvain (UCL), **GEB (Groupe Energie Biomasse, 2 place du Levant, 1348 Louvain-la-Neuve** created 1997) is characterised by the complementarity of its team (3 professors, 6 researchers, 5 technicians) and of its infrastructures (scientific equipment, test facilities and modelling systems). GEB's activities are based on the use of biomass as renewable and sustainable source of energy. In this goal, GEB's look for contributing to research, development and valuation of new efficient technologies for biomass conversion into energy. Our fields of R&D are:
  - technical, economic and environmental valuation of biomass energy routes
  - modelling of biomass gasification
  - technological development of power plants based on biomass gasification
  - characterisation of different biomass types (clean or contaminated, agricultural residues).

- Free University of Brussels, Faculty of applied Sciences, Department of Mechanical engineering, Pleinlaan 2, 1050 Brussels
  Responsible : Professor Jacques De Ruyck, jdruyck@vub.ac.be
  Design of integrated fluidised bed gasifier/gas turbine plant for base load CHP

3. Industries

XYLOWATT s.a. company: technological developments (GAZEL and REGAL projects) and feasibility studies have led to the creation of the commercial company "XYLOWATT s.a." selling CHP solutions based on wood gasification. This company collaborates with Electrabel, the main Belgian electricity company and offers fully integrated solutions (technical and financial) for wood industries and communities (www.xylowatt.com).
XYLOWATT SA, 2 place du Levant, 1348 Louvain-la-Neuve info@xylowatt.com.

4. Projects

1° **The SRC GAZEL Project**: Development of downdraft gasifier dual fuel system with a nominal capacity of 150 kW electrical. The plant is running full automatically on Short Rotation Coppice since September 2000, feeding the produced electricity in the local low voltage grid. Long duration test have so far been completed.

2° The REGAL project: this project aims at developing a commercial 300 kWe + 600 kWth CHP plant based on gasification. The test period is coming to its end and the plant will run from November 2002, feeding the produced heat in the local heat network of the university. It is a technical improvement of the GAZEL plant.

3° **The Waste Wood COGEN project**: in Belgium waste wood is a problem: It does not exist environmentally sound technologies to valorise this energy potential. Small scale gasification is an attractive way to convert wood into heat an electricity because most of pollutants are destroyed in the gasifier or kept in the high efficiency filtration system. The project aims at measuring for different types of waste wood pollutants in the exhaust gases, including dioxins and to compare it to European legislation. The gas cleaning system could be improved to treat some of special pollutants and to satisfy environmental legislation.

4° **The MINI-COGENBOIS project**: In Belgium an important part of the wood resource is a local resource. It will be interesting to valorise it locally avoiding transportation. This project aims at developing a standardized small scale CHP plant (20-50 kWe + 40-100 kWth) based on a downdraft gasifier coupled with an internal combustion engine.

5° **The Biopower Ruien project of ELECTRABEL**: Co-firing of pulverized wood in an existing coal plant. The gasifier capacity is about 8.5 t/h and will converts 40 000 tons of non-contaminated wood yearly (first phase, 14 MW_e). The project is based on a CFB gasifier. The second phase will start producing power (17 MW_e) end 2002 and 50 MW_t with an electrical efficiency of 34%, converting more than 100 000 tons of biomass (contaminated and non-contaminated wood). Commercial operations will start by 2003.

5. Implementation

1° THE SRC-GAZEL PROJECT: SHORT ROTATION COPPICE GASIFICATION FOR DECENTRALISED PRODUCTION OF PEAK ELECTRICITY.
This project aimed at studying the technical, economic and environmental feasibility of electricity production at a farm level based on cultivated wood. Currently a full automatic 150 kW_e gasification plant is running in a farm (20 km from Brussels) and delivers its electricity to the grid. **SRC-GAZEL** project, funded by the Walloon government together with Electrabel and involving four research centres, aims to develop and characterise a complete route from wood cultivation to electricity production by wood gasification and deliver this electricity to the grid.
Specific to this route is:

- *Localisation in a rural place near crops and small power (100 - 500 kWe) in order to reduce transportation distance*
- *Peak electricity production for high electricity selling price*
- *Automatic plant control and management for low maintenance and high reliability*

2° **ECONOLER** has built in the neighbourhood of Liege a 150 kW electric biomass gasification plant, based on a downdraft gasifier coupled with a V8 gas engine from Deutz. The system is constructed by AHT Germany and will accept only clean wood. There are some technical problems now and the plant is not operating. Unfortunately the plant could not operate because of time delay in the commissioning period and the outbreak of fire in the wood storage facility.
These projects are co-funded by the Walloon government and by Electrabel and realized by the Groupe Energie Biomasse from Université catholique de Louvain. All these projects are RD&D projects. The total funding of these project is about 3 million Euros.

3° Seco-Bois and Geddine; four times 300 kWe gasifier plants of Xylowatt under construction

Gasification Survey Country: **Denmark**

By: Martin W. Hansen, FORCE Technology and
Henrik Flyver Christiansen, Danish Energy Authority
Date: August 2004

1. DANISH ENERGY POLICY

The Danish energy plan Energy 21 was introduced in 1996 in order to ensure a strong Danish energy supply system, with emphasis on short-term targets, and preparation of longer-term sustainable development.
The important objective is to reduce the CO2 emission by 20% by the end of 2005 compared to the 1988 level, and 50% before 2030. The energy plan states that Demark has to be a driving force in international development of renewable energy with ambitious environmental goals, and to support the European opening of the energy market, with strong priorities on the environment. Further the Energy 21 confirms the need for dynamic, revised energy plans.
In 1999 the Danish parliament agreed on that in 2003 20% of the electricity should be produced from renewable energy sources (10% in 1998) and the gross energy consumption should increase to 12-14 % in 2005 and 35% in 2030 (9%in 1998).
The recent elected Danish government has reduced the funding for R&D projects on the Budget from approximately 500 MDK to aprox 250 MDK, with reference to that the industry has to invest in technology development.
Further the government has postponed the marked for REC, until there is a well functioning European market.
So all in all the new government has removed not only the technology push but also the market pull, for innovative biomass technologies, including gasification.
The current Danish energy policy is that Denmark will use the Kyoto mechanisms and buy CO2 reductions where they are most profitable.
Some years ago the utility companies own both the grid and the power plant. Now it have been split up in two utility companies ELSAM and Energy E2 and at the end of year 2004 the two grid companies Eltra and Elkraft System by law will bee one company. The utility companies are now allowed to make profit and the Grid Company will be a part of the Civil Service with out profit.
The power production from Windmill and CHP have become so big compared to the consumption that there at different time is an overflow witch not is possible to sell. To get a better regulation of production and consumption the government has chance different Energy laws.
By law from January 2005 more or les all kind of power production will as a basis electricity price get the Nord Poll price. Nord Pool is the Nordic Power Exchange (www.nordpool.no). CHP on Natural gas will on top of the Nord Pool price be supported compared to power production and there by the income at an average level for the year 2001 to 2003. The support is monthly regulated to this level. Existing private biomass power production get 0,60 dk kr/kWh (0,072 Euro) for a period of 20 years from production start up. The utility companies use of biomass according to “The biomass agreement” (1 mill. Tons of straw and 0,2 mill. Tons of wood yearly) get 0,30 + 0,10 (REC) + up to 0,03 = 0,43 dk. Kr/kWh (0,052 Euro) for a period of 10 years from production start up. New biomass plant get the Nord Pool price + 0,10 (REC) dk kr/kWh.

New biomass plant with particular technology interest for the future get 0,60 dk kr. (0,072 Euro) for a period of 10 years and 0,40 dk kr. (0,048 Euro) for the next 10 years.
New laws for CO2 quota allocation for all Energy production with fuel input higher than 20 MJ/s regulate the production from January 2005 to full fill the Kyoto protocol. Every utility companies, industry and private Energy production have to make a forward planning before the end of the year to full fill this.

2. NATIONAL PROGRAMMES

The Danish industry is very successful in attracting support to gasification projects from different European programmes i.e. JOULE, THERMIE, ENERGIE, ALTERNER and FAIR. Support is also achieved through EUREKA and the Nordic Energy Research Program.
When it comes to National programs a significant reduction in available public money for research and development has been the effect of a change in government:

- ? The Energy Research Program (EFP) - supporting mainly strategic energy research, has been reduced from 110 MDK to 75 MDK, further the advisory committee for Environmental Friendly Power and Heat Production in order to determine the most essential research needs has been terminated.
- ? The Development Program for Sustainable Energy (UVE) - supporting mainly the development and demonstration of renewable energy technology, has been reduced from 132 MDK to 0 MDK.
- Investment programme for heat and CHP from biomass technologies has been reduced from 25 MDK to 13,5 and was terminated in 2003.
- ? The program for supporting industrial energy conservation - supporting mainly the implementation of more efficient commercially available energy technology in industries - has been terminated.
- ? A Public Service Obligation provides the Utilities, Industri and others with the option to apply a part of the consumer price for electricity to ensure a continuous development of Best Available Technology for electricity production is maintained on 100 MDK annually.
- One newly introduced means for pushing research is the introduction of a tax deduction (150%) for companies buying research in another public Danish research institution.

The Danish Energy Authority Follow-up Programme for CPH supports the establishing of new CHP plants. The programme collects, evaluate and distribute production and performance data from commercial and semi-commercial/demonstration plants. The data are being controlled, registered and analysed by the general CPH monitoring program of the Danish Energy Authority. The program has been terminated with the end of The Development Program for Sustainable Energy (UVE). The results and draft reports have been forwarded at a seminar in 2004; final reports are expected in the end of the year.
The following institutes participate in the programme and are responsible for the validation and quality of the reported data. Danish Forrest and Landscape Research Institute (Fuel analysis), The Danish Technological Institute (Energy and environmental analysis), FORCE Technology (Ash analysis), Danish District Heating Association (Economy analysis), Danish Utilities ENERGI E2/ELSAM (Plant operation data), Technical University of Lund (Waste water analysis), RISØ National Laboratory (Tar and chemical analysis) and the Technical University of Denmark (Process analysis).
Data are presented every two months in the publication Danish Bio Energy (www.biopress.dk)

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3. INSTITUTES

Technical University of Denmark - The gasification group has concentrated their activities on three areas: 1. Carbon conversion 2. Modelling of gasification processes and systems, in order to improve reactor design, and system optimization. 3. Development of new gasification processes, e.g. the LT-CFB concept with Danish Fluid Bed Technology and a new fluid bed two-stage process with COWI. The verification of this process is ongoing.
Further the Department has constructed a 75 kWth two-stage gasification plant mainly for long term testing of the gasifier and for testing of essential components in the CHP setup. This gasifier has now been in full automatic operation for more than 2,200 hours, and has an overall efficiency from biomass to delivered electricity of 25%.

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Technical University of Denmark - The Stirling group has developed and demonstrated the Stirling engine technology for biofuels in a 9 kWel, 35 kWel and a 75 kWel version. Activities are related to optimization of engine performance. A field test of the 9 kWel engine operating on biogas and natural gas are ongoing. The 35 kWel engine is developed for direct combustion of wood chips and other biofuels. For the first 35 kWel plant a commercial available grate combustion system was further developed for this application. The combustion system for the second generation was based on combustion of a producer gas from an updraft gasifier without gas cleaning, the project is reconstruct in 2004 and results are expected at the end of the year. The first production series of 10 engines for lover the cost is made in spring 2004. A larger engine with an electric power output of 75 kW have been install in Austria for direct combustion of wood chips.

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Technical University of Denmark - The CHEC, Combustion and Harmful Emission Control, group carries out research in fields related to chemical reaction engineering and combustion, with emphasis on high-temperature processes, formation and control of harmful emissions, and particle technology. In recent years activities in CHEC have included work on pyrolysis and gasification of coal and biomass in laboratory and bench scale. Cofiring of biomass and Coal has given a higher priority.

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The Danish Forrest and Landscape Research Institute are representing Denmark in the international project; standardisation and characterisation of wood based fuels. The Institute has worked on determining the critical parameters related to the use of wood chips in gasifiers, and have proposed a classification for a “large gasification wood chip”.

Contact: Peter Daugbjerg Jensen, The Danish Forrest and Landscape Research Institute, 31 Kvak Møllevej, DK-7200 Vejle, phone +45 75 88 22 11, fax +45 75 88 20 85, email fsl@fsl.dk - www.fsl.dk

Risø National Laboratory is performing research within the fields of fundamental tar formation processes, advanced chemical measuring techniques and analysis.

Contact: Helge Egsgaard, Risø National Laboratory, Frederiksborgvej 399, P.O. 49, DK-4000 Roskilde phone +45 46 77 46 77, fax +45 46 77 56 88, email helge.egsgaard@risoe.dk - www.risoe.dk

Technical University of Lund, Sweden has performed thorough analysis of different techniques in order to determine the inhibition effect from all measured single tar components found in gas from up and downdraft gasifiers, and on effluents from purified tar water, following the Nordic test analysing method.

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Approved Technological Service Institutes

The Danish Technological Institute has been focused on research / development of measurement methods of energy and environmental performance for different CHP technologies. The Danish Technological Institute is representing Denmark in the work related to the EU tar protocol and the CEN tar measurement standard.

Contact: Uwe Zielke, Teknologisk Institut, Teknologiparken, 29 Kongsvang Allé, DK-8000 Aarhus C, phone +45 72 20 10 00, fax +45 72 20 10 19, email uwe.zielke@teknologisk.dk - www.teknologisk.dk

FORCE Technology did in 2004 acquire the activities in dk-TEKNIK ENERGY & ENVIRONMENT, including the work on ash characterisation, and aspects related to PAH concentrations. FORCE Technology is in co-operation with the Danish Energy Autherity performing economical and environmental analysis (LCA) for different technologies. FORCE Technology is in co-operation with TK Energi A/S participating in demonstrating the dry gas cleaning technology in Gjøl.

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4. INDUSTRIES, CONSULTANTS AND PILOT PROJECTS

Volund R/D Centre has for the last 15 years worked on commercialisation of updraft gasification based CHP of straw and wood chips. Since 1993 Volund have been working with the Harbooer gasification which until 2000 produce the heat for the town and then got to engine install for CHP. For the last 8 years they have worked with commercialisation of a combined gasification / Stirling CHP solution. A long-term test of the Stirling engine is expected to be finished mid 2005. Vølund R/D centre is a owned by Babcock & Wilcox.

Contact: Bjørn Teislev, Babcock & Wilcox Volund R&D, Falkevej 2, DK-6705Esbjerg, phone +45 76 14 34 00, fax +45 75 56 88 73, email bjt@volund.dk - www.volund.dk

Hollensen Engineering and Boilers Co has in co-operation with the Community of Herning worked on commercialisation of a down draft gasification technology. The Høgild project was initiated in 1994 and terminated in 2003.

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ENERGI E2 A/S has participated in the development of co-firing technology based on CFB gasification of straw for gasifiers coupled to boilers in co-operation with Finish companies and institutes. The aim was to produce an ash and K, Na and Cl free gas, which can be co-fired in modern high efficiency steam boilers. The results were promising and it was only because of

locally unfavourable prices and lack of long term experiences of warm gas cleaning that a 100 MWth was not realised. The activities are continued with various waste fractions as fuel, with emphasis on the development and verification of reliable warm gas cleaning in order to minimise the environmental impact from efficient conversion of waste to electricity and heat. ENERGI E2 was a partner in the Biocycle project, the Finish Lahti project (40–70 MWth, RDF and biomass) and in the EPZ (now Essent)/Amergaz project (85 MWth, waste wood).

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ELSAM A/S is operating the larges co-fired CHP plant, using up to 150.000 ton of straw annually. Further ELSAM has participated in the EU APAS and the Biocycle project.

Contact: ELSAM, 45 Overgade, DK-7000 Fredericia, phone +45 79 23 33 33, fax +45 76 22 20 09, email info@elsam.com - www.elsam.com

BioSynergi Proces ApS continues the development of an air-staged open core pilot gasifier. Previously has process design and erection of a test plant together with a combustion engine been carried out. Measurement results from more than 300 hours of test operation that includes 110 hours of gas engine operation at the test plant has proved that the gasifier was capable to produce a sufficiently clean gas for continuous operation of an engine. A continuous wood chip dryer was developed as well in the project and operated with a satisfying result. A 80 kWel demonstrations plant in Graested are in operation since 2003.

Contact: Henrik Houmann Jakobsen, BioSynergi Proces ApS, 108 Slotsbakken, DK-2970 Hørsholm, phone +45 45 86 14 30, email hhj@BioSynergi.dk

Weiss A/S is a well known manufacturer of straw and wood boilers in Denmark. Weiss is now upscaling the two-stage gasification process in corporation with DTU and COWI A/S. The aim is plants of 1MWe and up, with an electrical efficiency of 35%. A pilot plant with design data of 600kWth and 200kWe (35% electrical efficiency) will be established during 2004/2005.

Contact: Morten Grøn, Weiss A/S, Plastwænget 13, DK-9560 Hadsund. +45 96 52 04 44, email weiss@weiss.dk

TK Energi A/S has developed and tested a three-staged open-core gasifier, with dry gas cleaning technology. The testing has proved process stability in the pilot plant with a capacity of 300 kWth fired with wood-chips. TK Energi has in co-operation with Hedeselskabet received national funding for a study aiming at implementation of an up-scaled version of the gasifier, where the producer gas is used in an existing engine now fired with landfill gas. A third generation test plant, partly funded by PSO, will be tested at 500 kWth during 2002.
TK Energi has participated in a European Project aiming at developing a three staged, slagging entrained flow gasifier mainly for straw. A 300 kWth pilot has been tested.
TK Energi has high expertise in handling, preparation and feeding of straw.

Contact: Thomas Koch, TK Energi A/S, 4 Stationsvej, DK-4621 Gadstrup, phone +45 46 19 15 54, fax +45 46 19 15 38, email tk@tke.dk - www.tke.dk

KN Industries has developed an updraft gasifier for straw, using CO2 as gasification agent. The plant with an installed capacity of 250 kWth has with success been tested in pilot scale and proved process stability, including no ash agglomeration. KN Industries has in co-operation with the community of Løgstør received national funding for a study aiming at implementation of an up-scaled version of the gasifier. The 500 kWth unit has now been built, and is being tested with a 100 kWel dual fuel diesel genset.

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Danish Fluid Bed Technology Aps are testing and developing the “Low Temperature Circulating Fluid bed” (LT-CFB) gasifier within a cooperation between Danish Fluid Bed Technology Aps (DFBT), the Technical University of Denmark, FORCE Technology, Rica-Tech A/S and Tech-wise A/S.
The LT-CFB gasifier is designed in a way that allows the use of not only woody fuels, but also very difficult agricultural and waste fuels. The main idea is to convert such biomass and waste into a hot fuel gas with low content of ash, K and Cl, and to burn the gas in e.g. highly efficient power plant boilers.

Tests conducted with a 50 kW plant at DTU has given a number of encouraging results, such as no deposition or agglomeration problems in spite of gasifying difficult Danish wheat straws, > 6 % ash, > 1.8 % K and 0.8 % Cl (d.s.), and using ordinary silica sand with no additives as the bed material.

By re-using the bed material from earlier tests and by avoiding the addition of fresh sand a steady concentration of 5.3 % K in the bed material was reached. Moreover, retentions of particles and K beyond 90 % has been achieved using only an ordinary secondary cyclone operating at 600-650 C, and as a positive surprise the PAH concentration in the ash was only around 2 mg/kg. According to Danish regulations, this low PAH content allows the straw ash to be "returned" to the fields without further processing.

The two most recent test with the 50 kW plant has been on pig and hen manure. As expected also this type of fuel can be gasified without problems, whilst retaining most of the valuable nutrients (K, P, Ca, Mg) in the ash stream.

Furthermore a 10 times up-scaled (500 kW) LT-CFB test plant has also been build at DTU and commissioning this plant is planned for autumn 2004.

The LT-CFB gasifier is based on fast pyrolysis, and plans for optimising it for the production of bio-oil is intended. The ELTRA PSO R&D program, supports most of the efforts described.

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Elsam Engineering A/S is a consulting engineering company specialised in all kind of services related to energy and power plants and systems based on the utilisation of fossil fuels and renewable energy.

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COWI A/S is an independent consultant operating worldwide within all principal fields of engineering and related sciences. COWI works with several different gasification projects together with many partners. Examples of COWI's participation are upscaling of the two-stage Viking gasifier to a 500 kW demo, consultant on mechanical and electrical work for the 18 MW CARBONA gasifier at Skive, demonstration of 3 MW pyrolyser for superheating of steam cycles, development and demonstration of fluid-bed version of the low tar two stage gasification process LT-BIG. Participation in the EU supported BIOCELLUS project, where use of producergas in fuel-cells is being tested in order to optimise design of FC's and gascleaning. Analysis of several waste gasification and thermal treatment concepts in connection with WTE projects in Ireland, UK, Ukraine and Malaysia. COWI has further developed methods for HAZOP and safety analysis, which has been performed for various

gasification plant. COWI carries out design, tender and supervision of complete biomass, WTE and gasification plants.

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ReAddit Aps. is a company focused towards production and utilisation of additives and research -within the fields of additive utilisation in combustion and gasification of coal, biomass and waste. The basis of ReAddit is a professionally developed knowledge concerning, reactivity, kinetics, catalysis, ash chemistry, gas cleaning, reactor design and model evaluation of data.

Contact: Lasse Holst Sørensen, c/o CAT, P.O. Boks 30, 399 Frederiksborgvej, DK-4000 Roskilde, Denmark phone +45 46 77 59 32, fax +45 46 32 19 19, email LHS.ReaTech@catscience.dk - www.reatech.dk

ReaTech is a consulting research company, specialised in experimental scientific fuel characterisation and preparation. The work is focused towards research within the fields of combustion and gasification of coal, biomass and waste. The basis of ReAddit is a professionally developed knowledge concerning, reactivity, kinetics, catalysis, ash chemistry, gas cleaning, and model evaluation of data.

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5. IMPLEMENTATION

Harboøre CHP plant

In 2000 a complete biomass gasification process system fitted with two gas-engines of total 1,4 MWel was set in operation at Harboøre district heating plant. This was the final step in a development process, which started in 1988.
Based on a traditional German updraft moving bed gasifier Volund in 1988-1992 experimented with a pilot unit for gasification of straw. Next step was construction of a wood-chip fired version of this gasifier, which since 1993 has been supplying gas to the boiler at Harboøre district heating plant, and since 1996 the gasification plant has produced all district heating for Harboøre, with minimal operating staff. The final conversion to a CHP plant was completed in the summer of 2000. The gasifier has been operating 74.000 hours (8.100 hours / year since 1996)
Since July 2000 the engines has been operating 9.100 hours and 6.400 hours, the CHP power to the grid has been 7.700 MWh and the CHP district heating 65.000 MWh in total. Since December 2003 the engines has been full available. The operational data for the period until today (July 2004) are, woodchip fuel with a moisture content varying between 39 and 50%, 3691 MWh of power to the grid, corresponding to mean power efficiency (woodchips to power) of 27.2%.

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Ansager Stirling

In 1999 the Technological University of Denmark received national funding for the development of a 2nd generation Stirling unit. In connection to this project Volund received national funding for implementation of a combined Stirling/gasifier unit. The project in Ansager includes an updraft Volund gasifier, fired with wood chips up to 50% moisture. The gas is lead directly to a burner on top of the Stirling engine combustion chamber without any gas cleaning.

The plant has been operated for approximately 400 hours, and several improvements have been made. An electric power output of up to 37 kW has been measured, which is well above the predicted 35 kW. The results of a one-hour test showed that a net electric efficiency of 16,7% (woodchips to power) was obtained and the total energy conversion efficiency was 88 %. The project is reconstruct in 2004 and results are expected at the end of the year. The Danish company FLADDER International will operate the plant in the field test, which will soon be initiated.

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Løgstør CHP plant

The community of Løgstør are producing heat from straw fired boiler, and have together with KN Industries received national funding for the two first stages of a project including building of a first generation small scale demonstration plant, and a 2000 h test run of the gasifier located at the supplier. The straw fired gasifier, using CO2 as gasification agent, has been developed by KN Industries. Before the final stage, implementation at Løgstør, is funded and initiated a successful outcome of the test run is required.

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Kibæk CHP plant

In 1996 the community of Kibæk received national funding for implementation of a steam based CHP plant. In 1998 a review of the plant design and implementation showed an advantage in choosing a 2. generation of the Volund Harboøre gasifier, fired with wood chips (50% moisture) instead of the steam cycle. The gasifier is designed to have an installed capacity of 3 MWel (31%) and 6 MJ/sheat. The total efficiency is expected to reach 92%. Contractual negotiations with two diffret company are still ongoing.

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Skive CHP plant

I/S Skive Fjernvarme (District heating company in Skive town) has received European, US and national funding for a project aiming at the installation of a new biomass fired gasification plant producing gas for 3 biofuel modified gas engines, build in connection with an existing biomass boiler plant. The plant is a fluidized bed gasification plant (Carbona) utilizing palletised biofuels, the plant will have an installed capacity of around 20 MW base load and 28 MW extended load.

The local authority and the City Council of Skive has both approved the project and adopted the main part of the necessary permits, allowing the project to move into the construction phase. Engineering work on the plant building and the district heating system is nearly completed.

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Gjøl

Gjøl Private Kraftvarmeværk (District heating company in Gjøl) has received National and European funding for the establishment of a wood chip fired gasification unit, in order to be able to produce gasification gas for two existing natural gas fired Jänbacher engines, which will be modified to accommodate the gasification gas. The plant delivers heat for 300 housings, the annual heat sale is 5500 MWh and the electrical sale is 5,900 MWh. TK Energi A/S will deliver the gasifier, based on an open core gasifier and a patented wood chip dryer and dry gas

cleaning technology. All necessary approval has been obtained from the local authorities for the project to move into the construction phase. The construction of the building and the installation of the grab crane system and the biomass boiler will commence shortly. The consortium consists of Gjøl, TK Energi, FORCE Technology and European partners.

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Græsted

Græsted Fjernvarme (Græsted district heating) is hosting the BioSynergi demonstration CHP pilot plant. . The activities are performed in the ongoing project: *Optimizing and automatically operation of an Open Core gasifier pilot plant for combined heat and power with wood chips as fuel,* funded by the Danish Energy Authority

The aim is to demonstrate and optimize a staged Open Core gasifier fuelled with forest wood chips (45-50 % moisture on wet basis), as a part of a CHP plant.

The electrical output from the pilot plant is designed to 90 kWel and the thermal heat output to 200 kJ/s. The plant includes all components from wood chip storage and drying to output of energy in the manner of electricity for the electric distribution network and heat for delivery to the private district heating plant in the town of Græsted.

The completion of the plant and supply lines to the heat and electricity networks was finished in 2003. First half of 2004 was dedicated tests of the individual components and minor improvements of the plant design, leading to the ongoing long-term test period. Unmanned operation will be implemented as soon the safety procedures are tested with satisfying result. The long-term test period is settled to 3000 operation hours.

The future goal is to up-scale the CHP plant to 250-1.000 kW electrical output.

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Weiss A/S

A 200 kWe pilot plant of the two-stage gasification process is being established at the factory of Weiss A/S. In the two-stage gasification process, the pyrolysis and the gasification process are separated into two different zones. In between the pyrolysis and the gasification zones, the volatiles from the pyrolysis are partially oxidised. Hereby, most of the tars are decomposed into gas. To enable high energy efficiency, the thermal energy in the gasification gas and the exhaust gas is being used for drying, air preheating and for pyrolysis.

The two stage gasification process has successfully demonstrated that the process offers

- Low tar content in gas (<5 mg/Nm3)
- Stable unmanned operation
- High coldgas efficiency (>95%)
- Low environmental impact (clean condensate, high carbon conversion)

The process verification and documentation has been performed in small scale, and in order to manufacture economical actractive plants the process is now being upscaled. The two-stage gasification process is modified, so the drying is separated from the pyrolysis unit. The drying agent is steam and produced steam from the dryer is lead to the pyrolysis-gasification reactor, and hereby soot production is reduced and char reactivity is increased. scale

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Gasification Survey Country: **Finland**

By: Esa Kurkela and Pekka Simell
Date: 18.09.2002

1. Policy

Finland is first among the states of the industrialised world in the use of biomass
- 19 % of primary energy production based on wood fuels in 1998
- 10 % of power production based on wood fuels in 1998

Energy strategy from 1997

Power production
- taxes based on consumption of electricity
- wood fuels supported by 25 FIM/MWh (4.2 Euros/MWh)

Heat production
- taxes based partly on CO_2 emissions
- no taxes if wood fuels or REF used

Action Plan for Renewable Energy Sources 1999, targets

By 2010 growth of 50 % (3 Mtoe) from the level in 1995
- nearly totally from biomass
- 27 % of the total energy

By 2025 growth of 100 % (6 Mtoe) from the level in 1995
- biomass further dominating
- share of wind energy increasing
- 35 % of the total energy

2. Programs

National programs:
- PROGAS 1997 - 2001, basics of biomass/REF gasification 2002-2004
- WASTE TO REF & ENERGY AND MATERIAL 1998 - 2003, www.vtt.fi/virtual/waste/indexe.htm
- WOOD ENERGY 1999 - 2003, www.tekes.fi

EU 5th Framework

3. Institutes

- ***VTT Energy***; PO Box 1601; FIN-02044 VTT; internet: www.vtt.fi
- ***Foster Wheeler Energia***, Karhula R&D Centre; PO Box 66; FIN-48601 KARHULA

4. Industries

Foster Wheeler Energia Oy; PO Box 66; FIN-48601 KARHULA, fwenergy@fwc.com
- CFB and BFB gasifiers (atmospheric-pressure and pressurised)

Carbona Oy; Kaupintie 11; FIN-00440 HELSINKI, carbona@carbona.fi
- U-gas gasifier, low-pressure bubbling fluidised-bed gasifier

Condens Oy; Talkkunapolku 6; FIN-13100 HÄMEENLINNA, ilkka.haavisto@condens.fi
- heat recovery systems, updraft gasifiers

Entimos OY, FIN-95300 TERVOLA, saares@dlc.fi
- fixed bed gasifier

Ekogastek Oy, Laserkatu 6, FIN-53850 LAPPEENRANTA, ekogastek@kareltek.fi
- waste gasifier

5. Projects

R&D Projects at VTT

- CFB gasification of waste-derived fuels
- Fixed-bed gasification of wood residues and waste-derived fuels
- Development of selective catalytic oxidation (SCO) technology
- Scrubbing of gasification gas
- Participation in EU Tar Protocol project
- Synthesis gas production for liquid biofuels

6. Implementations

Lahti Kymijärvi Plant

In 1997 and 1998, the Lahden Lämpövoima Oy, has installed a 60 MWth capacity atmospheric pressure Foster Wheeler CFB biomass gasifier, at a cost of approximately US$ 15 million at its 200 MWe fossil fuel fired power station. 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 approx. 830-850°C to 700°C before it is transported in a pipeline to the boiler. The raw gas 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 vol%) is given below:

CO_2	12.9	N_2	40.2
CO	4.6	H_2O	33.0
H_2	5.9	C_xH_y	3.4

The heating value of the LCV gas is approximately 2.0-2.5 MJ/m^3n. The NOx emissions were reduced by 5% (permitted level is 230 mg/MJ for both NOx and SO_2) and the dust emission 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 from the gasifier, 69% Coal, 15% Natural gas to boiler, and 5%

Natural gas to gas turbine. The plant supplies 200 MWe power to the national grid (110 kV line round the town) and 250 MWth heat to the town (100,000 inhabitants) and surrounding houses (main pipe 700 mm). The district heat system was constructed in 1958.
The 200 MWe power plant was initially built in 1976 for using fuel oil. In 1982 the plant was converted to coal at a cost of approximately FIM 180 million (US$ 34 million) and the pay-back was only 3 years. In 1986 the burners in the boiler were converted to natural gas and a natural gas turbine cycle was added to the power station. The biomass gasification plant was installed primarily to use locally available fuels and waste materials including plastics. The annual average total efficiency is ~80%, the fuel to power efficiency with gas turbine in operation is 35%. The gas turbine has increased the efficiency by 4 % points.

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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, wherefrom it flows downwards through drying, pyrolysis, gasification and combustion zones. The residual ash is discharged from the bottom by the rotating grate. The temperature of the combustion zone is regulated by humidifying gasification air. Air and steam are fed as the gasification media through the grate. Since updraft gasification produces a raw gas with significant amount of tar, the gas cannot be either transported long distances or directly used in IC engines. In the existing BIONEER plants the gas is burnt in a close coupled boiler to generate steam and hot-water for district heating. During the mid 80's, VTT and BIONEER conducted extensive tests with a variety of feed stocks (ex. Wood chips, forest wastes, peat, straw, RDF pellets, and coal and RDF mixed with wood chips) in a 1.5 MWth pilot plant located at BIONEER's Hämeenlina works. A typical gas composition with 41% moisture content wood chips consists of 30% CO, 11% H2, 3% CH4, 7% CO2, and 49% N2, with a HHV of 6.2 MJ/m^3n. The tar content of dry product gas is estimated to be in the range of 50 to 100 g/m^3n. Between 1985 and 1986, when fuel oil prices were high, eight commercial BIONEER plants, with capacities ranging from 4 to 5 MWth, were commissioned, five in Finland and three in Sweden. Four plants are operated with wood or wood and peat mixtures while the rest are operated with peat only. Most of the gasifiers are in operation at small district heating plants to provide circulating hot water. The BIONEER plants are completely automated and operated with minimal personnel costs. A. Ahlstrom corporation bought the BIONEER company originally owned by YIT Corporation. After Foster Wheeler acquired Ahlstrom, in 1996 a 6.4 MWth plant was installed at Ilomantsi, in eastern Finland. The estimated investment cost for district heating applications is about 350 kECU/MWth, operating cost is about 17 ECU/MWh, and heat generation cost is about 20 ECU/kWh.

Wisa Forest Pyroflow Gasifier

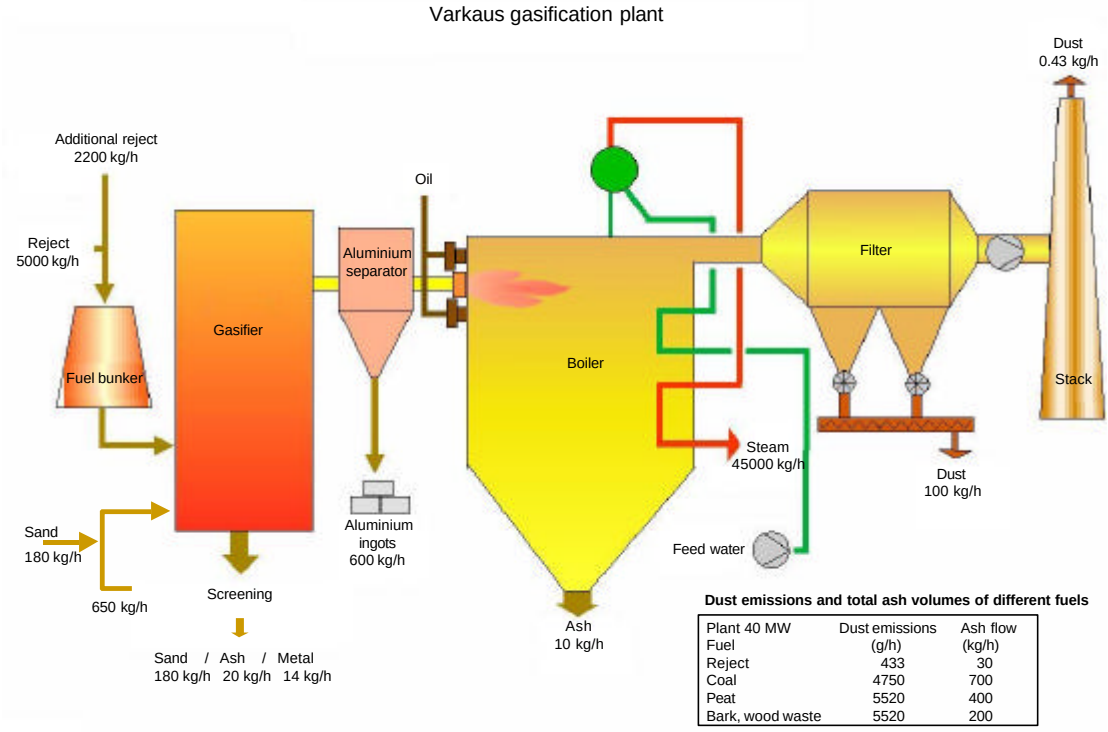
Description: In 1981, A. Ahlstrom developed the first 3 MWth capacity pilot CFB gasifier from its successful CFB pyroflow combustion technology at the Hans Ahlstrom Laboratory at Karhula. The first commercial Ahlstrom Pyroflow CFB gasifier was commissioned in 1983 at the present Wisa Forest Pulp and Paper Mill in Pietarsaari, Finland. The fuel for the 35 MWth (about 150 TPD of biomass) gasifier is primarily bark and saw dust, 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 with in a few months from start up. Between 1985 and 1986, three more gasifiers, two in Sweden (25 MWth at Norrsundet Bruks, AB, Norrsundet and 27 MWth at ASSI, Karlsborg

Bruk, Karlsborg) and one in Portugal (15 MWth at Portucel, Rodao Mill), were built and commissioned for firing lime kilns.

Contact: Foster Wheeler Energia Oy, Helsinki Office, P.O. Box 45, FIN-00441 Helsinki, Sentnerikuja 2, Ph: +358-10-39311, Fax: +358-10-393-6199, E-Mail: fwenergy@fwc.com

Varkaus gasification plant

Corenso United Oy Ltd. has built a gasification plant for energy production and aluminium recovery at its coreboard mill in Varkaus. The plant supplied by Foster Wheeler enables the complete exploitation of used packages containing wood fibre, plastic, and aluminium. It is the first plant in the world able to recycle the aluminium in used liquid packaging to create a raw material for foil for its original purpose, while simultaneously exploiting the plastic contained in the packages to produce energy.



Dust emissions and total ash volumes of different fuels

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

In Corenso's new gasification plant, the fibre material in multi-layer packages is recycled in coreboard, the aluminium being recycled as raw material for foil. The remaining plastic is gasified to create energy. The metal and packaging bands in the loads of collected raw material are sent to the metal industry for recycling. Thus, everything is recovered.

The cost of the new plant being built was around EUR 17 million. Finland's Ministry of Trade and Industry has allocated about EUR 3 million to the project. The investment includes the gasifier, an aluminium recovery unit and a new boiler designed specially for gasification gas.

The gasification plant generates about 40 MW of heat, with an estimated annual total energy production in the region of 165 GWh. An additional benefit will be the resulting improvement in air quality. The plant was taken into commercial operation in autumn 2001 and has since then operated with high availability (monthly gasifier availabilities > 90-95 %).

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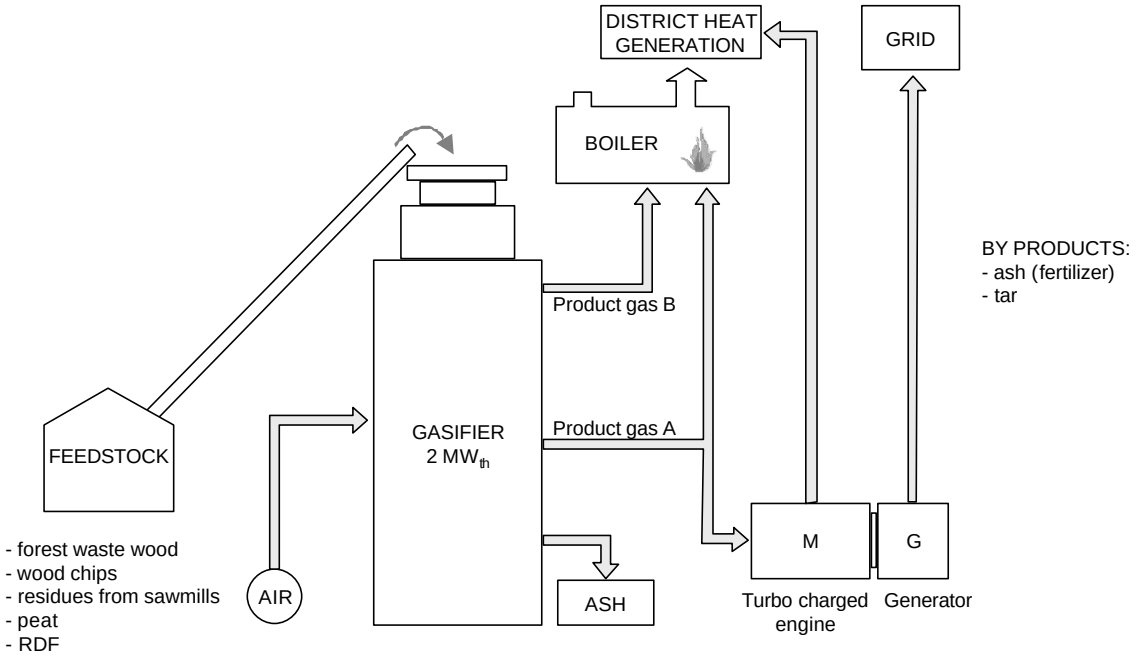
ENTIMOS gasifier

Entimos Oy (established in 1997) has constructed a new type of gasifier and a CHP plant in Tervola, which is community of ca. 2000 inhabitants in Lappland. The gasifier combines features from both updraft and downdraft gasifiers and is based on innovations partly originating from the times of the WWII. The special feature of this gasifier is two product gas lines: Gas B that is directly combusted and clean gas A, which is utilised in an engine.



The main features of the process are:
- combined updraft and downdraft gasification
- innovative feeding, grate and ash removal systems
- adjustable in large range: 20 - 100% of nominal capacity

The gasifier and the district heating system has been in operation producing district heat to the Tervola centre, while the gas cleaning and engine use is under commissioning phase in autumn 2002. The gasifier has fuel capacity of 2 MW and it is connected to a boiler and an Jenbacher engine. The plant will generate 1.1 MW of heat and power about 450 kW which corresponds about 90 % of the district heat and 10 % of the power capacity required by the Tervola community. Local feedstocks will be used, like various residues from sawmills and forest waste wood.

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Puhdas Energia Oy

Puhdas Energia Oy located in Tampere Finland is developing a small scale CHP process based on downdraft gasification. The objective of this project is to develop a commercial unit available in capacity range 100 - 3000 kWth for farms, greenhouses and communal CHP stations. The project has focused on the R&D of the gasifier and automation of the process.

The main features of the process are:
- new design of the gasifier internals
- stable operation with pellets and other good quality fuels
- simple construction and low investment costs

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e-mail: sampo.tukiainen@tut.fi, tel. +358-41- 593 265

Ekogastek waste gasification process

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

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NOVEL gasifier

VTT Energy and Condens Oy have developed a new type of fixed-bed gasifier, which is based on forced fuel flow and consequently allows the use of low-bulk-density (of the order of 150 - 200 kg/m^3) fibrous biomass residues. Presently a pilot-scale process is installed in the test hall of VTT with a nominal design capacity of 500 $kW_{th.}$ This plant is of the same quality as commercial gasifiers and can be directly scaled up to the first demonstration plant. Condens Oy is offering the Novel-technology both for heat alone and combined power and heat applications. The gas cleaning train based on VTT's catalytic gas cleaning know how followed by special wet scrubbing has been demonstrated in the pilot plant and is efficient enough to allow the use of gas in turbo-charged gas engines.

The main features of the process are:
- fuel feeding is not based on natural gravity alone
- suitable for various biomass residues and waste-derived-fuels
- high carbon conversion and low tar content
- can be scaled up to 8 MW
- no problems with leaking feeding systems or blocking gas lines
- demonstrated at pilot scale with
    - forest wood residue chips
    - sawdust and wood shavings
    - crushed bark
    - demolition wood
    - residues from plywood industry

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Gasification Survey Country: **France**

By: Laurent Van de steene, Philippe Girard, Cirad-Forêt.
Date: September 2002

1. Policies

No coherent and global policy can be assessed concerning biomass in France as far as energy policy is concerned. A succession of positive and negative measures has been taken in the last few years: for example, taxation of the fuelwood on one side, reduction in tax for liquid biofuels on the other side.
In the early 80s, after the petroleum crisis, an energy policy in favour of energy savings and renewable energies has allowed launching consistent Research and Development programmes. They covered all aspects of the biomass production and conversion into energy. Agricultural policy considerations remain henceforth the driving forces to develop biomass energy.

Energy policy
Centralised and powerful structures such as EDF, the French Electricity Board or the CEA, the Nuclear Power Committee, and their influence on the policy making process are the main characteristic of the French energy policy. The priority which has been given to the nuclear industry, and then its success, has been detrimental for the development of the entire renewable energy sector and particularly for the electricity production as well as for the auto-production through cogeneration projects.
Since 1993, the signature of an agreement between EDF and the ADEME to develop the Demand Side Management for the electricity sector in rural or remote areas has slightly changed the renewable energy scene. Pilot programmes are now launched together with local electrical grid authorities to promote electricity savings and the use of renewable energies for remote places not connected to the national grid.
But ministerial order fixing purchase price for electricity from biomass in France has been published in the beginning of May 2002. The price is 4,9 ceuros/kWhe (comparing to 15,25 ceuros/kWhe for solar and 8,38 for wind energy) with a premium according to efficiency (1,2 ceuros/kWhe in the best case for a global efficiency higher than 70 %). This price is clearly insufficient and does not encourage project elaboration on electricity production from biomass until 2010.

Agricultural policy
A side effect of the agricultural policy benefits to the wood energy sector. The "Levy Report" drawn up in 1993 at the Prime Minister request was at the origin of the creation of AGRICE (AGRIculture for Chemistry and Energy) a new and specific Agency dedicated to the development of agricultural products for non-food uses. The report also highlights the interest of solid biofuels for energy production compared to liquid biofuels.
In 1994, the Ministry of Industry together with the Ministry of Agriculture and ADEME have decided to launch a specific programme: the "Plan bois Energie et Collectivités locales" ("wood for Energy and Local Authorities programme") which aims to promote the use of wood in collective housing and tertiary sector. Since 1999, the boost of energy control policy, thanks to the PNAEE (National Programme of Improvement of the Energy Effectiveness) has allowed negotiating a new and more ambitious program for the period 2000-2006: Program "Wood-

Energy". This program continues the development of urban and industrial wood boilers, and also encourages the modernisation of the conditions of use of wood-energy on the domestic heating market.

Other policies
Environmental policy is up to now a very weak booster for biomass even if the development of the biomass use for energy needs is one of the 5 measures promoted by the International Energy Agency to reach the objectives of the Rio Agreement. Moreover, in 2000, government has ratified the PNLCC program (National Program of Fight against Climatic Change) which identifies about a hundred actions so that France will comply with the commitments taken in the Kyoto protocol by stabilising its greenhouse gas emissions in 2010 at the same level than in 1990.

1. Programs

The funding for R&D programmes comes from 3 resources:

- Public research bodies such as INRA (National Institute for Agronomic Research), CNRS (National Centre for Scientific Research), CEMAGREF (Technical Centre for Rural Engineering and Forestry), …
- Special taxes collected by IFP (French Petroleum Institute) and ANDA (National Association for Agricultural Development),
- ADEME's budget (the Agency for Environment and Energy Management). Through AGRICE, which is hosted by ADEME, the Agency co-ordinates and manages the French Biomass Programmes.

AGRICE is a Scientific Interest Group, originally created for 6 years (1994-1999) by Public Authorities to emphasise and to give consistency to the whole research on biomass. It gathered the different public entities involved in this sector as well as research organisations (INRA, IFP) or private companies (Total, Rhone-Poulenc) and farmers associations. In 1999, Ministries of Agriculture, Environment and Industry have decided to renew this group for another 6 years period. It organises yearly calls for research proposals with an annual budget of 10 M€. 6 M€ comes from the public sector, the remaining 4 M€ comes from companies, laboratories and farmers organisations. Between 1994 and 2000, AGRICE has supported financially more than 300 research projects for a total cost of approximately 80 M€; but few heat and power production projects has been supported.

Research and Development programmes are mainly focused on liquid biofuels and especially on vegetable oils and methyl ester including the production of electricity. Some experiments on short rotation forestry are carried out. Research activities on biogas, ethanol and methanol production are stopped.

There is no specific and structured research programme on solid biofuels but some R & D activities are currently supported and especially on:
- the production of the resources (residual wood, short rotation coppices and lignocellulosic plants),
- the optimisation of the combustion technologies,
- the qualification of domestic wood heating equipment
- and punctually some activities on pyrolysis and gasification.

The objectives for current solid biofuels R&D programmes are the following:

- to maintain the share of fuelwood in the domestic heating sector. If the consumption of wood for domestic heating is now evaluated to 8 Millions of Toe, its evolution in the near future is uncertain. The very small budget available in the sector is used for studies and the follow-up of users behaviour
- to follow-up the development of wood heating plants in collective housing and tertiary sector by :
  - the optimisation of wood harvesting technologies,
  - the production of new lignocellulosic plantations,
  - a better knowledge of the use of scrap wood waste and packaging waste as fuel.

The **CNRS** (National Scientific Research Centre) has launched in 2002 its Energy program 2002-2006.
Objectives of this program are:

- to increase the contribution of EnR and of the technologies, in addition or substitution of fossil energies, in the production of heat, in fuels for transport and for electricity,
- to improve processes performance as regards energy efficiency and pollutants reduction.

This program focuses on the following topics:

- New resources;
- Energy control;
- Process and environment;
- Socio-economy.

In this framework, biomass problematic takes part in the first topic. This call for proposal will allow the start up of a national network and a working program in the biomass domain.

2. Institutes

CEA:
The French Atomic Energy Commission (CEA) launched an R&D programme on biomass gasification two years ago, to develop a process that generate syngas from various biomass resources, to produce fuels or hydrogen with the required purity for direct industrial use. During the first stage of the programme, a process analysis has been performed in collaboration with IFP. The second stage of the programme, in progress, consists of modelling tasks (understanding of limitation processes) and preliminary experiments with laboratory pilots (~5 kW), defined according to the previously selected processes and focused on the remaining process difficulties to be solved. This overall approach allows to integrate the existing knowledge, to define which processes and conditions fit in the best way our requirements and to better understand the physics of the different phenomena involved in the biomass gasification. The third stage of this programme is devoted to the design of a "technological developing platform" (~500 kW), in collaboration with some European industrial and academic partners.
Contact persons: Jean marie SEILER (seiler@drngre.cea.fr), Gérard CLAUDET (claudet@drngre.cea.fr), Guillaume BOISSONNET (boissonnetg@drngre.cea.fr).

CIRAD:
CIRAD was created in 1984 by merging of research institutes specialized in agriculture, veterinary medicine, forestry and food technology. The main research programmes at LB2E, the

Cirad-Forêt Biomass, Energy and Environment Laboratory, concern the study of biomass thermochemical conversion process for the development of environment-friendly and effective technologies. LB2E specializes in the different agricultural and forest by-product thermochemical conversion processes, and is involved in developing innovative technologies meeting the environmental and energy requirements of both developing and industrialized countries, through numerous national and international projects. In gasification field, Cirad has been involved in 2 important European projects (see § 5-1) concerning staged gasification and gasification tars treatment.
Contact persons: Laurent VAN DE STEENE (steene@cirad.fr), Philippe GIRARD (philipe.girard@cirad.fr)

EDF:
The French National Company for Electricity Generation and Distribution had a multi-annual action under way to assess the various technologies using biomass for electricity or combined heat and electricity generation through technological monitoring, laboratory experiments and numerical modelling for simulation. It concerns mainly combustion systems and small size gasification systems for decentralised power production.
Contact person: Guillaume BOURTOURAULT(guillaume.bourtourault@edf.fr), Philippe LUTZ (philippe.lutz@der.edfgdf.fr).

IFP:
The Institut Français du Pétrole (IFP) is an independent research and industrial development, training, and information center, active in the fields of oil, natural gas, the automobile and energy. Its activities cover all aspects of oil and gas industry: exploration, production, refining, petrochemicals, engines, energy and the use
of petroleum products. IFP's calling is to develop the technologies that will allow sustainable growth of the oil, gas, automotive and energy industries and preserve the environment. IFP is also active in the field of biomass processing technologies to produce chemicals or energy. The research program is divided in three main parts: biofuels production (biodiesel, ethanol, syngas processing, liquefaction, chemical conversion), the production of hydrogen or of synthesis gas from liquid hydrocarbons or biomass, and energy production from wastes (pyrolysis and gasification).
Contact person: Eric MARTY (eric.marty@ifp.fr).

→ But also, some public laboratories are conducting research activities in biomass gasification:

EMAC ("Ecole des Mines d'Albi Carmaux", UMR CNRS 2392) :
The "Centre Energétique-Environnement" of EMAC has developed a number of experimental and modelling facilities in order to characterise the thermochemical behaviour of solid fuels from various origins (biomass, coal, petroleum coke). The reactions studied are the pyrolysis (or devolatilisation), the oxydation of chars, and their gasification. The temperature and atmosphere conditions can be those encountered in large scale fixed bed reactors, in fluidised beds or in flash reactors.
Contact person: Sylvain SALVADOR (salvador@enstimac.fr)

LGC
The Laboratory of Chemical Engineering of Toulouse (LGCT) has a recognized competence in the fluidized bed processes. In the field of gasification, the main objectives have been the transformation of biomass, fossil combustible or sewage to a gas, rich in hydrogen, suitable for

chemical synthesis (rich in CO and H_2) or combustible(rich in CH_4). The studies are devoted to:

- pyrolysis and gasification of sawdust in a fluidized bed of sand particles between 600 to 950 °C (1PhD Thesis),
- steam gasification of sawdust in a fluidized bed containing catalytic or inert particles (1PhD Thesis),
- steam gasification in the presence or not of oxygen of coal in a continuous fluidized bed (3 PhD Thesis),
- gasification and combustion of humid sewage in fluidized bed (2 PhD Thesis),
- experimental evaluation and modeling of a catalytic fluidized bed reactor for methanation of sulphurized carbon monoxide and hydrogen mixtures,
- Catalytic steam reforming of a gas rich in CH_4 in fluidized bed.

These studies have shown the predominant effect of biomass particles heating rate, gas residence time and nature of fluidized medium on the gas product quality. The use of an adequate supported catalysis as fluidized medium can orientated the gas product to a mixture rich in H_2 or to a synthesis gas.
Contact persons: Mehrdji. HEMATI (Mehrdji.Hemati@ensiacet.fr),
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LGPC

The Laboratoire de Génie des Procédés Catalytiques (LGPC) of Lyon carries out researches on catalytic chemical engineering (catalyst and/or reactor design) in environmental, energy and molecular chemistry areas. One of our applied researches concerns catalytic cracking of heavy components of petroleum cuts. Those components being close in terms of chemical structure and nature to those contained in tars from Biomass gasification, our knowledge in catalyst chemical engineering can be applied to this area.
Contact persons: Daniel SCHWEICH (daniel.schweich@lgpc.cpe.fr),
Isabelle PITAULT (isabelle.pitault@lgpc.cpe.fr)

LSGC

The «Laboratoire des Sciences du Génie Chimique» of Nancy is an independent unit of the CNRS, the French Science Foundation and part of its Engineering Science Department. It is organised in 5 research groups. One of them (Chemical Reaction Engineering) includes a specific team working since about 20 years on the thermal upgrading of biomass (pyrolysis and gasification).
The team is involved in three projects (experiments and modelling) of gasification performed via the fast pyrolysis of biomass: 1) Study of the multifunctional properties of the cyclone reactor (simultaneous heating and reaction of biomass, separation of charcoal and quenching of the fluid products). Up to 80 % gasification yields can be reached. The gas heating value is 3 times higher than in usual air gasification. Contract between CNRS and ADEME (research support and PhD thesis); 2) Elucidation of the thermal cracking of the condensable vapours formed during biomass pyrolysis in order to enhance the gasification yield and improve gas qualities. Contract between ADEME and IFP (research support and PhD thesis); 3) Study of the fundamental processes involved in the thermal decomposition of biomass submitted to a concentrated radiation. The experiments performed with cellulose and now with lignin reveal the formation of gases containing up to 90 % of H2 and CO.
Contact person: Jacques LEDE (Jacques.Lede@ensic.inpl-nancy.fr)

UTC:

The research activities of the laboratory Génie des Procédés Industriels (LGPI) (UMR CNRS 6067) of the University of Technology of Compiègne (UTC, France), headed by Professor G. ANTONINI, is oriented towards problems related to energy conversion and thermal treatment of solid wastes.
The expertise of the team concerns high temperature systems (combustion, pyrolysis, gasification). The objective of these activities is the development of innovative technologies and the acquisition of new scientific competencies in relation with associated equipment and metrologies.
In that field, the LGPI has developed a new process for solid thermal treatment by pyrolysis, using a vibro-fluidised bed thermal reactor. The new developments of the team concern essentially steam gasification of char at high temperature, in relation with tar cracking and downstream gas treatment.
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Ammar BENSAKHRIA (ammar.bensakhria@utc.fr)

Owing to CNRS' program (National Scientific Research Centre), National Networks and Integrated Projects have been proposed and should start before the end of 2002.

3. Industries

The only significant gasifiers constructor (for trade purpose) in France is Touillet/Martezo. Touillet Establishment, Mercedes concessionaire at Poitiers, has been developing for forty years a gasifier, under the denomination of Martezo. It is a co-current fixed-bed with a section restriction at the bottom gasification zone. Various set-ups are proposed from 70 to 450 kW but tests carried out on a 450 kW unit have never been validated.
Various raw materials have been tested. However, wood chips constitute the recommended and most used fuel. In any case, raw material must be dried and packaged to respect the following criteria:

- moisture lower than 20 %
- size of 4-10cm
- ash content lower than 10% of the dry weight

Touillet/Martezo sent about ten gasifiers (downdraft type). In particular, two of them operated for electricity production and gave relatively good results:

- Raud Company (Wood company), Cavignac, France: 100 kW_{el}, 15000 working hours, Start up : 1983
- Briolet Establishment (Wood furniture constructor), Montlieu la Garde, France: 200 kW_{el}, 7000 working hours, Start up: 1987

4. Projects

Present

Two R&D programmes have just been completed on gasification, both being supported partly by the European Union with Cirad as co-ordinator.
Clean biomass staged gasifier based on a new tar cracking and ash slagging techniques for efficient CHP generation (Ref. JOR3-CT98-0220)

The approach developed consists in:

- Introducing a new device called Total Char Combustion and Tar Cracking Chamber $(TCC)^2$ between the pyrolysis unit and the char reduction chamber in a stage divided gasifier. With this design, the char conversion takes place in 2 stages. The first stage is the char reduction Chamber (CRC) whose main purpose is to convert as much as possible carbon of the char supplied directly from the pyrolysis unit into gas by means of reduction reactions. The second stage takes place in the $(TCC)^2$ whose purpose, with respect to the char, is to perform a complete conversion of the remaining carbon from the CRC drain off and where pyrolysis gases are thermally cracked and residual ashes vitrified and eliminated as slag.
- Designing and implementing a new vibrated fluidisation pyrolysis unit able to achieve an appropriate and constant quality of char with minimum preparation of biofuel with a good phase separation.
- Offering the opportunity to orientate the process for gas and solid reactions according to plant requirement and market conditions.
-

For all industrial partners, scopes were:
1. to eliminate the present and costly tar cleaning set up,
2. to increase the process efficiency with a carbon content in ashes close to zero,
3. to obtain a cleaner gasification process,
4. to eliminate operational problems arising from a low melting point of biomass ashes, owing to the vitrification process.

This project has involved 8 partners: CIRAD as co-ordinator, TKE, GRADIENT/UTC, PROCEDIS (FR), EDF (FR), ITC(FR), TUT (FIN), Planmiljo (DK)

Biomass gasification for CHP with dry gas cleaning and regenerative heat recovery (Ref. Erk-CT1999-00003):
The objective of the project was to develop, integrate and prove a complete biomass gasification combined heat and power small scale prototype plant. The innovative idea of the project is a newly developed dry gas cleaning and heat recovery system, which integrates all other plant components in a linked system. The dry gas cleaning concept, i.e. no waste water, intends to solve and eliminate the tar problems associated with the operation of biomass gasifiers. The ultimate objective is therefore to create a new generation of energy efficient and environmentally friendly gasification systems. The most essential part of the process is the gas cleaning. The gas cleaning includes a high temperature dust separation at the gasifier outlet followed by a special regenerating counter-current tar condensing heat-exchanger, which is operated alternately in two phases. Change of phase concerns change of flow direction as well as flow side. The hot gas is cooled by two separate streams of air. Regeneration has the effect of decomposing the tar deposits at high temperatures and returning the cracked tar products into the gasifier by means of preheated gasification air. The cooling air for feedstock drying is

uncontaminated with cracked tar products. The produced gas is cooled at 10-20 ^{o}C above the dewpoint, and thus no waste water is generated.
The project has concerned three partners: CIRAD as co-ordinator, TKE and DK-Teknik (DK).

Others French organisations have been involved as partners in European projects, in particular:
- EDF (Electricité de France): Ref. NNE5/506/1999. Title: HTW Gasification for the 400 Mwe IGCC Power Plant at Vresova C, R - A first CCT - Step towards Eastern Europe
- Laboratoire d'Etude de la réactivité catalytique des surfaces et interfaces (Strasbourg): Ref. ENK5-2000-00314. Title: Biomass-Gasification and Fuel-Cell coupling via high-temperature gas clean-up for decentralised electricity generation with improved efficiency.

Past (1979-1985)

The different public funded projects to work in this field have opened up research on gasification to a considerable extent, with experimentation aiming to cover the widest possible scope:
- comprehensive testing of all possible applications for gas producing techniques, i.e. driving power, electricity, heat, chemical base products, etc..
- testing the maximum number of reactor configurations to solve problems in the transfer of materials (fixed-, fluidised-, and moving-bed designs), and problems concerning gas quality and specifications (charcoal gasification, internal or external recycling of gases, double fluidised-bed, reforming of gases),
- testing a wide range of possible fuels (wood, charcoal, agricultural waste of various origins and with different particles sizes).

These projects, involving original gasifier designs, led to the experimentation on pilot industrial plant or on full-scale prototypes:
Power or electricity generation
- suspension-bed gasifier for gas production from powdery agricultural waste (CEMAGREF, Pillard),
- external recycling gasifier (Delacotte type, developed by Entropie),
- internal recycling gasifier (Cemagref process),
- downdraft gasifier (Pillard, Alsthom, Genetrans, Chevet, Touillet),
- charcoal gasifier (Cemagref).

Heat production
- fluidised-bed gasifier (Framatome/Creusot Energie),
- circulating double fluidised-bed pyrolyser (TNEE).

Results for the majority of these installations weren't successfully.

5. Implementation

As far as we know, there is no demonstration project actually carrying out in France.

Gasification Survey Country: **GERMANY**

By: Eberhard Oettel
Date: June 2004

1. POLICIES

Since the beginning of the Rio-Process more and more short-, medium and long term national aims for minimizing green-house gases and soil contaminants, for lessening the overwhelming dependence from oil and gas resources in conflictive international regions, for taking care of energy supply in times before the exploitation of oil, gas und uranium becomes critical have been elaborated by the Bundestag (Federal Parliament) und the Federal Government. This process was facilitated by the European Union (f.i. "White Paper Energy for the Future: Renewable Sources of Energy", "Green Paper Towards a European strategy for the security of energy supply" and relevant guidelines on renewable energy, biofuel etc.), the Kyoto- and Johannesburg-Processes and activities of non-governmental organisations. The founding of the International Partnership for a Hydrogen Economy and the European Hydrogen and Fuel Technology Platform stipulated gasification for a hydrogen rich gas. Since the last report GasNet / IEA-Report on Gasification in September 2002 the need for a higher velocity has been increased by the Iraq war, soaring fuel demand in the USA and the dramatic growth of energy and fuel demand in China, leading to a possibly irreversible in the long run price increase of oil on the world market.
In EU-Europe the total mineral oil based fueI demand should be substituted by bio or new fuels to 2 % in 2005 and 5,75 % in 2010. In Germany by 2005 carbondioxid-emissions should be decreased by 25 % in comparison to 1990, in 2010 the power supply by renewable sources should be doubled to 12 %. Only recently the Federal Government published the Environmental Report setting the target for the end energy supply from renewables to 50 % by 2050.
Based on these aims first steps were gone to elaborate a strategy for the application of renewable energy as first moves for creating reliable conditions for long-term investments. The most important single step had been to establish a legal basis. This is characterized by guaranteed feeding into the grid, long-term fixed prices for every kilowatt per hour electrical power produced from renewable energy sources to be paid for by the consumers. Electricity from in the years to come new built plants is remunerated at periodically descending prices. Further steps were the uniform definition of "allowed" biomass, legislation on biofuel (tax free), co-generation, economizing energy, taxation (previously announced periodically elevation of taxes on power consumption).
In Germany renewable energy has boomed since 2000, as the "Act on Granting Priority to Renewable Energy Resources" was implemented. While German economy is stagnating with a growth rate of less than 1 %, the application of renewable energy resources was soaring between 2000 and 2002. The growth rate of bioenergy has been climbing to estimated 40 % from July 2001 to the end of 2002. The waste wood market was exhausted in as short as two years to fuel newly built wood combustion power plants. But because of the since April 2002 ongoing amending of this Act, thus creating once again insecurity for investment, the speed of bioenergy use slowed down substantially. New regulations envisioned in the New Act might give a renewed push to the energetic use of biomass, including gasification. For the first time a

bonus for new technologies, as thermal gasification, microturbines, Organic Rankine Process, stirling engines will be introduced.
As in 2005 landfilling of organic waste will be prohibited the search for suitable technologies to make use of this secondary raw materials intensifies.
Renewable energy has matured to a new industrial branch, highly attractive to investment capital and employment. More than 30 investment funds were established. They started in wind power and are now pulling money into solar and bioenergy. 130 000 new jobs have been created since 1990. This is as much as the total labour occupied in the conventional power industry. Overall annual turnover reached more than 7.5 billion € already in 2000.
This process was accompanied by intensified search for regional bound industrial applications as alternative to globalisation.
Discussion started for the need to elaborate a national research strategy and program on minimizing the energy consumption, elevate energy efficiency and the supply from renewable sources. By the end of 2004 a strategic federal research program on energy will be elaborated.
In the last two years there had been a shift of political and financial attention in gasification from combined heat and power generation to the production of synthetic gas as basic gas for biofuels, consequently from decentralized to large plants, thus on the one hand opening the door for giant strategic projects, including combining increasing the energy density of biomass in numerous distributed CHP-bio coke or bio oil plants with a central gasification and biofuel production unit but on the other hand obstacling already achieved progress in technological development of small and medium scale.
One of the principal barriers is the difficulty of innovative small and medium enterprises (SME) to get access to finances because of the ever growing resistance of banks to deliver credits.

2. Programs

All measures that have been taken so far are not sufficient to create equal conditions between renewable on one hand and fossil and nuclear energy carriers on the other hand. Last both are highly subsidized. Costs caused by them for doing damage to climate, environment, nature, heath, cultural, industrial and other values are not internalised into the prices.
This is one of the major reasons why the use of renewable energy is not overall economically, although the amount of at least medium and long-term profitable applications is growing.
Even the Act on Granting Priority to Renewable Energy Resources facilitates up to now profitability only in rare cases, as wind generators at sites with high wind current speeds, co-digestion of biomass, biomass combustion power plants fuelled by waste wood.
To counter this disadvantage, several, very different direct and indirect subsidy programs had been started to stimulate research, development, manufacturing and application. They are characterized by divers sources (the Republic and every of 16 Bundesländer have their own regulations), different forms (credits, interests, taxes, loans, grants, guarantees etc.) and recipients (manufactures, consumers). Some are given for the investment into building a new manufacturing plant, some for technological innovations, others for installation a plant or appliance, some for minimizing emissions. These programs often change for political or budgetary reasons. These changes cause again and again critical situations for the enterprises which depend on this highly fluctuating market demand.

Some of the most important programs are

- Act on Exempting Biofuels from the Mineral Oil Tax as the most important single driver of gasification technology

- Investment Program into the Future (ZIP Zukunfts-Investitions-Programm. BMWA Federal Ministry for Economics and Labour. Subsidies for applied research into strategic high-tech solutions as synfuels by gasification of biomass and waste, fuel cells, low-consumption vehicles)
- an amended Market Stimulation Programme (MAP Marktanreizprogramm. Bundesamt für Wirtschaft und Ausfuhrkontrolle, Federal Office for Economics and Export Control. Grants for investors into solarthermal plants, biogas plants, some kind of biomass boilers etc.)
- Investment Programme for Minimizing CO_2-Emissions (KfW Kreditanstalt für Wiederaufbau. Federal Agency for Reconstruction. Credits at lower interest rates)
- Market Introduction Programme for the Material and Energetic Use of Industrial Crops (BMVEL Federal Ministry for Consumer Protection, Food and Agriculture via FNR Fachagentur Nachwachsende Rohstoffe. Applied research, introduction of innovations into the market. Grants. Used also for gasification of biomass projects), but just this budget for the year 2004 was cut short by approx. one third.
- 100-Tractors-Programme (FNR. Program for testing tractors fuelled by natural rape oil)
- Act on Co-generation (for power generated by fuel cells the operators receive a 0,05 € higher remuneration per kW/hr).

The recent legislation on emission trading is expected to push clean energy generation forward in the years to come, although to the contrary the allocation plan favours utilities operating lignite combustion plants and other operators of high-emitting plants of the heavy industry.

In the process of amending the Act on Energy Economy the possibility of feeding biogenuous gases into the gas net is discussed and might open a new application as biomethane in the future.

3. Institutes

Responsibility for research on gasification of biomass and waste is executed by four ministries, BMBF Federal Ministry for Research and Education, BMU Federal Ministry for Environment, Nature Protection and Reactor Security, BMWA Federal Ministry for Economics and Labour, as well as BMVEL Federal Ministry for Consumer Protection, Food and Agriculture.
As no energy research strategy exists there is also no coordinated and stringent program on biomass gasification. An improvement of this situation is going to be expected by elaborating a bioenergy research program as part and parcel of the strategic national energy research program by the end of 2004. Nevertheless, the level of gasification research and the scientific results are remarkably high. It is influenced by at least two factors. First, by the long scientific tradition and rich industrial experience in coal gasification (in East-Germany town gas und syngas for gasoline production were generated by gasifying lignite until the beginning of the nineties) and, secondly, by the numerous scientific institutes mainly for applied research & development, less for basic research in this field directly or indirectly related to gasification of biomass and residues. The Federal Ministry for Consumer Protection, Food and Agriculture tendered a mayor analysis on the gasification in Germany, tar formation and the need for research and development.

The research community on gasification was strengthened in the last years. Forschungszentrum Karlsruhe, one of the main German research centers, changed its principal subject from nuclear research to bioenergy, especially gasification.

New trends and results in research are, f.i.

* generation of hydrogen rich gas,
* new catalytic processes for elevating the calorific value of the producer gas and for gas cleaning,
* application of producer gas in fuel cells,
* feasibility of biomass gasification in a heatpipe reformer,
* basics of tar formation.

In preparation to this report questionnaires were sent to all known research institutes to update their data on main subjects, plants and projects.
Some of most important results are listed as follows:

* Bundesforschungsanstalt für Holz- und Forstwirtschaft, Institut für Holzchemie, Hamburg-Bergedorf, (Federal Research Agency for Wood and Forestal Economics, Institute for Wood Chemistry. (Mainly pyrolysis, new process of fast ablative pyrolysis. Involved in several EU-projects on pyrolysis and the pyrolysis phase of gasification)
* Fachhochschule Aachen NOWUM-Energy Institut (microturbine [Capestone]), jointly with G.A.S. Energietechnik GmbH, Krefeld, and Fraunhofer-UMSICHT, Oberhausen

* Forschungszentrum Karlsruhe GmbH Technik und Umwelt, ITC Institut für Technische Chemie and IKT Institut für Kernenergietechnik, Eggenstein-Leopoldshafen, (Research Center Karlsruhe GmbH Technique and Environment ITC Institute for Technical Chemistry and IKT Institute for Nuclear Technology. Basic research on straw gasification, on flash pyrolysis in combination with pressurized entrained flow gasification [two-stage bio-slurry gasification for generation of syngas], on gasification with supercritical water, mainly for the generation of synthetic gas for biofue]),

* Forschungszentrum Karlsruhe GmbH, ITAS Institut für Technikfolgenabschätzung und Systemanalyse (Research Center Karlsruhe GmbH Institute for Technology Assessment and Systems Analysis. Assessment of gasification of biomass, biogenic residues and waste for energy, on environment, impact of innovative technologies. Energy from bio residues and waste, Federal project BMVEL 91/NR219. Generation of gas from biomass, preliminary research for a 1 … 2 MW_{th} pilot plant MLR: 46(54)-8214.07)

* Fraunhofer-Institut für Fabrikbetrieb und –automatisierung, Magdeburg, (Fraunhofer-Institute for Factory Operation and Automation. Completely controlled bubbling fluidised bed gasification pilot plant with catalytic and chemical gas treatment, tar measurement, kinetic measurement [drop tower, inline probes], gas engine, stirling engine, BFBC and CFBC test rigs, gas measurement, modelling of gasification and combustion processes, CFD modelling.)

* Fraunhofer-Institut Umwelt-, Sicherheits-, Energietechnik – UMSICHT, Oberhausen, (Fraunhofer-Institute for Environmental, Safety and Energy Technology – UMSICHT. Completely controlled bubbling [500 kW_{th}] and circulating fluidised bed gasification, BFBC [100 kW_{th}] pilot plant with catalytic gas treatment, gas engine [250 kW_{th}]. Process ready for scale-up [to 5 MW_{th}, 1.5 MW_{el}] and pre-commercial demonstration, stirling engine, several fuel cells, microturbine [Turbec 100], BFBC and CFBC test rigs, gas measurement, modelling of gasification and combustion processes, CFD modelling. Technical and economical optimising the gasification of wood in a BFC-plant, Federal project BMVEL 00NR178. Hydrocracking and reforming of producer gas containing tar from biomass. Additionally moving bed gasification, biomass co-generation, tar formation, plant design)

* IE Institut für Energetik und Umwelt GmbH, Leipzig, (Institute for Energy and Environment gGmbH. Energy and material balances, technical, economical and ecological evaluation)

* ILK Institut für Luft- und Kältetechnik gGmbH, Dresden, (Institute for Air- and Cooling Technology, gas cleaning)

* IUTA Institut für Energie- und Umwelttechnik e.V., Duisburg, (Institute for Energy and Environmental Technology. Combined co- and counter-current moving bed test reactor, gas analytics, gas cleaning)

* Martin-Luther-Universität Halle/Merseburg, Institut für Agrartechnik and Fachbereich Ingenieurwissenschaften (Martin-Luther-University of Halle/Merseburg, Institute for Agricultural Technology, Faculty for Engineering Sciences. Moving bed plant with co-generation and cooling, process automation, for gasification of different biomass)

* Otto-von-Guericke-Universität Magdeburg, Institut für Apparate- und Umwelttechnik (Otto-von-Guericke-University of Magdeburg, Institute for Apparatuses and Environmental Technology. Bubbling and circulating fluidised bed, small BFB test plant, multiple biomass fuels)

* Technische Universität Bergakademie Freiberg, IEC Institut für Energieverfahrenstechnik und Chemieingenieurwesen (Technical University Mining Academy of Freiberg, Institute for Energy Technology and Chemical Engineering. Reactor modelling, entrained flow, waste and biomass, tar generation, gas cleaning, solid fuel preparation, synfuel, Gas-to-liquid test plant)

* Technische Universität Berlin, Institut für Energietechnik (Technical University of Berlin, Institute for Energy Technology. Research on reactive multi-phase flows in simulation and experiments. Turbulence chamber test reactor [20 kW_{th}], BFB [10 kW_{th}], ferrocement moving bed reactor, raman-spectroscopy. Gasification of rape straw. EU-project. Tar formation)

* Technische Universität Clausthal-Zellerfeld, Institut für Energieverfahrenstechnik und Brennstofftechnik (Technical University of Clausthal-Zellerfeld, Institute for Energy Technology and Fuel Technology)

* Technische Universität Dresden, Institut für Energietechnik and Institut für Kraftwerkstechnik (Technical University of Dresden, Institute for Energy Technology, Institute for Power Plant Technology. Moving bed, fluidized bed, gas cleaning, mathematical modelling, fuel cells, moving bed test reactor, delivered by VER GmbH)

* Technische Universität München, Lehrstuhl Thermische Kraftanlagen mit Heizkraftwerk (Technical University of Munich Chair for Thermal Power Plants with Heat and Power Plant. Fluidized bed combustion chamber for biomass 50 kW_{th}, heatpipe 200 kW_{el}, heatpipe reformer 15 kW_{th}, microturbine 30 kW_{el}. Heatpipe reforming to generate a hydrogen rich producer gas to use it in a microturbine, EU-project BioHPR NNE5-2000-181. State: Looking for partners for a demo plant. Utilization of producer gases in fuel cells, for solid oxide fuel cell in preparation. EU-project BioCellus)

* Universität Bremen, Fachbereich Produktionstechnik (University of Bremen, Faculty for Production Technology. Gas formation and gas quality in small scale moving bed gasifiers)

* Universität Dortmund, Fachbereich Chemietechnik (University of Dortmund, Faculty for Chemical Technology. Biochemical transformation of biomass to hydrogen and carbonic acids)

* Universität Hohenheim, Institut für Pflanzenproduktion und Weidelandforschung (University of Hohenheim, Institute for Crop Production and Grassland Research. Biomass Fuel)

* Universität Karlsruhe, Engler-Bunte-Institut (University of Karlsruhe, Engler-Bunte-Institute. Thermal and catalytic cracking of hydrocarbon compounds, gasification of biomass and conditioning of synthetic and pyrolysis gases for synthesis to alternative fuels. Test plants for entrained flow and fluidised bed, several test rigs for catalysts, catalytic cracker. Catalytic conversion of tars, fate of alkalines and heavy metals during thermal treatment of biomasses, rich experiences on different types of reactors and on catalysts, Fischer-Tropsch-synthesis, conversion of CO_2 into fuels. Joint Research Center "Integrated filter and gas treatment systems", Helmholtz-Gemeinschaft VH-FZ-012)

* Universität Kassel, Institut für Thermische Energietechnik (University of Kassel, Institute for Thermal Energy Technology. Pyrolysis, gasification and activation of coal and biomass. Indirectly heated rotary tube reactor [5 kW_{th}], indirectly heated moving bed reactor [< 4 kW_{th}], indirectly heated multiple tube reactor [55 kW_{th}]. Modelling and simulation of pyrolysis and gasification reactors, reaction kinetics and heat ransfer, tar conversion. Indirectly heated biomass gasifier ready for scale-up and demonstration. EU-Project)

* Universität Rostock, Institut für Energie- und Umwelttechnik (University of Rostock, Institute for Energy and Environmental Technology. Straw bale moving bed gasifier, fluidized bed for straw and other biomass, co-generation, straw moving bed gasification and stationary fluidized bed test plants)

* Universität Siegen, Lehrstuhl für Energie- und Umweltverfahrenstechnik (University of Siegen, Institute for Energy and Environmental Process Technology. Gasification of biomass, residues and waste. Integrated Pyrolysis and Gasification [IPV®]-reactor [120 kW_{th}], BFB-reactor [49 kW_{th}], electrically heated rotary tube furnace, washer, wet precipitator. Development for the IPV®-process to co-gasify biomass and dried and stabilized bio waste, joint project with Herhof-Umwelttechnik GmbH, Solms-Niederbiel, to prepare industrial application. Tar transformation, mathematical modelling of gasification,)

* Universität Stuttgart, IVD Institut für Verfahrenstechnik und Dampfkesselwesen (University of Stuttgart, Institute for Technology and Steam Vessels. Fluidized bed, tar formation and measuring, gas cleaning, process simulation),
Institut für Verfahrensengineering und Kraftwerkstechnik (Institute for Process Engineering and Power Plant Technology. Biomass fuel)

* WTZ Wissenschaftlich-Technisches Zentrum für Motoren- und Maschinenforschung Roßlau gGmbH (WTZ Scientific-Technical Center for Research on Engines and Machines. Several test sites)

Some institutes starting research on or changing mainly to gasification of biomass and bio residues during the last two years are

* CUTEC – Clausthaler Umwelttechnik Institut GmbH, Abteilung Thermische Prozesstechnik and Abteilung Chemische Prozesstechnik, Clausthal-Zellerfeld (CUTEC Clausthal Environmental Institute GmbH, Department for Thermal Engineering and Department Chemical Process Technology. Bubbling and Circulating fluidized-bed 50 kW_{th} and 400 kW_{th}, rotary tube 40 kW_{th}, advance feeding grade 300 kW_{th}, back feeding grade 900 kW_{th}, gas cleaning plant, hydrocracker, Fischer-Tropsch plant, engine test rig. Renewable fuels for advanced power trains, EU-project FP6-502705. Fluidized bed gasification for synthetic fuels ("art-fuel") from industrial crops. Project of the Ministry of Environment of Lower Saxony No.17-32344/6/0/1/12-04032-5084 (2002)

* Hamburg University on Applied Science (gas cleaning, conversion of gasification gas in fuel cells),

* Hochschule Niederrhein Fachbereich Maschinenbau und Verfahrenstechnik, Krefeld (University of Applied Sciences Lower Rhine, Branch for machinery and engineering. Thermal engineering and gas cleaning)

* Ruhr-Universität Bochum, Lehrstuhl für Energieanlagen und Energieprozesstechnik (Ruhr-University of Bochum, Chair for Energy Plants and Energy Process Technology. Traditional expertice on coal and lignite pyrolysis and gasification was applied to biomass and waste. BFB 100 kW_{th}, flash pyrolysis reactor, downcomer reactor, flat flame burner, pressurized combustion chamber. New burner systems for decentralized utilization of low-calorific gases in microturbines, solid currents in a biomass gasification reactor}

* ZSW Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg Gemeinnützige Stiftung, Abteilung Regenerative Energieträger und Verfahren, Stuttgart (Center for Solar Energy and Hydrogen Research Baden-Württemberg Non-profit foundation, Department of Regenerative Energy Carriers and Technologies. Regenerative fuels (hydrogen, methanol, pyrolysis bio oil, generation of hydrogen and syngases, gas cleaning. Pyrolysis plant [5 kg/h], several reformers, fuel cells, small test reactors. New thermochemical biomass conversion process Federal project BMVEL 220 008 01, AER Absorption Enhanced Reforming EU-Project NN5E-2001-00139. Small module power plants and tar cleaning of biogenuous gases for fuel cells)

Among the institutes that since 2002 have interrupted their activities in gasification are

* Energieressourcen-Institut e.V. c/o Brandenburgische Technische Universität, Cottbus, (Energy Resources Institute of the Brandenburg Technical University. Gas cleaning, Thermoprocessor),

* the Institut für Wärmetechnik und Thermodynamik of the Technische Universität Bergakademie Freiberg (Institute for Heat Engineering and Thermodynamics of the Technical University Mining Academy Freiberg. Moving bed, hot gas turbine, biomass integrated generation combined cycle demonstration plant at Siebenlehn)

* Technische Universität Chemnitz-Zwickau, Institut Allgemeiner Maschinenbau (Technical University of Chemnitz-Zwickau, Institute for General Machine Construction) after terminating successfully research on agglomeration and building a big pellet machine

* Universität Kaiserslautern, Arbeitsgruppe Verbrennungsmaschinen (University of Kaiserslautern, Task Group Combustion Engines for engine design, moving bed test reactor was dissolved)

Two EU-R & D projects led to promising results in laboratory and pilot plant scale tests:

* The AER Absorption Enhanced Reforming of biomass to generate a hydrogen rich producer gas of ZSW Center for Solar Energy and Hydrogen Research Baden-Württemberg non-profit Foundation and the Institute of Process Engineering and Power Plant Technology of University of Stuttgart jointly with their international partners reached an amount of 75 % vol % of hydrogen in the producer gas (ENK5-CT-2001-00545).
  Contact: ZSW Dr. Michael Specht michael.specht@zsw-bw.de

* At the Institute for Thermal Power plants, Technical University of Munich, the consortium of at all nine European partners tested successfully during a 72-hours- duration test the first prototype of a biomass heatpipe reformer for small standardized biomass-CHP-plants (BioHPR-project No. NNE5-2000-00181).
  Contact: TUM LTK Dr.-Ing. Jürgen Karl karl@ltk.mw.tum.de

At an early stage but with a high potential of development, several institutes of the Forschungszentrum Karlsruhe pursue a concept which may help to resolve the problems of low energy density of biomass, of high cost and intermediate storage of agricultural waste, i.g. straw, and the challenging production of biofuel via pyrolysis, gasification and synthesis. The concept, in the first step, comprises the employment of small units for fast pyrolysis, f.i. in an innovative twin screw reactor tube with circulated heat carrier, at 500 °C. The units up to 50 MW_{th} (size equals a throughput of approx. 12 tons/h of dry ash-free straw, hay, wood etc) are to be located in rural areas. From this feedstock approx. 10 tons/h of slurry is produced containing condensed pyrolysis oil mixed with fine grain coke simultaneously produced, in total up to 80 % of the energy content of the biomass. In a second step, about 20 to 40 of these relatively small units will feed one central gasification and synthesis complex. Pyrolysis and gasification have been demonstrated in simultaneous tests at the entrained-flow reactor of FUTURE ENERGY GmbH in Freiberg
Contact: FZK ITC Dr.-Ing. edmund.henrich@itc-cpv.fzk.de; FUTURE ENERGY Dipl.-Betriebswirt Dirk Volkmann d.volkmann@future-energy.de

Another new project for the generation of synthetic gas from biomass started at Clausthal-Zellerfeld. The project group is coordinated by CUTEC Clausthaler Umwelttechnik-Institut GmbH. Partners are T & M Engineering GmbH, Bad Frankenhausen, to engineer the plant mainly consisting of a circulating fluidized bed reactor, and Volkswagen AG as partner for the automotive fuel, called art-fuel, produced by Fischer-Tropsch-synthesis after cleaning the syngas by sorption and balancing the H_2:CO-relation
Contact: CUTEC Dr.-Ing. Stefan Vodegel stefan.vodegel@cutec.de

More groups for joint research, development and implementation of synthetic fuels were formed. Besides the network of excellence RefuelNet, guided by Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg Gemeinnützige Stiftung, Stuttgart and Ulm, more focussed on basic and applied research on biofuels and hydrogen was established a group for joint research and development of a new gasification path to synthetic fuel combining pyrolysis in decentralized units to produce bio liquids of high energy density and convert it in a large entrained flow gasification plant. The coordinator Forschungszentrum Karlsruhe GmbH

Technik und Umwelt was jointed by Bundesforschungsanstalt für Holz- und Forstwirtschaft, Institut für Holzchemie, and FUTURE ENERGY GmbH, Freiberg.

FEE Fördergesellschaft Erneuerbare Energien e.V., Berlin, manages two **national task groups**, one on **"Gasification of Biomass"** (since 1994) and the second on **"Biogenuous Gases - Fuel Cells"** (with scientific consultancy of Hahn-Meitner-Institut GmbH, Berlin**,** supported by the Federal Ministry for Consumer Protection, Food and Agriculture. Since December 2001). Both groups act as interfaces between

* science – industry and market,
* applied research – technological development with market orientation,
* SMEs and big industrial companies,
* **industrial - regional and rural development,**
* home and international market.

Contact: Eberhard Oettel, fee-ev@t-online.de

By the end of 2003 a new national Project (Federal Ministry of Education and Research) started for the first time as an **"International Network for Research on Renewable Energy"** with focus on biogenuous gases. This network is coordinated by the private DBI Gastechnologisches Institut gGmbH, Freiberg, involving five German and three scientific institutes from new East-European EU-Member states (Czech Republic, Hungary, Poland) and the non-governmental association FEE Fördergesellschaft Erneuerbare Energien e.V., which is responsible for gasification gas.

4. Industries

The above mentioned recent developments in energy policy and new regulations have been even boosted by the need to substitute power plants with an installed electrical power of as much as 40 GW in the next 20 years to come (!).

There had been some changes in the list reported in September 2002, comprising a representative selection of industrial enterprises, only, manufacturing feeding systems, gasifiers, gas cleaning plants and prime movers :

* AAN Anlagen- und Antriebstechnik Nordhausen GmbH, Bielen, (gas engines)

* A.H.T. Pyrogas Vertriebs GmbH, Bergisch Gladbach (double-fire moving bed gasification plants)

* A.U.G. Neue Aktivkohle und Umweltschutztechnik GmbH, Döberitz, (activated charcoal)

* Apparate- und Industrieanlagen Gruessing GmbH & Co. KG, Rudisleben, (shaft reactors)

* BETH Lufttechnik GmbH, Lübeck, (electrostatical precipitators, bag filters, cyclone precipitators, scubbers)

* ECH Elektrochemie GmbH, Halle, (precipitators, filters)

* EVN Energie Versorgung Nord GmbH & Co KG, Harrislee, (small scale gasification plants)

* D.M.2 Verwertungstechnologie Dr. Mühlen GmbH & Co. KG, Herten, (steam reforming plantswith pepple energy carriers)

* D.M.T. Deutsche Montan Technology GmbH Modern Fuels, Essen, (reforming plant)

* EMREC GmbH, Ahaus, (biomass fuel processing)

* Energiesysteme Kuntschar & Schlüter GmbH, Wolfhagen-Ippinghausen, (moving bed gasification plants and combined heat and power engines)

* FMI Feld Maschinen- und Industriebau GmbH, Oer-Erkenschwick, (gasifiers of the 3rd generation of oxygen melting gasification developed by Ingitec Ingenieurbüro für Giesereitechnik GmbH, Leipzig, called IMeGa-Process)

* G.A.S. Energietechnik GmbH, Krefeld, (gas engines, microturbines [Capestone])

* GET Energietechnik GmbH, Unterlemnitz, (ORC-plants), jointly with GMK Gesellschaft für Motoren und Kraftanlagen GmbH, Bargeshagen

* GNS Gesellschaft für nachhaltige Stoffnutzung mbH, Halle, (catalysts)

* HERLT SonnenEnergieSysteme, Vielist, (straw bale and quarter gasifier for heat production)

* Keramische Industriebedarfs Gesellschaft Paul Gatzke GmbH & Co. KG, Berlin, (Moving bed gas generators, burners)

* KLEIN Stoßwellen GmbH, Niederfischbach, (gas cleaning by shock waves)

* KUG Kunststoff- und Umwelttechnik GmbH, Forst, (thermolysis plant for wood and plastics), jointly with MET Motoren- und Energietechnik GmbH, Rostock, (multiple fuel engine)

* LEHMANN Maschinenbau GmbH, Jocketa, (standard gasification fuel press)

* Lock Engineering Group GmbH, Erlangen, (engineering of gasification plants for biomass and waste)

* Lurgi Envirotherm GmbH, Ratingen, was renamed to Lurgi Energie and Entsorgung and moved to Düsseldorf (complete large sized gasification plants up to 100 MW. BGL gasifier)

* mesa electronic GmbH, Geretsried-Gelting, (sensors for measuring wood humidity)

* MAN Dezentrale Energiesysteme GmbH, Mannheim, (gas engines)

* Pall Schumacher GmbH, Crailsheim, (ceramic filters)

* RAB Rohrleitungs- und Anlagenbau GmbH, Leipzig-Engelsdorf, (complete gasification plants, among others Carbo V). RAB changed its name into nacap.

* Schulz Verfahrenstechnik GmbH, Britz (fuel and sewage sludge dryer, recently: wet gas cleaner)

* T & M Engineering GmbH, Bad Frankenhausen, (moving bed gasification plant)

* TAF Technische Apparate Freiberg GmbH (Carbo V-[entrained flow] and Carbo-Compact small scale plants)

* Westerhoff Energietechnik GmbH, Heidenau, (gas turbines)

* Wolfgang Fröhlich Verbrennungsanlagen und Automatisierungstechik, Halle, (precipitators)

Some of the than listed companies went into bankruptcy or stopped mainly for non-technical reasons business related to gasification. These are

* AquaBioTechnologie GmbH, Wildau, (gas water cleaning reactor). Bankruptcy. The technology was taken over by an other company.

* ECH Elektrochemie GmbH, Halle, (precipitators, filters). Bankruptcy,

* FUT Feuerungs- und Umwelttechnik GmbH, Leipzig-Holzhausen, (OMEGA reactor vessels, ex-2SV-reactors. The technology was taken over by
OxyTec Energy GmbH, Leipzig-Holzhausen, which, too, is no longer active on the market),

* GekaKonus Energie- und Umwelttechnik GmbH & Co. KG, Karlsruhe, (fluidised bed plants). This subsidiary of Siempelkamp AG stopped its activities in the field of gasification,

* MHB Umwelttechnik GmbH, Fürstenwalde, (moving bed gasifier up to 500 kW_{el}). Activities in wood gasification was stopped and the gasifier sold,

* PPS Pipeline Systems GmbH, Quakenbrück, (complete gasification plants, among others fixed bed). As former subsidiary of the bankrupt Babcock was taken over by an Austrian building enterprise, which let off all activities in gasification and plant engineering,

* SVZ Sekundärrohstoff-Verwertungszentrum Schwarze Pumpe GmbH, Spreewitz / Spreetal and IngAD Ingenieurbüro für Anlagenbau und technische Dokumentation GmbH, Schwarze Pumpe, (waste wood and waste fuel processing plants, continuously on-line oxygen measuring device in producer gas). The SVZ is currently in the state of insolvency. Efforts are going on to rescue the company and the technologies. The IngAG had been liquidated.

* VER Verwertung und Entsorgung von Reststoffen GmbH, Dresden, (DFT® Steam-Fluid-Dryer plants for drying and conditioning of tar and other difficult sludges as fuel for gasifiers, LQV-gasifiers). VER declared insolvency. The technology might be rescued.

* Zeppelin Power Systems GmbH, Nordhausen, (Caterpillar, USA. Gas engines). Zeppelin stopped any activities with gasification gas engines.

Some newcomers or re-established enterprises offered engineering or the supply of plants and main components to the market, f.i.

* DreBe GmbH, Altdorf- Biessenhofen (small moving bed plant)

* EAW Energieanlagenbau GmbH, Westenfeld (gas engine, combined with adsorption cooling unit)

* FUTURE ENERGY GmbH, Freiberg (Formerly BBP Power Plant GmbH, formerly NOELL-KRC GmbH, formerly Deutsches Brennstoff-Institut, complete entrained flow gasification plants)

* GEMES Abfallentsorgung und Recycling GmbH, Schöngleina (thermolysis plant)

* Kopf AG Umwelt und Energie, Sulz-Bergfelden (sewage sludge gasification plant)

* Kreisel GmbH & Co. KG Umwelttechnik, Krauschwitz (gasifers)

* Krypton GmbH, Bremen, (gasifier)

* Mothermic Energiesysteme GmbH, Pfalzfeld (complete semi-automated gasification plants for wood chips)

5. Projects

Major trends in biomass gasification have changed substantially:

This modified situation caused an enormous upswing of gasification to produce syngas for sun fuel or synthetic fuel as well as for a hydrogen rich producer gas.

Even first projects for preparing the use of gasification gas in fuel cells started.

The first ever strategic partnerships between global players (automobile industry, mineral oil companies) and innovative small and medium sized enterprises (SME) were formed. . Additionally to the first **strategic network** formed by research institutes, enterprises, specialized on gasification, automobile industry for the development of biofuel and fuel cells, comprising CHORen Industries GmbH, Freiberg, DaimlerChrysler AG, Stuttgart, (methanol), UET Umwelt- und Energietechnik Freiberg GmbH and Volkswagen AG, Wolfsburg, (Sunfuel™

), was added a second one formed by CUTEC – Clausthaler Umwelttechnik Institut GmbH, Bundesland Lower Saxony and Volkswagen AG.

The technology of first choice is the entrained flow gasification.

The interest rises in co-gasification of biomass and residues, especially sewage sludge and municipal solid waste, and the mono-gasification of waste.

However, the combined heat, cold and power-generation is characterised by contradictory developments, progress in process stability is counter-balanced by an increasing number of failures for technical and non-technical reasons and an growth of newcomers and home-mechanics.
This ambiguous situation led to growing insecurity of public authorities and negligence of their necessary support.

In relation to worldwide growing pressure to cleaner coal combustion processes with less or no CO_2-emissions possibilities on integration of gasification technology into a combined process are being investigated. A promising path was presented by engineers of the former VER GmbH in public, only recently .

The current state-of-the-art is characterised as follows

* The overall situation did not change. There still at least 35 test-, pilot- and demonstration and the very first commercial plants for combined heat and power generation or production of methanol or synthetic gas as well as refuse disposal and recycling are realized or in operation in Germany or with German technical participation abroad. They range from some ten kilowatt installed thermal power to 100 megawatt. In this case, plants in scientific institutes are not counted.

* An extraordinary variety of technologies, performances, fuel, gasification and application aims prevails.

* As far as mini, small and medium scale plants are concerned, up to now in no case unlimited marketability could be achieved, but the first plants could accumulate several thousand operation hours.
In almost all old and new processes where gasification was developed as a uniform continuous process but with certain clean separation of the four main partial phases the developers made promising progress.

* The majority of projects are either suffering from technological immaturity, insufficient investment due to deficiency of own capital resources and enforced discontinuous development.

* Innovative small and medium sized enterprises are still the main driving force, sometimes supported by research and scientific institutes.

* Efforts to concentrate technological development in a biomass gasification center failed, but to organize networking for accelerating R & TD as well as demonstration were successful.

Some of the major projects and their changes are:

1 Moving bed

1.1 Multiple-staged moving bed in order to separate mayor gasification phases

1.1.1 Double zone gasifier from originally A.H.T. Dipl.-Ing. Johannes Ferges gasification system, Bergisch Gladbach, (modified KHD gasifier) delivered to:

* EVN Energie Versorgung GmbH & Co. KG, Eckernförde (Gasification project stopped by the main socio Stadtwerke Eckernförde GmbH for technical failures and economic reasons)

* FÖST Fördergemeinschaft Ökologische Stoffverwertung e.V., Halle/Saale

* Kirchmayr Compost & Energy, Sattledt, Austria

* Pyroforce Energietechnologie AG, Emmenbrücke, Switzerland, (150 hours test in co-generation under third parties observation according to Verenum-Guideline, more than 1,000 hours operation during the working week)

* TPF – Econoler N.V., Brussels, Belgium (project stopped for technical failures)

* Technical University Graz Institute for Heat Technology, Austria

Almost all A.H.T. plants had been completely and in most cases successfully modified by the operators.
A recently developed technology of catalytic-partially allothermic gasification by GNS Gesellschaft für nachhaltige Stoffnutzung, Halle / Saale, has shown in the first tests at the gasifiers at Eckernförde (BEVN) and Halle (FOEST), that the efficiency of downdraft gasifiers can be enhanced essentially. The complete realisation of catalytic-allothermal gasification requires new constructive solutions. To realise this concept, GNS cooperates with IUT Ingenieurbüro für Umweltschutz & -technik GmbH & Co. KG, Harrislee, in different projects.

In a joint project of IUT, GNS and reNet-Austria a new plant will be built at Wiener Neustadt (Civitas Nova) for the Energie Versorgung Niederösterreich AG, where IUT had realised principal steps of new constructive solutions (f.i. drying in a rotating drum tube). The pilot project is ongoing with strong scientific support by the Technical University of Vienna.

In a further R&D-project, coordinated by FÖST, GNS built a new pilot plant at the campus of Fachhochschule Merseburg to realise all steps of the catalytic- partially allothermal gasification. For this project BEVN has supplied technical components of a gasifier for reconstruction.

1.1.3 Double staged moving bed with internal milling of coke developed by Kiefer Engineering GmbH, Leipzig, failed because of insolvency of the company.

1.1.4 Mini scale (13 kW_{el}) double-staged moving bed using the fuel feeder as dryer and pyrolysing tube self-manufactured by the in wood gasification experienced inventor and farmer Mr. Bernhard Joos, Bodnegg (Two 200 hours tests in co-generation under third parties observation for operation only. 3,500 accumulated operational hours. Although, plant evaluation by Swiss MENAG group and gas analysis by Verenum showed deficiencies)

1.1.5 A semi-automatically operated moving bed gasification plant with promising test results had been developed by Mothermic Energiesysteme GmbH, Pfalzfeld

1.2 Moving bed gasifers for biomass fuel other than wood

* for straw bales so far for heat generation by Herlt SonnenEnergieSysteme, Vielist. Already seven plants are commissioned.

* for different biomass for co-generation and cooling by T & M Engineering GmbH, Bad Frankenhausen, in co-operation with Martin-Luther-University Halle-Merseburg and AAN Anlagen- und Antriebstechnik Nordhausen GmbH, Bielen,

1.3 The concept pursued by several developers is co-gasification of biomass, sewage sludge and / or waste, f.i. by Kopf AG Umwelt- und Energietechnik, Sulz-Bergfelden, Kuntschar & Schlüter Energiesysteme GmbH, Wolfhagen-Ippinghausen, by N.R.P. Natur-Rohstoff Pyrolyse GmbH, Oberthingau, by Schulz Verfahrenstechnik GmbH, Britz

2 Fluidized bed

2.1 Circulating fluidized bed gasification pilot plant for co-generation of Fraunhofer-UMSICHT

2.2 Bubbling fluidized bed gasification and gas treatment under development by Fraunhofer-Institute of Factory Operation and Automation, jointly with Otto-von-Guericke-University Magdeburg.

The WSV 400 fluidized bed gasification test plant serves to test the plant concept for the autothermal gasification of waste wood and other fuels in a bubbling air-blown fluidized bed and to check the subsequent gas utilization by an engine. Aim about 500 kW_{el}.
After preceding studies on primary measures for reducing tar, secondary measures for reducing tar by means of gas scrubbing and/or catalytic tar reforming are now being dealt with. Market introduction is planned for 2003. The systems engineering target parameter is decentralized combined heat and power in small units of up to 5 MW of thermal output of the fuel gas.

2.3 Small scale containerized version trade-named Carbo-Compact, manufactured by TAF Technische Apparate Freiberg GmbH in co-operation with UET Umwelt- und Energietechnik Freiberg GmbH, CHORen Industries GmbH, Freiberg

2.4 PulseEnhanced™ fluidized bed steam reforming (technology of MTCI Manufacturing & Technology Conversion International, Inc. Baltimore, USA) to generate a hydrogen rich producer gas. Two projects under preparation jointly by Biomassezentrum Spreewald GmbH & Co. KG, Dresden, (future operator), ECS Energie Consulting und Service GmbH, Dresden, (project developer), EBU GmbH, Ludwigshafen, (engineering) and SPIRIT of TECHNOLOGY AG (financing), Hosenfeld, at Vetschau and a second site in Bavaria seemed to be abandoned. A third project was started with V.I.A. Biomasse-Heizkraftwerk GmbH & Co. Kirchmöser KG to burn the gasification gas in an existing waste wood combustion but run into serious difficulties with the permitting authorites

2.4 Gasification of wood straw and other biomass by University of Rostock, Institute for Process Engineering and Environmental Technology

2.5 BISEA-Project (5.3 MW_{th}) in preparation by CET Christan Eder Technology e.K., Neunkirchen / Saar, with a stationary fluidized bed gasifier, based on tests by University of Stuttgart, Institute for Technology and Steam Vessels (IVD) and own experiences with an oil gas cleaning process for CHP combined with an ORC-plant

3 Entrained flow gasification

3.1 Carbo V®-Technology by UET Energie- und Umwelttechnik Freiberg GmbH jointly with Zeppelin Power Systems GmbH, Nordhausen, (a 200 hours duration test in co-generation mode has been passed. Longest continuous operation with engine was 500 hours). A methanol synthesis plant is being built at the pilot plant in Freiberg.

3.2 ARLIS®-Technology for the gasification of different biomass fuel was jointly developed by TRE Terra Recycling und Entsorgung GmbH, Wiesenburg (Brandenburg) in co-operation with ex-BBP Power Plant GmbH, Freiberg. This technology (high-temperature vertical vessel for straw bales, using oxygen as gasification agent) is going to be integrated into a waste wood IGCC plant of V.I.A. Biomasse-Heizkraftwerk GmbH & Co. Kirchmöser KG. Basic engineering started. But the project failed because of the insolvency of TRE

* Forschungszentrum Karlsruhe GmbH Technik und Umwelt (Research Center Karlsruhe Technology and Environment) researches on a Supercritical Water Gasification-Process (SCWP called “VERENA”) for methanol and power generation from straw.
The Institute for Technical Chemistry (ITC) constructs a plant for the gasification of high moisture biomass in supercritical water operable at 320 bar and 650 °C with a 40 L reactor volume and a throughput of 100 kg/h aqueous feed VERENA.

The installation of the plant is scheduled to be put into operation by the year 2003 and is supposed to be than the largest facility for this type of process worldwide.

4 Several different variations of the above mentioned basic technologies

4.1 Staged steam reforming at atmospheric pressure, using pebbles as heat carriers to produce an up to 60 % hydrogen enriched gas by Dr. Mühlen GmbH & Co. KG, Herten. Pilot plant commissioned

4.2 Heat pipe reforming (Gasifier, filter chamber and burning chamber in one vessel linked by heat pipes. EU-Project) by Technical University of Munich, Institute for Thermal Power Plants with Heating Power Plant, Garching

4.3 Oxygen blown melting process in a shaft reactor

* by Apparate- und Industrieanlagen Gruessing GmbH & Co. KG, Rudisleben, in cooperation with vti Thüringer Verfahrenstechnisches Institut für Umwelt und Energie e.V, Saalfeld

* by Ingitec Ingenieurbüro für Giesereitechnik, Leipzig, (developer and holder of patents on the technology)

5 Joint development of manufacturers and operators of gasification plants and gas engines continued

* by AAN Anlagen- und Antriebstechnik Nordhausen GmbH, Bielen, jointly with T & M Engineering GmbH, Bad Frankenhausen, and Martin-Luther-University Halle-Merseburg

* by G.A.S. Energietechnik GmbH, Krefeld, jointly with Fraunhofer-UMSICHT

* by GE Jenbacher Energiesysteme GmbH, Mannheim, (GE Jenbacher AG, Austria), jointly with several German partners

* by MET Motoren- und Energietechnik GmbH, Rostock, (multiple fuel engine for pyrolysis gases), jointly with KUG Kunststoff- und Umwelttechnik GmbH, Forst

Because of the bankruptcy of the Babcock Borsig company and some of its subsidiaries several projects had to be interrupted.

* FUTURE ENERGY GmbH, Freiberg, was formed by new investors out of BBP Power Plant GmbH (ex-NOELL-KRC, ex-Deutsches Brennstoffinstitut), the test site of an pressurized entrained flow gasifier with inner cooling screen wall (only all over the world gasifier of this kind with several special burners able to gasify numerous kind of fuel including very difficult chemical residues) could be rescued. The older small-scale test facility with a gasifier of 3...5 MW_{th} was originally built in 1979 in order to prove the entrained flow gasification concept, to develop prototype designs and to determine process conditions for different feedstock. This plant is now available for qualification tests of most various fuels and combustible residues under different operating conditions. A new gasification test plant was started up in 1996/97 with gasifier capacity of 7...10 MW_{th}.

* several projects of BBP Power Plant, as engineering the first gasification plant for chloride residues to generate syngas for power production for Dow Chemical, Houston (Freeport), USA, and the development a gasification technology for black liquor jointly with Chemrec AB, Sweden

* the BIGCC Biomass Integrated Combined Cycle Demonstration Plant Siebenlehn of PPS Pipeline Systems GmbH

* several Thermoprocessors (ex-Steinmüller, ex-Hugo Peterson, ex-Wamsler) at different sites

6. Implementation

Up to now successful demonstration and implementation depend on the use of negatively priced fuels or integration of the gasification technology or plant into a profitable industrial process already in permanent operation. In the near future is expected that the production of synthetic

gas and fuel and the gasification of straw might be demonstrated with at least technically positive results.

The few more or less successful examples are

* The at the moment in trouble being ex-BBP Power Plants GmbH (formerly NOELL KRC Energie- und Umwelttechnik GmbH), Schkeuditz and Freiberg, commissioned an entrained-flow plant for gasification (30 MW_{th}) of toxic, nitrogen-organic residues from caprolactam production in May 2001 to BASF plc., Seals Sands, Middlesbrough, UK.
At Seal Sands plant approx. 110,000 t/a of residual products are generated from various stages of the acrylonitrile-synthesis, which are gasified. The residues are liquid, ash free mixtures, which essentially contain nitrites, amines, ammonia-sulfates and prussic acid. There is a content of up to 24 Ma-% of organic bonded nitrogen. The syngas produced is used for power production.
FUTURE ENERGY won a tender of Chemoproject Praha for engineering a pressurized entrained-flow gasification plant fuelled by heavy oils and brown coal tar for an Integrated Generation Combined Cycle at Sokolovská uheln´, Czech Republic.
Contact: Dipl.-Ing. Dirk Volkmann, info@future-energy.de

* BEV Biomasse Energie Versorgung Domsland GmbH tried to integrate the gasification process into a heating plant based on combustion of natural wood chips at Eckernförde. The reactor is a twin-zone-gasifier operating on the KHD Klöckner-Humboldt-Deutz-method, delivered by A.H.T. Dipl.-Ing. Johannes Ferges. It combines the down-draft moving bed gasification in the upper reaction zone with the updraft gasification of the lower reaction zone. Gasification agent is air and steam. Producer gas is sucked out by vacuum. The gas is treated by wet cleaning (cooling, column washer, desintegrator, drop separator, drying, antifoam detergent) and is used in a co-generation module type 2842 made by MAN.
Commissioning April 2000. Gas quality was analysed by reNet Austria (TU Vienna, Institute for Process, Fuel and Environmental Technology, by University Stuttgart and Jenbacher AG, Austria). Results: Fluctating values of gas composition, lower heating value, tars. High values for carbonmonoxid in the exhaust gas and ammonia before engine.
Guaranteed 180 kW_{el} installed power could not be reached. No continuous operation was possible. The project was abandoned.
In tests conducted by GNS Gesellschaft für nachhaltige Stoffnutzung mbH in 2000, an essential increase of the heating value and the volume of produced gas was achieved under modified and catalytic conditions. The engineering company of BEV IUT Ingenieurbüro für Umweltschutz & -technik GmbH & Co. KG won an order of EVN AG, Austria to built a plant of 2 MW_{th} at Wiener Neustadt. The project was realized together with GNS and rennet Austria. Necessary constructive changes including the realization of the catalytic-partially allothermal principle were realized.
Contact: For BEV, BEVN, IUT: Dipl.-Ing. Wolfgang Baaske, info@iut-flensburg.de. For GNS: Prof. Dr. Herbert Spindler, gns-halle@t-online.de

D.M. 2 Verwertungstechnology Dr. Mühlen GmbH & Co. KG, Herten, engineered a 1 MW_{th} atmospheric staged steam reforming pilot plant for gasification of biomass and waste to generate a hydrogen-rich producer gas for co-generation or a combined cycle or synthetic gas, the Blue Tower at Herten. The plant consists of three vessels, reformer and pyrolysis reactor and a vessel for heating-up the heat carrier and a burning chamber. All three vessels are moving bed reactors, with the moving bed formed by the heat carrier pebbles powering the

process by transporting the high temperature heat to locations where it is needed. In the test plant, sintered Al_2O_3 pebbles serve as heat carriers. The biomass is fed into the pyrolysis reactor, heated up and split into a char and a gas stream. The pyrolysis gas flows upwards into the reformer vessel. This reformer vessel is situated in between the heat carrier preheater above and the thermolysis reactor beneath. In the reformer, the pyrolysis gas is heated up together with steam to 950 °C. This results in a product gas with 50 – 60 % hydrogen, which is nearly nitrogen free. Below the thermolysis reactor coke and heat carrier pebbles are separated. The pebbles are transported to the preheater at the top of the plant, the coke is transferred into the combustion chamber and burned to provide hot flue gas for powering the process. The heat contained in the hot flue gas is transferred to the heat carrier pebbles inside the preheater at the top of the plant. The process is managed by a suitable lock and dosing system between the vessels.
The plant was commissioned at the end of 2001. Since than the process has been tested with promising results. The originally planned project to build a demonstration and at the same time commercial plant (2,5 MW_{th}) at Emsland in 2003 did not mature. Instead of it an up to 10 MW_{th} demo plant at Herten was engineered. Two licences were sold to Japan and one to Mexico.
Contact: Dr.-Ing. Heinz-Jürgen Mühlen, muehlen@dmt.de

* HERLT SonnenEnergieSysteme, Vielist, developed a straw gasifier for one bale or quarter for heat generation.
The gasifier consists of two chambers the spacious bale gasification chamber and a turbulence gas combustion chamber coated by ceramic material with catalytic effect. The two chambers are linked by a tuyer. At the rear side of the gasification chamber a ventilator with two arm-like nozzles is installed. A spacious straight-up standing box-reactor is situated tangentially of the bottom of the combustion chamber. Heat exchanger and exhausting ventilator complete the plant.
The gasification chamber is preheated by combusted wood. The straw bale is fed into the gasification chamber. The ventilator presses air as gasification agent into bale to its peripherically crusted combusted rim at the outside of the bale. Thus the burned and coked outside ash layer is continuously blown off. The temperature in the bale rises immediately leading to an intensive gasification process until the complete conversion of the bale. The straw gas is sucked off by an exhauster from the gasification chamber into the turbulence combustion chamber, where the gas is burned-up completely at about 950 °C. The gas enters into a spacious box-reactor. Because of the turbulent motion and the big cross-section of the box-reactor gas velocity is slowed-down and dust falls out. By expansion the gas is cooled down to less than 600 °C, below the ash melting point of straw. Thus, agglomeration of ash particles is avoided. The pre-cooled gas is drawn into a heat sink and cooled down to 170 °C.
In 2002 and 2003 the gasifier was tested positively by TÜV, the technical surveillance authority. Since than seven plants have been erected at different sites in Germany.
Contact: Dipl.-Ing. Christian Herlt, ch.herlt@t-online.de

* Keramische Industriebedarfs Gesellschaft Paul Gatzke GmbH & Co. KG, Berlin, has a long tradition in designing and manufacturing of reactors and burners. The company engineered the counter-current gasification reactor that since several years has been operating at the Harboere plant of Babcock Wilcox Vølund ApS, Esbjerg Oe, Denmark.
Contact: For Keramische Industriebedarfs Gesellschaft Paul Gatzke GmbH & Co. KG: Dr.-Ing. Horst Gatzke, phone 0049-30-3228116. For Babcock & Wilcox Vølund: Bjoern Teislev, MSc., Ph.D., bit@volund.dk

* Now Lurgi Energie und Entsorgung GmbH, Düsseldorf, integrated a 100 MW thermal power circulating fluidized bed gasifier into a cement production process of Rüdersdorfer

Zement GmbH (Readymix Group). The plant was commissioned in 1996 and since than has been in commercial operation.
The Lurgi CFB air-blown gasifier produces approx. 40,000 m³/h gas for supplemental firing. Coal is replaced by combustible residues (waste wood, waste, plastics, RDF in total 25 tons/hour), thus improving the overall economics.
Apart from Rüdersdorf, Lurgi has built so far 3 commercial plants for gasification of biomass and a variety of industrial waste materials. These include the 38 MW_{th} bark gasifier in Pols, Austria, (1987) and a 85 MW_{th} demolition wood N.V. EPZ gasifier in Geertruidenberg, The Netherlands, (2000) for co-firing a PC boiler (Amergas Project).
Contact: Dipl.-Ing. Claus Greil, claus_greil@mg-lee.de

* The oxygen blown melting process in a shaft vessel like a cupola furnace is still th be proved. All projects failed by series of insolvencies and bankruptcies The original technology was developed by Ingitec Ingenieurgesellschaft für Giesereitechnik GmbH, which is now offering a third generation of the technology. Main components are the oxygen-blown cupola furnace, a spray dryer, bag filter, acid washer, alkaline washer, cooler, condenser, gas store, gas engines (Jenbacher). Different fuels (waste wood and residues) are shreddered, mixed with lime and coke and gasified in a co-current two-staged process at high temperatures (>1,600 °C) to melt slag and metal parts. The gas is sucked off the reactor with about 800 °C and treated.
Contact: Dipl.-Phys. Joachim Mallon ingitec.Leipzig@t-online.de

* PPS pipeline systems GmbH, Quakenbrück, as general contractor with scientific support of the Technical University Mining Academy of Freiberg Institute for Heat Engineering and Thermodynamics built a BIGCC Biomass Integrated Generation Combined Cycle Demonstration Plant at Siebenlehn. The gasification technology was jointly developed with ProCone AG, Gunzgen, Switzerland, from the Juch process.

The main components of the plant are air-blown moving bed co-current gasifier with movable grade, gas cleaning, combustion chamber, high temperature heat exchanger, hot gas turbine, heat recovery boiler for steam generation, steam turbine.

The producer gas generated in the gasifier (designed 8.5 MW_{th}). is sucked-off via a draught fan, being cooled, roughly cleaned and burned in the combustion chamber. The heat exchanger is placed between the chamber and the compressor of the hot gas turbine. Thus, heated fresh and clean air serves as working medium of the gas turbine (1.3 MW_{el}). The gas turbine exhaust not needed for combustion is fed through a bypass to the heat recovery boiler for generating fresh steam for the attached extraction condensation steam turbine (extraction 0.7 MW_{el}, condensation 1.0 MW_{el}). The heat of extracting steam of the turbine serves to cover technological and heating warmth of the consumer.
The plant was commissioned in April 2001. The real gasifier output was approx. 80 % of the designed value. The hot gas turbine cycle was put into operation successfully. Most interruptions, which obstructed the continuous running of the plant were not caused by the innovative components.

The plant is shut down for non-technical reasons and is on sale
Contact: For the moment FEE Eberhard Oettel fee-ev@t-online.de

* In July 2002 SVZ Sekundärrohstoff-Verwertungszentrum GmbH, Spreetal/ Spreewitz, was sold off by its owner the Berliner Wasserbetriebe to ORESTO Ostdeutsche Gesellschaft für Reststoffverwertung mbH, a subsiduary of Nord GB Gesellschaft für Beteiligungen mbH, Hamburg. Investors are lawyers of Dr. Weiland und Partner, Hamburg. After 40 years of gasification the management declared insolvency in April 2004. In May the plant started operation again.

SVZ is one of the rare examples all over the world for gasification plants in long duration industrial operation.
Between 1992 and 1994 the moving-bed and entrained flow gasifiers already in several years of operation to generate town gas from brown coal were adapted to new fuels (waste wood, oil slurries, municipal sold waste, plastics and more different residues) and new final products (power [75 MW_{el}], methanol [max. 120,000 tons/year grade AA], gypsyum, heat).
The main plant components consist of several lines of fuel treatment, including pelletizing plastic residues, several 25 bar pressurized moving bed gasifiers, two entrained flow gasifiers, one slag bath gasifier, multiple plants for gas and water cleaning, a methanol synthesis plant and a combined cycle plant.
The moving bed reactors are used for gasifying solid waste and the entrained flow for liquid residues.
In 2002 Britisch Gas and Lurgi Envirotherm GmbH (now Lurgi Energie und Entsorgung GmbH), Düsseldorf, commissioned the first BGL slagging bath gasifier in Germany for processing pretreated solid waste. SVZ is worldwide the first applier of the slagging gasification technology for residue gasification. The BGL gasifier is expected to triple the fuel throughput of the old moving-bed gasifers and more than double the specific gas amount. A second BGL gasifier is planned to be built.
In 2001 for the first time ever in the history of gasification SVZ started operation of a DFT®-steam-fluid-dryer to dry tar sludge and condition it for being gasified. The technology was developed and patented by VER GmbH, Dresden, for difficult industrial sludges. VER engineered the SVZ plant, which is running continuously since commissioning with a drying capacity of 20 tons of tar per hour, so processing “tar lakes”, where tar from several dozens of years of gasification had been stored. This opens a new technological path for gasification plants. Instead of avoiding tar at any price the tar-loaded gas might be purified by highly efficient wet cleaning. The washed out tar can be recycled into the gasifier. In 2003 SVZ as first and only company got the permission the gasify shredder light fraction of the automobile recycling.
Contact: For SVZ: Dr.-Ing. Bernd Buttker, butterk@svz-gmbh.de. For ex-VER: Dipl.-Ing. Norbert Topf, norbert.topf@web.de or for the moment: FEE, Eberhard Oettel fee-ev@t-online.de

* UET Umwelt- und Energietechnik Freiberg GmbH is a subsidiary of CHORen Industries GmbH, Freiberg.
Based on long-term experience on industrial entrained flow gasification of lignite, UET developed the CARBO V®-technology and built a pilot plant (approx. 1 MW_{th}) at Freiberg, for different fuels (natural wood, waste wood, municipal solid waste, sewage sludge, animal meat, lignite and hard coal), aimed at generating a tar free producer gas with a high heating value suitable for gas engines, turbines and to be upgraded into a syngas.
The main components are a low temperature gasifier, an external coke mill, an air-, steam- or oxygen-blown entrained flow gasification vessel and gas cleaning to be adopted according to its subsequent utilization.
In the process, pyrolysis and gasification are consequently separated. The fuel is pyrolized in a constantly moved quasi fluid bed in an horizontal vessel. Gas and coke are separated. The hot coke is transported to an external mill. Gasification agent and thermolysis gas are jointly blown by a burner into the upper combustion chamber of the entrained flow gasification vessel. The fine coke dust is injected into the hot flame of the gas and very rapidly transformed at high temperatures (>1.400 °C) into a producer gas with no or very low tar load.
Until 1995 the CARBO V®-technology was developed. The Freiberg pilot plant was commissioned in April 1998. Since that time more than 5.000 hours in several test runs have been accumulated. In 2001 an originally for 200 hours planned duration test with a turbocharged Carterpillar gas engine jointly with Zeppelin Power Systems GmbH, Nordhausen,

was prolonged to 500 operational hours. The longest single continuous test run of the gasification part was more than 1.000 hours.
By the end of 2001 the construction of the methanol synthesis plant started. In 2002 the project group was formed integrating DaimlerChrysler AG, CHORen and Volkswagen AG. In September last year DaimlerChrysler AG and Volkswagen AG signed an agreement with CHORen Industries GmbH for joint R & D and construction of an industrial fuel plant until 2005 on the base of CHORen's Carbo V®-Technology. After four weeks of continuous methanol production (11,000 litres of 78 % raw CH_4 instead of expected 50 %) from wood this part of the R & D program was accomplished and the first production of Fischer-Tropsch-liquids started. All main components and processes could be proven (CO_2-washer, ultra-purification, gas treatment, catalyst, relations between process pressure and methanol output, change of inert gas, high methanol out of H_2/CO ration = 2.1 … 2.3). More than 30.000 operational hours of the pilot plant were reported by CHORen. Since September 2003 the 50 MW_{th} industrial syngas plant has been in commissioning so far without gas cleaning. As part of an EU-project an industrial fuel plant is going to be built.

Several projects are under preparation.

Contact: For CHORen and UET: Dr.-Ing. Bodo Wolf, bodo.wolf@choren.de.

* Fraunhofer-Institute for Environmental, Safety and Energy Technology – UMSICHT, Oberhausen, and its industrial partner G.A.S Energietechnik GmbH, Krefeld, designed and built a circulating fluidized bed gasification pilot plant to gasify biomass for combined heat and power generation with an gas engine at Oberhausen.
The plant consists of an air-blown atmospheric CFB gasifier (500 kW_{th}), a catalytic reformer, gas cooler, filter and an internal combustion engine (block heat and power plant, turbocharched, 6 cylinder 4-stroke, type DEUTZ MWM G22B-6), adapted to producer gas. The electrical output of 50 kW_{el} for natural gas was therefore derated by 20 % to 40 kW_{el}.
In multiple test runs the plant could be improved. The CFB-gasifier allows a very stable gasification with only small variations in gas composition. As a result of a thoroughly selected bed material, hot gas reforming placed between gasifier and gas cooler and fabric filter the tar content in the producer gas could be kept constantly below 50 – 100 mg/Nm³.
Design started in 1994. The plant (gasifier and gas cleaning) was commissioned in 1996. A 150 hours test was performed in April 2000. The technical feasibility of the whole plant could be proofed, was optimised afterwards and is now ready for scale-up in a demo plant.
The process is ready for up-scaling to about 5 MW fuel input capacity. In the long term, the system is considered to be profitable for industrial heat and power generation in the range of 5 to 20 MW fuel input capacity.
Several projects are under consideration.
Contact: For UMSICHT: Dr.-Ing. Markus Ising, markus.ising@umsicht.fhg.de. For G.A.S.: Dipl.-Ing. Ludger Dinkelbach, l.dinkelbach@g-a-s-energy.com

Gasification Survey Country: **GREECE**

By: Papamichael Ioanna
Date: September 2002

1. Policy

The main policies that affect the penetration of R.E.S. in the Greek energy system are:

- The new law 2773/99 regarding the liberalisation of the electricity market in Greece. The main points are:
  - Priority is given by the system Operator to the electricity produced from RES to cover the demand of electricity.
  - A ten year contract will be given to the producers of electricity from RES by the System Operator at a price which will be 90% of the existing medium voltage tariff, at maximum, for the energy produced.

- Law 2244/94, regarding revisions on the electricity production code from RES, and the implementing Ministerial Decision 8295/95, which broke new ground for the promotion of RES in Greece. This was the necessary regulation tool for the production of electricity by independent producers, making a distinction between independent producers, selling the total of production to PPC, and auto-producers, covering primarily their own energy needs and selling surplus energy to the Public Power Corporation (PPC). This law remained in force only until the end of 2000. Then it was replaced by law 2773/99 (described above) but it still acts as a reference.

- The development law 1892/90 together with its amendment 2234/94, which is a general "development law" that provides several types of subsidies (including capital subsidies of 40-60%) for new investments by the private sector, including renewable energy scheme.

- The new development law 2601/98, replacing 1892/90, which is expected to be the main funding tool of RES applications in the future. The law foresees a combination of subsidy options that is either a) capital investment subsidies up to 40%, interest subsidy up to 40% and subsidy for leasing up to 40% or b) tax deduction up to 100% and interest subsidy up to 40% for investments in RES.

In addition to the above, Law 2364/95, foresees tax exemptions for the purchase and installation of renewable systems and natural gas systems (about 75% of the total investment for individuals and enterprises).
www.cres.gr, www.rae.gr,

2. Programs

Although some national programs existed that supported research including RES (eg PEPER, PENED) and some new ones, especially for RES and RUE, are expected to be announced no such program is currently running.

The Renewable Energies Sub-programme of the Operational Programme for Energy (1994-1999) was the main funding mechanism for RES installations. The programme supports mainly RES investments, but also broad "infrastructure" work, such as the development of the National Certification System, the assessment of the technically exploitable RES potential or the determination of the optimum administrative and legislative framework for RES.
www.cres.gr, www.rae.gr, www.ypan.gr.

3. Institutes

Center of Renewable Energy Sources
Biomass Department
Address: 19th Km Marathonos Av., 19009, Pikermi Attikis
Tel: +3 010 6603300, Fax: +3 010 6603301, website: www.cres.gr
Contact: Loukas Gavriil, lgavriil@cres.gr
Ioanna Papamichael, ioannap@cres.gr

National Technical University of Athens
Heroon Polytechniou St. 9, 15780 Athens
www.ntua.gr.

Department of Chemical Engineering
Prof. E. Koukios, koukios@chemeng.ntua.gr
Head, Bioresource Technology Unit (BTU), http://btu.chemeng.ntua.gr

Department of Mechanical Engineering
Laboratory of Steam Boilers and Thermal Plants, www.ntua.gr/lsbtp
Prof. Em. Kakaras, ekak@central.ntua.gr

Institute for Solid Fuel Technology and Applications
Prof. Em. Kakaras
www.lignite.gr
Contact: Mr. Karlopoulos Ev. Tel: +3 04630 53842

Aristotle University of Thessaloniki
Laboratory of Heat and Environmental Engineering
Prof. Moussiopoulos Nikolaos
Mr Koroneos Christoforos, koroneos@aix.meng.auth.gr
Mrs Zambaniotou Sonia, sonia@cheng.auth.gr

Agricultural University of Athens
Iera Odos St. 75, 11855, Athens
www.aua.gr
Department of Agricultural Structures
Prof. Kyritsis
Contact: skir@aua.gr

Chemical Process Engineering Research Institute
6th km Charilaou Thermi Str., P.O.Box 361, 57001, Thermi, Thessaloniki
www.cperi.forth.gr
Prof. C. Constandinidis
Prof. J. Vasalos

Prof. A. Karampelas
Contact: cperi@cperi.certh.gr

4. Industries

No Greek industry exists constructing and supplying biomass gasifiers.
PPC, the largest power generating utility in Greece, has implemented studies and has participated in projects dealing with gasification and co-gasification.
Phillipopoulos S.A., an industry designing industrial utilities networks, has funded one project for the gasification of cotton ginning wastes.
ENVITEC S.A. is now involved in the construction of the peripherals of a fluidized bed gasifier (pretreatment, gas cleaning).
TOMI S.A. has taken permit to construct a gasification CHP unit in Meligala.

5. Projects

Center of Renewable Energy Sources

- *Switchgrass (panicum virgatum I) as an alternative energy crop in Europe*
  FAIR CT 97 3701
- *Bioenergy Chains from Perennial Crops in South Europe*
  ENK6-CT2001-00524
- *Biomass Production Chain and Growth Simulation Model for Kenaf*
  Contract negotiations

In all the above projects the work of CRES is focused in the production of the raw material, measuring adaptation and productivity in the Greek soil- climatic conditions and under different cultivation techniques and the provision of data for the economic evaluation of bioenergy schemes fuelled with energy crops.

- Evaluation study of the feasibility for the development of a medium scale power plant fuelled with biomass in Central Greece.
  AL – 2000 - 173
  The primary objective of the action is to evaluate the feasibility for the implementation of a biomass fuelled gasification CHP plant in central Greece. The expected result will be a complete study for the construction of the plant, by the Public Power Corporation (P.P.C.). CRES is focused in the analysis of the fuel supply chain as well as in the overall analysis of the scheme.
  - *Improved Technologies for the Gasification of Energy Crops*
    Subcontracting. Completed before 2000.

National Technical University of Athens
Department of Chemical Engineering
Bioresource Technology Unit (BTU)

- *A novel bioprocess for hydrogen production from biomass for fuel cells*
  QLK5-1999-01267
- *BioNorm*
  Development of standard methods for the bioenergy sector. BTU works on the prediction of the thermal behaviour of the ashes produced from the gasification of various biomass types.
- *IRENE*
  Thermie

Prediction of the methods to achieve the goals of the White Paper for the electricity production from RES. BTU worked on the subject of bioelectricity production via combustion and gasification.

Department of Mechanical Engineering
Laboratory of Steam Boilers and Thermal Plants

- *Biomass Heatpipe Reformer (BioHPR)*
  ENK5-2000-00311
  Dealing with gasification experiments with cotton plant residues
- *Development of a standard method (protocol) for the measurement of organic contaminants "tars" in biomass producer gases*
  ERK6-1999-20002
  Development of a standard measuring method for organic contaminants in biomass gasification

Institute for Solid Fuel Technology and Applications

- *Demonstration of BGL-Gasification under optimised conditions for the European and the Asean market.*
  SF/008/98/DE
  Under that contract a preparatory study for the prospect of the installation and operation of a lignite and RDF co-gasification unit in the area of West Macedonia.

Aristotle University of Thessaloniki
Laboratory of Heat and Environmental Engineering

- *Cotton Waste Gasification in Cotton Ginning Mills*
  Funded by two greek private industries (Asbestoder Ltd., Filippopoulos S.A.)
  Planning of an innovative cotton gin waste gasification system with a view to the coverage of the thermal needs of a lime industry.
  Completed before 2000.

Agricultural University of Athens
Department of Agricultural Structures

- *Alternative Crops Integration in a Spatial Analysis*
  4.1030/Z/01-018
  Development of a complete, versatile and robust integrated software package analysing the regional integration of energy crops in the EU. The decision making tool performs multicriterial analysis and will be validated through the analysis of two case studies.

- *Improved Technologies for the Gasification of Energy Crops*
  JOR3-CT97-0125
  Provision of data that increase opportunities for fuel flexibility in state-of-the-art fluidized bed gasification concepts, as well as addressing a few restraining factors for the commercial introduction of energy crops.
  AUA contributed in the determination of criteria for larger scale operation, particularly handling and feeding of voluminous fuels (along with CRES and PPC) and in the fuel characterization task. AUA also carried out gasification tests in its own fluidized bed gasifier.
  Completed before 2000.

Chemical Process Engineering Research Institute

- *Compact hot gas clean-up system for particulate removal phase* – 1
  JOF3970047
  Development of a compact hot gas particulate clean-up system by integrating three specifically tailored, advanced high temperature ceramic materials into a novel and cost-effective filter design. CPERI had undertaken the design of the prototype system as well as the evaluation and the selection of the best material.

  Public Power Corporation (PPC)
- Evaluation study of the feasibility for the development of a medium scale power plant fuelled with biomass in Central Greece.
  AL – 2000 - 173

6. Implementation

1 MWe Biomass Fluidised Bed Gasifier Power Plant with Catalytic Conversion of Tars
NNE5/312/2000
Demonstration of the efficient gasification of biomass residues to a fuel gas, the innovative and efficient catalytic conversion of tars, the continuous and stable combustion of the clean fuel gas in a gas engine/generator of nominal rating of 1 MWe, the operational reliability of the complete plant and the significantly lower environmental impact compared to fossil fuels. A greek industry, ENVITEC S.A., have undertaken design and construction of the preatreatment island as well as the gas cleaning procedure. The fuel will be prunings from the municipality of Nea Makri.

Bioelectricity Network
RENA-CT94-0042
A wood fuelled CHP unit has been designed and installed in Elia (prefecture of Evros, Province of Thrace, northern Greece). The unit was based on a downdraft gasifier coupled with a modified Diesel engine. The reactor had a volume of $2m^3$ and the capacity of handling 1 ton of hard wood 20% moisture content per 8 hours, yielding 75 kWe and 240 kWth. Despite the successful operation of the unit, after the ending of the project, its operation was ceased due to administrative reasons.
Completed before 2000.

Gasification Survey Country: **ITALY**

By: Emanuele Scoditti
Date: April 2004

1. POLICY

Main acts and position papers

- National Programme on Renewable Energies from Biomass, October 1998. *(Ministry of Agricultural Policy)*
- Deliberation of the Interministerial Committee for the Economic Planning (CIPE) of 19 November 1998 "Approval of the Guidelines for the National Politics and Measures of the Greenhouse Gas Reduction".
- National White Paper on Renewable Energy Sources, November 1998. *(ENEA, approved by CIPE in August 1999)*
- Laws: D.L. No. 79/99 dated 16 March 1999 "Liberalisation of the electricity market", Decree 401/99 "Incentives for use of agricultural and forestry residues for their conversion into heat and/or power. *Decree 11/11/99 "Green Certificates".*
- DPCM – March 8th, 2002 *(Decree of the Ministries' Council President):* "regulations for fuels affecting the environment as well as the technical characteristics of the combustion plants (including gasification and pyrolysis).
- Law Decree n. 387 of December 19th 2003: for implementing EU Directive 2001/77/EC

Strategy for the promotion of the energetic use of biomass

The Government at national level intends to:

- Establish a permanent form of consultation to assure technical support for the co-ordination of the sectorial policies and the integration of different competence levels;
- Transfer the planning, the promotion and the administration to the Regions and other Local Authorities;
- Promote information and training activities;
- Strengthen research and demonstration projects;
- Simplify the present bureaucratic procedures with certain time schedule.

To increase power by RES, the Government is introducing the following specific measures:

- Decentralised continuation of incentives for the power supplied to the grid, distinguishing the type of source;
- Assure dispatching precedence;
- Compel enterprises, which produce or import electricity over 100 GWh/a to supply a quota from RES not less than 2% (to be reviewed periodically);
- Give priority in the use of RES in isolated grids.
- "Green certificates" (Decree of 11/11/99): energy by RES producers have dispatching priority at current market price and can trade their green certificates to energy producers by fossil, in ad hoc market, in order to accomplish the measure indicated in the first point of this list.

To realise the objectives regarding the bio-fuel use, the Government intends:

- Favour the production and the dissemination of the use by voluntary agreements between Institutions, entrepreneurial associations and users;
- Provide the obligatory use of bio-diesel in the public transport and in pleasure boating, and ETBE in the petrol (if the previous point will fail);
- Increase the quota of bio-diesel exemption from taxes, (this quota was 125,000 t in 1998).

Other Legislative and Fiscal Tools (Law 388/00 "Financial Law 2001")

- Financial support to **"district heating"** fuelled with geothermal and biomass in cold climate areas (20.56 euro/kW for the connection costs and 10.33 –25.82 euro/MWh for heating supply);
- Reduction of excises on bio-ethanol, ETBE and other additives from biomass and tax exemption on bio-diesel (up to 300,000 t);
- Fund financed with 3% of incomes from Carbon Tax for implementing the Kyoto commitments (**CIPE resolution n. 137/98**) by relevant national and regional programmes;
- Specific fund (~130 Ml of euros) to the Ministry of Environment for the sustainable development including a greater use of RES;
- Extra contribution of 103 Ml. euros, in three years, to ENEA budget for the research, development and demonstration of solar thermo-electric plants and fuel cell technologies.

2. PROGRAMS

After Kyoto a Decree on Renewable Energy Sources Established 2,300 MW Power by 2010 for Biomass.

Program for the Valorisation of Agro-Forestry Biomass
Proposed by the Ministry of Agricultural and Forestry Policies, puts forward a structured series of goals, the main are:

- Reduction of GHG emission (3-4% by 2008-12);
- Protection of the land;
- Recouping of nutritional quality of soil;
- Use of agro-forestry biomass and by-products as fuel;
- Development of eco-compatible agricultural methods.

Program "Biomass Fuels" (PROBIO)
Its primary goal is the implementing actions addressed to regional administrations for a greater development of biomass, even through incentive systems coming from other sources.
Financial support for executing this programme is expected for an expense up to about 2.6 million euros starting from the year 1999.

3. R&D INSTITUTES

ENEA, ENEL, University of L'Aquila, Napoli, and Sassari.

4. INDUSTRIES

CCT (Marcegaglia Group), Ansaldo, Technimont (ex Daneco)

5. PROJECTS

R & D projects

- "Clean Energy from Biomass".

Full Name: Biomass-Gasification and Fuel Cell coupling via high-temperature gas clean-up for decentralised electricity generation with improved efficiency.

- *Coordinator*: Università di L'Aquila, Chemical Engineering Dept. (UNIVAQ), Italy

Partners: Italian National Agency for New Technology, Energy and the Environment (ENEA), Ansaldo Ricerche (ARI), Italy - Chemical Engineering Department, (TUV), - Chemical Engineering Dept., University College London (UCL), United Kingdom - Ecole de Chimie, Polymeres et Materiaux, University of Strasbourg (ECPMS), France - Schumacher Umwelt- und Trenntechnik GmbH (SUT), – Germany.

- *Objectives*
  - Promote a new technology, which will help, in the short- to mid-term, a wide scale application of Biomass Gasification and Fuel Cell integrated systems for decentralised power generation.
  - Improve the efficiency of Biomass Gasification and Fuel Cell coupling via innovative, cost-effective, high-temperature gas clean up.
  - Prove the technical feasibility of this integration by operating a pilot plant, which includes catalytic biomass steam-gasification, hot gas purification and a 125 kWe molten carbonate fuel cell.
  - Carry out accompanying research activities in selected key areas, aiming at a reliable simulation of the overall system and catalyst upgrading.
  - Estimate investment and operating costs.

Status: 36th month progress, hot gas clean-up completed, section commissioning in Nov. 2003. Assembly of MCFC stack completed and under testing. New proposal submitted for Hydrogen storage.

6. IMPLEMENTATION

- *SAFI, Greve in Chianti*, 3.5 MW_e.

  Status: Under revamping. (gas-clean-up improvement)

  Reactor: Commercial TPS CFB gasification plant 18 MWth.

  Feedstock: RDF pellets, up to 150 mm long, at a rate of about 3 t/h.

  The TPS gasifier operates at low (2500 mm water) pressure and a temperature of about 875 °C, employing air as the gasification/fluidising agent.

- AMGA Legnano (VA), 1 MWe (two CCT 500 kWe) to be constructed.

Status: changed the gasifiers technology, functional tests on going of two up-draft fixed bed units (gas-clean-up problems).

Demonstration projects:

- *DANECO*, Villasantina (UD), 0.6 MWe. Status: (no recent news)

- Thermoselect, Fondotoce di Verbania, 1.1 MWe. Status: (no recent news).
- *ARI* (Ansaldo Ricerche), Genova. 3.0 MWth fixed bed (up-draft), RDF fuelled. Status: funding and permission requested. *ROSSANO ENERGIA S.p.A.* – Rossano (CS). 4.2 MWe fixed bed (up-draft), olive pits fuelled.

Status: Experimental tests on-going (gas clean-up problems)

Pilot Plants:

- *ENEA Trisaia, 15 kW_e* Downdraft Fixed Bed: Status: experimental tests on going (not continuously).
- *ENEA Trisaia, 80 kW_e* Downdraft Fixed Bed: Status: dismantled
- ENEA Trisaia, Multi-fuel 160 kW_e Fluid Bed: Status: installed in China under revamping (gas cleaning and feeding device).
- *CCT, Gallarate (VA), 50 kWe*: Status: experimental tests on going (no recent news).
- *"Hydro gasifier 500 kWth (Joule III).*

Status: experimental tests on going

Gasification Survey Country: **The Netherlands**

By: Harrie Knoef, BTG, Bram van der Drift, ECN and Kees Kwant, Novem
Date: May 2004

1. Policy

The Netherlands has a strong policy on promotion and implementation of renewable energy. The overall goal is to meet 5% of the nation's energy demand from renewable sources in 2010 and 10 % in 2020 (in 2000: 37PJ or 1.2%). Waste and biomass play a major role in meeting these targets. Fiscal measures, green funds, green certificates and an energy tax have been introduced to create a market for renewable energy.
In 2004 an action plan for bioenergy was annonced to realise the 2010 targets. Large Scale waste incineration with energy recovery, cofiring (as part of a covenant) and decentralised CHP will all have to contribute.
In the Coal Covenant, a voluntary agreement between the central Government and 6 power producers, the latter commit themselves to reduce CO_2 emission of the coal fired power stations with 3.2 million tons per year in 2012 (related to the emissions in 2002).
In 2003 the fiscal support for green electricity was replaced by the non-fiscal MEP-levy (i.e. Environmental Quality Energy Production), that will subsidise Dutch producers of green electricity. Under the MEP the total level of operating support is determined by the sum of the MEP feed-in tariff and the value ecotax exemption. However, the law does contain a maximum feed-in tariff, which is set at 7 €ct/kWh (Article 72p). The government guarantees this total level of support for a period of 10 years after entering into operation. The table 2 gives an overview of the MEP feed-in tariffs, the ecotax exemption, and thus the total level of operating support per renewable electricity category. This MEP support took effect as from July 1st 2003. In September 2003 it was announced that the ecotax reduction for green electricity would be reduced over the next years. This would allow for additional revenues for the Ministry of Finance.

Change after to €ct/kWh	Juli 2003	Jan 2004	Juli 2004	Jan 2005
Ecotax reduction Green electricity	2.9	2.9	1.5	0
Biomass > 50MW (3yr)	4.8	4.0	5.5	7.0
Mixed waste/biomass	2.9	2.9	2.9	2.9
Biomass <50 MW	6.8	6.7	8.2	9.7
Wind at sea/solar	6.8	6.7	8.2	9.7
Wind at land	4.9	4.9	6.4	7.8

Table 2 Feed-in tariffs support Renewable Electricity after July 2003 (€ct/kWh)

2. Programmes

RD&D is funded by both EU programmes and national programmes. The national programmes that are most relevant for biomass gasification are summarised in the table on the next page.
The DEN programme (Renewable Energy Support), that support the development and market introduction of renewable energy technologies, including biomass, that are close to commercialisation is the major instrument with a budget of upto € 4 milion per year for biomass. The program will close in 2004.

Funding for non-fundamental sustainable energy *research* with a somewhat longer tem perspective is subsidised in the programme implemented by SDE (Agency for Research in Sustainable Energy). The focus is on seed research in biomass and infrastructure, and most research projects will be concluded in 2005.
The Netherlands developed a new Research Strategy (EOS) where the focus is on areas with a strong knowledge base and a potential high contribution to sustainable energy supply. Biomass was chosen as a key area and within that the biorefinery and gascleaning as a focus area. The first tenders are expected to start at the end of 2004.

Since	Programme/ Impl. agency	Focus	Technologies	Budget
2001	DEN (Novem)	Demonstration and market introduction	Renewable energy conversion technologies	20 M€ per year ('01 and '02)
1999	SDE (Ministry EA)	Medium-term R&D (seed research)	Biomass conversion and system integration	8 M€ until 2003 (5 year period)
1999	GAVE (Novem)	Medium-term chain demonstration + R&D	Gaseous and liquid energy carriers	14 M€ for chain demonstrations
1997	EET (Novem and Senter)	Medium-to-long-term R&D	Renewable energy (amongst others)	43 M€ per year ('01 and '02)
1997	CO_2 (Senter)	Demonstration	CO_2 emission reduction investments	454 M € in total (since 1997)
2004	EOS (SenterNovem	Research on 5 areas	Biorefinery, power and gasification and gascleaning	For all 5 areas, 35 M€

The GAVE (Gaseous and liquid energy carriers) programme targets the demonstration of new climate neutral substitutes for petrol, diesel and natural gas, derived from biomass as well as from fossil fuels. GAVE aims at demonstrations of entire energy chains - from production up to and including application of gaseous and liquid energy carriers, as well as supporting research and development. Perspective demonstration projects pass an alliance building stage (establishing agreements on joint undertakings between parties comprising the total chain) and a blueprint stage (detailing all technical and organisational aspects of chain demonstration projects) before reaching the actual project demonstration stage.
The EET (Economy, Ecology, Technology) programme supports medium-to-long term research from idea to product in the area of Ecological Environmental Technologies. Renewable energy is one of the five programme themes. The program closed in 2003.
Funding for energy *demonstration* projects is available under various programmes. By far the largest of these is the CO_2-reduction plan, an initiative that focuses on large-scale investments projects that will substantially decrease CO_2 emissions.

3. R&D Institutes

For details: www.biomasster.nl

ECN:	Energy Research Institute, fixed bed and CFB gasification 0.7 MW_t. Gas cleaning, incl. tar removal/conversion www.ecn.nl
KEMA:	Research for the power producers and utilities www.kema.nl
TNO:	Research linked to waste combustion and pyrolysis, modelling www.tno.nl
BTG:	Research on biomass, fixed bed and fluid gasification. Research on tar conversion, tar protocol www.btgworld.nl
Gastec:	Research on gas utilisation www.gastec.nl
Ecofys:	Consultancy and research www.ecofys.nl
Universities:	Univ. Utrecht: studies, research TU Delft: pilot CFB 2 MW_t gasifier TU Eindhoven: gasification research Univ. of Groningen: gas cleaning

4. Industries

KARA Energy Systems: Almelo, up to 250 kW_e fixed bed gasifiers, www.kara.nl
Host : Hengelo: fixed bed gasification 60 – 700 kWe, CFB gasification 0.2 - 8 MWe, www.HoSt.nl

5. Projects

R&D projects (see also www.biomasster.nl and www.den.novem.nl)

- Mixing of fuels to minimize the risk of agglomeration (ECN, Essent) running from Nov 2001 until June 2003
- HELGA: development of a novel fluid bed gas cooling system for biomass gasfication (ECN, Geurts) running from March 2004 until March 2004
- Duration test (1000 hrs) of biomass gasification chain CFB-cooling-gas cleaning-gas engine (ECN, HoSt, Habo, Dahlman, Essent) running from Feb. 2004 until March 2005
- OLGA: development of an advanced tar removal system based on oil (ECN, Dahlman) running from Feb. 2002 until Dec. 2005
- Syngas: inventarisation of production methods and applications (ECN) running from Dec. 2003 until Feb. 2004
- GASREIP C: development of product gas cleaning system (ECN, HoSt) running until Dec 2003
- Micro Gas Turbines: firing a micro gas turbine with biomass gasification product gas (ECN, Geveke, COGEN, HoSt) running from March 2003 until Dec. 2004
- SNG production from biomass and waste (incl bench-scale facility) (ECN, Gasunie) running from Aug. 2001 until Nov. 2005
- EARS: development of an early recognition system for fluid bed agglomeration (ECN, TUDelft, Essent, IPCOS) running from Nov. 2001 until Sept. 2005
- TACOS: development of a tar control/measurement system (ECN, Michel Instruments) running from March 2003 until Sept. 2004
- Cleaning of waste water from gasification (ECN, HoSt) running from April 2002 until Jan. 2003
- CFB-TREC: development of a low tar gasifier (ECN, HoSt, GIPEC) running from Oct. 2001 until May 2003

- Higher carbon conversion CFB gasifier (ECN, HoSt) running from Nov. 2001 until Jan. 2003
- Two-stage gasification and fuels cell combination (ECN, Siemens, GIPEC) running from Feb.2004 until March 2006
- High-efficiency co-production of SNG and Fischer-Tropsch fuels (ECN, Shell) running from April 2002 until June 2003
- R&D support for European tar measurement standard within CEN framework (ECN, Several partners) running from Jan. 2004 until June 2005
- SACHA: Chlorine and sulphur removal in product gas for high Cl and S fuels (ECN, Siemens, Solvay, HaboLek, Host, Geveke) running from Jan. 2004 until June 2005
- Supercritical gasification for H2/SNG production (ECN, BTG, Utwente) running from Aug. 2003 until March 2004
- Techno-economic assessment of the potential of bioH2 (ECN) running from May 2002 until Dec. 2002
- HoSt: cofiring fuelgas in existing gas fired power plants
- TNO e.o. modelling CFB gasification
- CES: gasification in Torified bed.
- ECN/BTG: tar measurement protocol
- KEMA: The formulation of unit operations in the case of gasification systems
- HoSt/ECN: Gasreip, several projects aimed at cleaning gas from CFB to gas engine specifications
- BTG/UT/Sparqle: supercritical gasification
- BTG/ECN: thermal tar cracking with reserve flow principle

New SDE projects (2 – 4 year, 2.5 MEuro) ***(www.sde-research.nl)***

- Torrefaction for entrained flow gasification (ECN, TUEindhoven, Shell) running from Jan. 2003 until May 2003
- EF Syngas: Entrained flow gasification of biomass (ECN, Shell) running from Jan. 2003 until Dec. 2003
- Gascleaning with plasma reactors (ECN, TUEindhoven, Beth) running until 2003
- Tar and ammonia removal from biomass product gas (ECN, HoSt) running from 2002 until 2003
- Gas cleaning for integrated biomass gasification and Fischer-Tropsch systems (ECN, Shell, UUtrecht) running from 2000 until 2003
- Primary measures to reduce tar formation in fluidized bed biomass gasification (ECN, TNO-MEP, KEMA, UTwente, TUEindhoven) running from 1999 until 2003
- Modelling of gasification and tar formation
- Secondary measures for tar cleaning by Rotating Particle Separator and plasma reactors

New GAVE projects (www.gave.novem.nl)

Two projects were promoted to the *blueprint phase* in the summer of 2002:

- Methanol production from biomass residues (biomass gasification yields syngas, which is converted with hydrogen into biomethanol). Co-ordinator: HGP International. Demonstration of the complete chain is envisaged for 2005/2006..
- Production of synthetic natural gas (SNG) from biomass (biomass (co)gasification yields synthesis gas, which through methanisation is converted into SNG). Co-ordinator: TNO-MEP. Demonstration of the complete process is envisaged for 2006/2008.

EET projects (www.eet.nl)

In recent years EET has supported two biomass gasification projects. Both concern limited technical-economic evaluations of technologies involving high technological risks.

- Hydrogen and other fuel gases from aqueous biomass by supercritical water gasification. Partners: Sparqle, Promikron, BTG, and TNO-MEP (Kiem 98.114)
- Green natural gas via hydro gasification of biomass (gasification in a hydrogen atmosphere). Partners ECN, Gasunie (Kiem 20.007)

DEN projects (see R&D-projects)

- Removal of tar biomass gasification
- CES: Tar removal in torbed reactor gasifier

6. Implementations

The 30 MW_e Amergas BV gasifier at Geertruidenberg

The project is in the start-up phase since end 2000 at the Amer Power Station, at Geertruidenberg, to gasify demolition wood (about 150,000 t/y, replacing 70,000 t/y of coal) which cannot be recycled by the chipboard industry. The gasifier is a 83 MW_t low-pressure, Lurgi CFB gasifier, operating at 850^oC. After cooling and cleaning, the product gas is burnt in the pulverised coal fired Amer 9 co-generation unit, using 4 special gas burners, one added to each corner of this corner-fired boiler. The unit has a net production of 600 MW_e and 350 MW_t. Originally, the gas was to be cooled down to 220 ^oC, filtered at that temperature and scrubbed after that to remove ammonia. These cooling and cleaning steps caused many teething problems, and have now been modified: Gas cooling is now in a modified gas cooler to 450^oC and cleaning is limited to particulates removal in a cyclone. Due to an accident in the Amer 9, the gasifier start-up is scheduled for the second half of July 2004.
Contact: W. Willeboer, Essent, tel +31 73 8538624, email: wim.willeboer@essent.nl

The 150 MW_t co-firing CFB gasifier project at Nijmegen by Electrabel

Electrabel operates the 600 MW_e Gelderland-13 pulverised coal fired plant in Nijmegen. Parallel with the existing boiler, it is planned to install a biomass gasification unit with a capacity of 58 MW_e. Biomass input capacity will be 350,000 t/yr, substituting 146,000 t/yr of coal. The biomass to be used will include wood and liquid biofuels like fat and bio-oil, with an average LHV of 11 MJ/kg. The gasification unit will consist of: storage and transport facilities, a CFB gasifier with a capacity of 150 MW_{th}, transport system of the syngas to the firebox of the boiler. Arrangements will also be made to add the biomass directly to the coal conveyor. The permit procedure is still running.
Contact: F.W.M. Penninks, Electrabel, tel + 31 38 4272920, e-mail: frans.penninks@electrabel.nl

The 30 MW_e cofiring project at Hemweg by Reliant Energy

At the 630 MW_e Hemweg pulverised coal power station a biomass gasifier will be constructed, that converts waste wood (some 150-200.000 t/yr, replacing 76,000 t/y of coal) into syngas. After dust removal, the syngas will be fed into the firebox by special burners. The gases will be cooled to approx. 360^oC by producing steam that will be tied in to the existing steam system. The system is equal to the described Electrabel concept. Net power production capacity is 33 MW_e. The Dutch Government has approved a financial support of 12 M€ under the CO_2

reduction plan, and Reliant is now awaiting approval from the European Commission. The plant is scheduled to start operation in 2004.
Contact: A. C. van Dongen, Reliant Energy, tel +31 30 2472835, email: avandongen@reliantenergy.nl

The NUON coal gasifier at Buggenum
NUON Power Buggenum B.V operates a 253 MW_e coal gasification plant in Buggenum (the former Demcolec Power station). The gasifier is based on the Shell gasification process. A part of the coal input (74.000 ton/yr) will be replaced by biomass (chicken manure, dried sewage sludge, sawdust, in total some 200.000 ton/yr). Each type of biomass will be pre-treated to enable it to be added directly to the coal conveyor. Project is waiting for approval of the Board of Nuon. Construction is scheduled to start in autumn 2004. The plant is scheduled to start operation in spring 2005.
Contact: R. Seegers, NUON (tel: +31-6-52505351), e-mail: rene.seegers@nuon.com.

The chicken manure gasifier in Friesland
HoSt B.V. starts the construction of a 3 MW chicken manure gasifier in the north of the Netherlands (Friesland) in 2004. The gasifier is a circulating fluidized bed. The gasifier is based on CFB technology. The gas will be used in a gas boiler to produce heat and electricity. The chicken farm will use the heat. Power will be delivered to the grid. Contact: H.F. de Kant, HoSt B.V., tel + 31 74 240 1843, e-mail: dekant@host.nl

The 60 kW_e BTG/Duis poultry manure CFB gasifier at Bladel
This joint project of poultry farmer Duis V.O.F and BTG was started in September 2000. The aim is to develop a gasification process for manure conversion, which provides at least sufficient energy for system operation and converts manure to non-manure material. The feasibility of gasification was investigated by pilot tests and financial evaluation at the BTG laboratories.
The conversion of more than 600 tonnes of manure per year takes place at about 700 °C in a bubbling fluid bed gasifier. This results in fly ash and producer gas contaminated with particles, HCl, H_2S, ammonia and higher hydrocarbons also referred to as tar. Based on preliminary testing, a gas cleaning system is developed consisting of a rotating particle separator (RPS), a thermal catalytic reverse flow tar cracker (RFR) and a cooler. Particles, HCl and H_2S have already been successfully removed by the first RPS cleaning step by means of using additives while the RFR tar cracker has shown to be able to remove all ammonia and tar from the gas stream. After this cleaning stage, the gas is cooled down from about 800 °C to 40-70 °C in a first-stage air cooler and a second stage water cooler. The hot air is used in the drier while the hot water is stored in a boiler. At this stage the gas is suitable for an internal CHP combustion engine. The first 60 kW_e plant is being constructed in Bladel, The Netherlands. At the moment, the last technical problems with the RPS are being solved and full operation has been achieved for a limited number of hours till now.
Contact: Mr. J. Duis. Email: josduis@hetnet.nl

Downdraft Fixed Bed Gasifier, HoSt
HoSt has built a 200 kW_e downdraft fixed bed gasifier that is located at Boeldershoek near Hengelo. The gasifier has been developed for gasification of shredded waste wood of 1-15 cm. with a maximum moisture content of 25%. The gas cleaning consists of 2 cyclones, an organic and a water scrubber and a sawdust filter. The cleaned gas is fed into a Caterpillar gas engine for production of 200 kW electricity and 440 kW heat. The aim of the demonstration project is to develop an automatically operated, unmanned gasification system with gas cleaning, which can meet the Dutch emission legislation. A special catalyst to reduce the NO_x emissions is

delivered and developed by Steuler. Secondary aim of this demonstration project is to develop this complete gasification installation for a future sales price of less than 3000 Euro/kW_e.
Contact: H. Klein Teeselink, HoSt, tel +31 74 2401807, email www.host.nl

Chicken manure Circulating Fluidised Bed gasifier, HoSt
HoSt is building a 1 MW_{th} Circulating Fluidised bed gasifier coupled to a steam cycle. The installation is designed to gasify 4,000 ton chicken manure a year. The syngas is burnt in a steam boiler, which is coupled to a steam cycle. Through this technique, the necessary heat for heating the stables of the chicken, green electricity and ashes (fertiliser) are produced. The installation saves approximately 305,000 Nm^3 natural gas and produces (in the steam cycle) 525,000 kWh electricity in a year. In two years, the plant will be enlarged with a gas cleaning system and a gas engine to gain a higher electrical yield. The electricity production will rise to 1,260,000 kWh a year.
Contact: H. Klein Teeselink, HoSt, tel +31 74 2401807, email www.host.nl

Table 1 Gasification projects in the Netherlands, status September 2002

Location/initiative	Capacity	Biomass fed	Subsidy	Status
Co-firing				
Amer, Essent	30 MW_e, CFB	Waste and demolition wood	Thermie & CO_2 reduction plan	Starting up after modification
Nijmegen, Electrabel	150 MW_t, CFB	Wood; liquid fuels like fat and bio-oil	CO_2 reduction plan	Waiting for approval
Hemweg, Reliant	30 MW_e, CFB	Residues	CO2 reduction plan	Waiting for approval
NUON Power Buggenum (formerly Demkolec)	Part of 253 MW_{el}	Chicken manure Dry sewage sludge Sawdust	CO2 reduction plan	Waiting for approval
Gasification				
Bladel, Duis/ BTG	60 kW_e, CFB	Chicken litter	EWAB	Testing and problem solving
Hengelo HoSt/ Geveke	200 kW_e, FB	Waste wood	EWAB	Demonstration tests at the WIP site
Tzum, Atsma / HoSt	1 MWt, CFB	Chicken manure	EWAB	Under construction

FB: fixed bed
CFB: circulating fluidised bed

Table 2 Addresses of suppliers and research institutes

Company	Address	Phone	E-mail/website
R & D			
ECN, H. Veringa	P.O. Box 1 1755 ZG PETTEN	+31(0)224-563487	Veringa@ecn.nl www.ecn.nl
KEMA, M. Beekes	P.O. Box 9035 6800 ET ARNHEM	+31(0)26-3562705	m.l.beekes@kema.nl www.kema.nl
TNO-MEP, S. van Loo	P.O. Box 342 7300 AH APELDOORN	+31(0)55-5493745	s.vanloo@mep.tno.nl www.mep.tno.nl
SDE, C. Daey Ouwens	P.O. Box 37107 1030 AC AMSTERDAM	+31(0)20-4923745	Info@sde-research.nl www.sde-research.nl
BTG, H. Knoef	P.O. Box 217 7500 AE ENSCHEDE	+31(0)53-4894490	Knoef@btgworld.com www.btgworld.com
Ecofys, R. van den Broek	P.O. box 8408, 3503 RK Utrecht	+31(0)30-2808300	www.ecofys.nl
Industry			
KARA, K. Reinders	P.O. Box 570 7600 AN ALMELO	+31(0)546-876580	Kara@kara.nl www.kara.nl
CES, van Aurich	Wildekamp 1/b 6704 AT WAGENINGEN	+31(0)317-421114	Ces@gld.bart.nl http://www.pro-ces.nl/
HoSt, H. Klein Teeselink	P.O. Box 920 7550 AX HENGELO	+31(0)74-2401801	Kleinteeselink@host.nl www.host.nl
Jacobs Engineering, F.P. Kerkhof	P.O. Box 141 2300 AC LEIDEN	+31(0)71-5827111	www.jacobs.com
Agency			
NOVEM K. Kwant	P.O. Box 8242 3503 RE UTRECHT	+31(0)30-2393458	k.kwant@novem.nl www. Novem.nl

Gasification Survey Country: **New Zealand**

By: Shusheng Pang (shusheng.pang@canterbury.ac.nz), the University of Canterbury, Christchurch, New Zealand. Representative of New Zealand for Task 33 Thermal Gasification of Biomass, Bioenergy Group, IEA

Date: August 2004

Government Policy:

The New Zealand Government announced its confirmed policy package on climate change in October 2002, setting out its policies for meeting New Zealand's greenhouse gas reduction target under the Kyoto Protocol. The target is to reduce its greenhouse gas emissions to the level they were in 1990, or take responsibility for excess emissions. Government actions have been announced time to time to ensure the achievement of the set target. The policies and actions will enable New Zealand to achieve its international obligations and move the country towards a sustainable energy future, while protecting the nation's economic interests. Policies include price-based and non price-based measures. It is intended that these policies will be added to and adapted over time to meet changes in the international environment and in the dynamics of the Kyoto Protocol.

The climate change policies of introducing an emission charge of no more than NZ$25/tonne from 2007 and offering 'carbon credits' to new cleaner energy projects have brought forward significant new electricity generation proposals. Recently, the Government has offered $NZ6 million ($US4 million) to fund renewable energy research including biomass gasification, wind power generation and solar energy utilisation.

Bioenergy currently contributes about 5% (35PJ) to New Zealand's primary energy supply. More than half of the energy from woody biomass is sourced directly from wood processing residues and domestic firewood sources. The remainder is from black liquor in the pulp and paper industry. Almost all is converted by combustion to give heat energy, although there is a small amount of electricity generated from cogeneration. The wood processing industry is the major consumer of woody biomass derived energy, 25 PJ. The other significant user is residential wood burners consuming around 5 PJ. It is predicted that the woody biomass will supply 50 PJ/year by 2010 from the available forest residues. In the industrial, commercial and domestic sectors, an additional 50 PJ of heat demand is available, which could be based on combustion or co-generation solutions. This would represent a total contribution of over 10% of consumer energy.

In assistant with the promotion of bioenergy, Energy Efficiency and Conservation Authority (EECA) and the Bioenergy Association New Zealand (BANZ) have worked closely with the Government. EECA is a Government Agency with responsibility for government policy and operational matter related to bioenergy. BANZ represents the commercial bioenergy sector and provides a central focus point for liaison with Government agencies, the dissemination of information amongst the industry and long-term positioning of bioenergy into New Zealand's energy system. Other Government agencies involved in the bio-energy area are Investment New Zealand, Ministry of Agriculture & Forestry (MAF) and the Climate Change Office. In addition, some district councils are promoting the use of woody biomass locally as there are potential future electricity supply restrictions to these areas and local generation is being assessed as an option.

National Programs

Industrial Process Heat Programme

The programme, managed by EECA, has the primary focus on encouraging the use of woody biomass as a fuel for the generation of heat and/or electricity in the wood processing industry and other industries such as dairy and meat processing. EECA has commissioned studies into drying of biomass, co-firing of biomass with coal, and the manufacture of and potential market for wood pellets in the residential, commercial and industrial sectors. A national database of existing heat plant (boilers) of all fuel types has been developed to help establish the potential for the use of woody biomass.
Other areas EECA is working in are the use of biogas and other bio fuels such as ethanol.
Programme manager: John Stewart, John.Stewart@eeca.govt.nc

R & D Institute:

Wood Technology Research Centre, Department of Chemical & Process Engineering (CAPE), University of Canterbury, Christchurch
The university has been undertaking research on combustion and domestic utilisation of wood biomass. Recently, the university, represented by the Wood Technology Research Centre, has been awarded a $NZ1.9 million grant to undertake research for four years on biomass gasification technologies for conversion of wood wastes to energy. The research group includes three industry partners and twp research collaborators in New Zealand.
Contact: Associate Professor Shusheng Pang (shusheng.pang@canterbury.ac.nz)

Forest Research Institute, Rotorua.
The Institute has conducted investigation of technologies for combustion and gasification of woody biomass, biogas from anaerobic digestion of MSW and ethanol from wood hydrolysis and fermentation. However, there is no current activity for further development of those technologies.

CRL Energy Ltd, Lower Hutt
CRL is a coal research institute. They have had the facilities to conduct biomass combustion and gasification tests in co-operation with Forest Research. There is no current activity for biomass gasification.

Institute of Technology & Engineering, Massey University, Palmerston North
The University has developed a small downdraft gasifier which was operated under high air pressure to give greater outputs than if naturally aspirated and giving an improved conversion efficiency of about 40%. There is no current activity for biomass gasification.

Industries

Page MaCrae Engineering Ltd. Toruanga

A 1 MWth gasifier has been built to convert wood wastes to thermal energy for the Plywood mill processing. The gasifier has been sucessfully tried to generate clean gas for a gas boiler to supply low/medium pressure steam for log conditioning. Installation of a gas turbine has been planned.
Contact: Bryce Coulter (projex@page-macrae.co.nz)

Fluidyne NZ Ltd

Research and development of large scale tar free gasifiers (1MWe) has continued with the introduction of the Mega Class series in Canada to develop an integrated package of power generating technology. Testing of the Mega Class was conducted between September 2000 – September 2003 providing positive results and a larger Mark 2 Mega Class (3MWe) has now been built for operational testing. It is expected that commercial implementation will commence in 2005.

Parallel development and construction of the gas cooling and cleaning system has now been completed with atmospheric emission testing commencing September 2004. Waste heat collection from the gasifier and cooling system is programmed for late 2004 to early 2005.

Power generation for this project is investigating a multi engine concept using spark ignition engines especially modified for producer gas, to overcome the cost of large singular engines. The ultimate aim of this project is to interface Mega Class gasifiers with appropriate gas turbines when available.

Contact: Doug Williams, Managing Director, Fluidyne Gasification graeme@powerlink.co.nz

AB Power Systems Ltd, Northland

A gasification process using pine wood waste has been developed and built to demonstrate the use of the produced gas with a Caterpillar 170kW engine running on 80% produced gas and 20% diesel. The gasifier is a downdraft type and gas cleaning uses a fabric filter. The process is currently in operation.

Contact: Jack Humphries (powerhearth@clear.net.nz)

Projects

Woody BIGCC technology for NZ
This project is lead by Associate Professor Shusheng Pang, the University of Canterbury, funded by the Foundation for Research, Science and Technology of New Zealand for four years started from 1 July 2004. The aim of the project is to adapt and develop a BIGCC system to utilise the readily available woody biomass in New Zealand for generation electricity and thermal energy. The project involves another two research organisations and three industry partners as listed below:

- University of Otago, Department of Physics, Dunedin
- Deltas Technologies, Dunedin
- Page MaCrae Engineering Ltd. Toruanga
- Meridian Solutions (a business of Meridian Energy Ltd), Wellington
- Selwyn Plantation Boad Ltd, Christchurch

Implementations

The demonstration or small commercial scale of gasification processes are briefed in the Section of Industries of this report.

Gasification Survey Country: **Norway**

By: Morten Fossum, SINTEF Energy Research
Date: march 2001

1. Policy

Governmental funding for bioenergy has increased the last 2-3 years. The national budget presented for 1999 indicate a further increase in financial support for bioenergy project. For the period of 1998 – 2002 the goal is to increase the Norwegian use of bioenergy with 5 TWh. However, with the price situation of electricity and fossil fuels, this increase in energy from biomass can only be achieved by subsidising bioenergy plants.

2. Programs

Governmental funding are channeled to different RD&D programs.

NYTEK support RD&D projects related to renewables and development of technologies.

KLIMATEK supports RD&D projects related to development of technologies and systems that will reduce emission of climate gases.

The programs supporting RD&D normally require industrial participation in the project and the financial support from the program can go up to 50%. For PhD studies the program can give 100% financial support, but encourage industrial participation.

GREP supports PhD studies of more fundamental character.

3. R&D Institutes

SINTEF Energy Research
Norwegian University of Science and Technology
The Agricultural University of Norway

4. Industries

Organic Power AS

Manufacturer of downdraft gasification systems with maximum capacity of approximately 2 MW. The technology is aimed at small-scale energy from waste plants. Web address http://www.opas.no/

Enviroarc Technologies AS

Manufacturer of updraft slagging gasifiers integrated with a plasma reactor with capacities down to 1t/h. The technology is of special interest for energy from waste and also for special or hazardous waste fractions.

Prototech AS

A company developing fuel cells and also integrated systems of fuel cells and biomass gasification.

5. Projects

R&D projects
Gas cleaning system for biomass gasification systems (PhD study)
CHP production based on biomass gasification and co-combustion of fuel gas and natural gas (PhD study).
Gasification of biomass (PhD study, more specific title to be determined).

6. Implementation

The following industrial gasification projects has been realised:

Enviroarc Technologies AS has built a gasification system with CHP at Osterøy outside Bergen. The fuel is tannery waste, which is dried before entering the gasifier. The system includes a 450 kWel gas engine from Jenbacher. The electricity and heat produced in this system is utilised by the tannery.

Organic Power AS has built a 750 kWth gasfication unit for heat production at Tingvoll. The plant will operate on biomass and waste fractions such as paper and cardboard. At the moment the plant is fuelled with biomass, awaiting the necessary approvals The heat is delivered to a district heating system, which supplies heat to municipal buildings in the area.

Organic Power AS has built a full scale 2MW demonstration plant at Notodden.

Gasification Survey Country: **Portugal**

By: Filomena Pinto, INETI
Date: September 2002

7. Policies

The use of biomass for energy is integrated in the overall policy to encourage the utilisation of renewable energies in Portugal. The policy has no specific identification of what processes could be used to employ biomass for energy. This is left to the end-user to select the process.

8. Programs

Currently, there is no specific incentive program to encourage the use of biomass for energy; however, a new legislation to this effect is being prepared. This will provide a special tariff for the power generated and enabling the sale of the excess energy to the grid. This will be applicable to all forms of conversion of biomass for energy. No specific funding program exists for biomass gasification but those interested in using biomass gasification could apply to the following programs for funding: R&D: Program "Ciência", Development: Program "Ciência" and Program POE and Demonstration: Program POE and Program POA. No program is available for the market introduction of biomass gasification.

9. Institutes

INETI is a public institution devoted to Research, Development and Demonstration (R, D&D) and technical, technological and laboratory assistance. It is a corporate entity endowed with academic, administrative and financial autonomy. INETI belongs to the Ministry of Economy and was created with the objective to contribute to the modernisation of Portuguese industry in their effort to undertake new initiatives and assimilate new technologies.
INETI´s scientific and technological activities are integrated in coherent programmes and projects. The priority areas are the following:

- Biotechnology, Fine Chemistry and Food Technology
- Materials and Production Technologies
- Environmental Technology
- Energy Technology
- Information Technology
- Technical Information for Industry
- Technology and Innovation Management
- Training Management and Engineering

Department of Energy Engineering and Environmental Control of INETI

The main areas of activity are:

- Cleaner and more efficient use of fuels
- R,D&D activities with the purpose to introduce new energy technologies in the commercial and industrial sectors
- Demonstration and promotion activities related to energy
- Promotion and increased use of national energy resources, through the use of new and renewable forms of energy

The Department of Energy Engineering and Environmental Control has developed activities related to:

- Fuel characterisation
- Combustion
- Gasification
- Liquefaction
- Pyrolysis
- Fluidised bed technology
- Emissions control
- Use of alternative fuels and wastes for energy production

Gasification Activities

The gasification activities developed at INETI have been the result of co-operation between: INETI, municipal authorities, Industries, Portuguese Government and European Commission, mainly ECSC Programme. The main aims of the work done so far have been:

- Study the effect of using different feedstocks: biomass, plastics mixture and waste materials co-processed with coal (as wastes: paper, composites, textiles and several plastics).
- Understanding of gasification process and the formation of either desirable or undesirable components of the fuel gas.
- Process optimisation to maximise gas yield and quality.
- Production of a high quality gas with heating value acceptable for many end-use applications, such as: electricity and heat production, using gas engines, gas turbines and fuel cells.
- Study steam gasification (with the purpose of reducing the diluting effect of N_2 from air and eliminating the need of an expensive O_2 plant).

10. Industries

There is none.

11. Projects

The most important R&D projects in the area of biomass gasification are:

- 7220-PR/089 — "Comparison of combustion and gasification technologies to process coal and waste mixtures" — "ECSC-European Coal and Steel Community, RTD Programme".
- 7220-PR/078 — "Development of alternative use of marginal coal achieving a thermal improvement blending with biomass (COLIVE)" — "ECSC-European Coal and Steel Community, RTD Programme".

- 7220-PR/142 — “Thermal Improvement of High Rank Coals-Oil Wastes Blends Combustion and Gasification (CO-OIL)” — “ECSC-European Coal and Steel Community, RTD Programme”.

12. Implementatin

A description of the realised demonstration project. (About 20 lines per project with, location, size, fuel, description of system references etc.)

Portugal — Gasification Demonstration Unit

This gasification unit generates combustible gas from the gasification of pine husk, a by-product of the factory main activity. The combustible gas obtained in the gasifier is fed to either a lime kiln or an auxiliary steam generation boiler. A fraction of the gas is also fed to hot gas generator, to help in the drying of the wet pine husks.

The process is done on circulating fluidised bed gasifier. This incorporates two cyclones at the gasifier exit, the first to promote solids recirculation and the second to promote a further removal of the ashes and unburned carbon particles that passed the first cyclone. Between the two cyclones is installed a heat exchanger that promotes the pre-heating of the gasification air.

The main components of this installation are:

- Gasifier PYROFLOW PG-096
- Hot gas generator
- Pine husks dryer including shredding unit
- Drying gases scrubber
- Hopper for the wet pine husks
- Separator / hopper for the dry husks

Gasification Survey Country: **Spain**

By: José L. Sánchez, Aragón Institute of Engineering Research (I3A),
University of Zaragoza
Date: May 2004

1. Policies

In Spain, in what concerns electricity production, Special Regime Producers are distinguished form Ordinary Producers. Production under the Special Regime includes electricity generated by: cogeneration, solar energy, wind energy, hydroelectric power (less than 50 MW), geothermal energy, primary biomass (annual vegetable crops), secondary biomass (including manure, sludge from wastewater treatment, farming and forest residues, bio-fuel and biogas) and urban waste treatment.
Since 1980, electricity production under the "special regime" has been regulated. The 80/1980 law was enacted in order to face the petroleum crisis, with the objectives of improving energetic efficiency and reducing Spanish energetic dependency from abroad. In 1997 the Electrical Sector Law was enacted in order to accomplish the liberalization of electrical market, and, at the same time, to warranty electrical supply minimizing environmental impact. The decree-law 2818/1998 sorted Special Regime producers in different categories and established special bonus (that must be added to market price) on the electricity production for the different categories. In March 2004 this decree-law was abolished by the decree-law 436/2004. In the following table the different categories set by the decree-law are shown:

Category	Group	Description of power station
a	a.1	Cogeneration Stations
	a.1.1	If at least of 95% Natural gas is used
	a.1.2	Rest of cogeneration stations
	a.2	Power production from residual energy
b	b.1	Solar energy (provided than total installed power in Spain is smaller than 50 MW)
	b.2	Wind power.
	b.2.1	Located on land
	b.2.2	Located on the sea
	b.3	Geothermal power, tides power
	b.4	Water power, small
	b.5	Water power, medium
	b.6	Biomass I
	b.7	Biomass II

	b.8	Biomass III
c	c.1	Power from MSW
	c.2	Other residues different from c.1.
	c.3	c.1 and c.2 plus conventional fuel (up to 50%).
	c.1-c.3	c.1-c.3 with installed power between 10 and 50 MW
d	d.1	Power generated during pig manure treatment and reduction, small capacity
		Same but medium capacity
	d.2	Power generated during sludge treatment and reduction, small capacity
		Same but medium capacity
	d.3	Power generated during other residues treatment and reduction, small capacity.
		Same but medium capacity

Special Regime electricity producers can choose between two options to sell the electricity:

- To the electricity distribution company. In this case electricity price is set by a regulated rate. This regulated rate consists in a percentage of the mean or reference electricity rate (also published in a different decree, for 2004 it is 7.2072 c€/kWh).

To the electricity free market. In this case to the market price, it can be added and incentive and/or a bonus (this one is not applicable to all the groups). The incentive and bonus consist in a percentage of the mean electricity rate, fixed by the category of the installation and also the installed power.

The regulated rates and bonus for electricity production from biomass or residues are:

- Group b.6 Biomass I (biomass from energy crops, agricultural or gardening activities, forest exploitation and other activities in forests and green spaces). Regulated rate will be 90 % (of reference rate) the first 20 years of the installation life and after that period 80 %. Bonus: 40 %. Incentive 10 %.
- Group b.7 Biomass II (biogas from anaerobic digestion, farming residues as pig manure, chicken manure, meat-processing residues, sludge from biological wastewater treatment (urban or industrial), biofuels (liquids as vegetable oils, ethanol and ETBE obtained from farming products, or solids obtained by densification or other treatments from vegetable residues). Regulated rate: 90 %. Bonus: 40 %, incentive: 10 %.
- Group b.8 Biomas III (residues from the agro-forestry industry, including residues from food industry, as “orujo”, “alperujo” and “orujillo” (from the olive oil production), olive husk, residues from vegetable oil extraction (from seeds other than olive), residues from wineries, vegetable canning industry, juice production, residues from wood transformation (as bark, sawdust, chips, …), wood pulp production (as black liquor). Regulated rate: 80 %. Bonus: 30 %, incentive: 10 %.
- Group c.1 Municipal Solid Waste. Regulated rate: 70 % during the first 15 years, 50 % afterwards. Bonus: 20 % during the first 15 years, 10 % afterwards. Incentive: 10 %.

- Group c. 2 Other residues not considered in previous groups. Regulated rate: 70 % during the first 15 years, 50 % afterwards. Bonus: 20 % during the first 15 years, 10 % afterwards. Incentive: 10 %.
- Group c. 3 Power stations which use at least 50 % (as low heating value) of residues. Regulated rate: 50 %. Bonus: 20 % during the first 10 years, 10 % afterwards. Incentive: 10 %.

These regulated rates, bonuses and incentives will be revised in 2006.
In December 1999, in tune with the EU, Spanish Government passed a Renewable Energy Promotion Program, which collects the necessary strategies to achieve a growth in all the renewable energy areas such that they will represent, at least, 12% of the primary energy consumption by 2010. This means to double the energy production from renewable sources.

Biomass is recognized inside the Program as the renewable source which requires the biggest boost, in different aspects as the ones related to energetic crops, development and demonstration of fluid bed boilers for specific kinds of biomass, gasification technology and efficiency improvement. In what concerns action lines included in the Program to develop Application Technologies, development of efficient gasification systems, gas cleaning technologies for combustion and gasification gases and efficiency improvement of biomass boilers appear with priority I. Priority II items are fluid bed development for biomass combustion, improvement of feeding systems for combustion and gasification and gas turbines and engines adjustment to gas from biomass gasification. The "Instituto de Diversificación y Ahorro Energético" (IDAE) is the public organization responsible of the promotion and management of the Renewable Program (www.idae.es).

2. Programs

Besides EU Framework programs, support can be asked for from different sources:

- R&D projects of public or private institutions can be funded by CDTI (Centro de Desarrollo Tecnológico Industrial – Industrial & Technological Development Center).
- Funding by Autonomous Community governments, for example Aragonese Government funding for biomass use in energetic progress could cover up to 20% of the project investment. R&D projects in renewable energy could also be funded with up to 20% of the investment.
- PROFIT (PROgrama de Fomento de la Investigación Técnica – Technical Research Promotion Program). Funding provided by PROFIT to R&D projects can be of three different sorts: subsidies, zero interest rate loans or a mixture of subsidy and zero loan. Subject priorities for funding are given in National Programs, even though gasification doesn't appear specifically, in the "Energy National Program" innovative technologies for biomass utilization to produce energy are mentioned, as well as development of energetic valorization of residues (www.mcyt.es/profit).
- The "Instituto de Credito Oficial" (ICO) is a public entity which acts as a financial institution with the aim to promote economic activities which contribute to the growth and better distribution of national wealth. There is an open funding program devoted to projects on renewable energy and energetic efficiency in collaboration with IDAE, which is in line with the objectives of the Renewable Energy Promotion Program. Under the ICO financial program there are 136 M€ available for bank loans. Renewable energy projects include biomass (thermal and electrical) and use of residues for energy production. The loan can be up to 70 % of the investment and initially at a rate of

euribor + 1%. Renewable energy projects can have a discount of 3 % on the rate (which would result in a rate of euribor –2%) depending on an IDAE assessment.

3. R&D Institutes

CIEMAT (Centro de Investigaciones Energéticas Medioambientales y Tecnológicas). Public research institution attached to Science and Technology Ministry. The Fossil Fuel Department researches on biomass combustion and gasification. http://www.ciemat.es.

University Complutense of Madrid-University of Zaragoza. Chemical Engineering Dept. Gasification of biomass and wastes and hot gas cleaning.

University of Santiago de Compostela. Eco-efficiency Group of the Chemical Engineering Dept. They work in pyrolysis, gasification and combustion of biomass and wastes. http://web.usc.es/~eqbaolab/ecoefi.html

University of Valladolid. The Thermal Engines Dept. works in biomass gasification coupled to internal combustion engines, in collaboration with the Mechanical Engineering Dept. of the University of Castilla-La Mancha.

University of Sevilla. The Chemical and Environmental Engineering Dept. is working in different research projects on gasification of biomass and residues in laboratory and pilot plants.

University of Zaragoza. Aragón Institute of Engineering Resarch. The Thermochemical Processes Group researches on pyrolysis and gasification of biomass and other wastes. http://www.cps.unizar.es/~proter.

4. Industries

Cadagua S.A. – Gasification of biomass and residues. Contact information: Gran Vía, 45, 7ª-8ª, P.O. Box 834, 48011 Bilbao (VIZCAYA), Spain, i+d@cadagua.es, phone # + 34 94 481 73 60.

Environmental International Engineering S.L. – This Spanish company (of whom Enerkem is a shareholder) is the licensee of Enerkem's Biosyn technology for Spain, Southern Europe and Latin America. Contact information: C/ Lincoln, 11, 1°, 08006 Barcelona (BARCELONA), Spain, eie@logiccontrol.es, phone # + 34 93 415 40 31, fax # + 34 93 415 72 45, Mr. Ignacio Sanchiz, General Manager. Web site www.eiegasif.com.

EQTEC Iberia S.L. - Energía Natural de Mora, S.L. – EQTEC and Energía Natural de Mora have developed and commercialize a biomass gasification system, based on fluid bed. Contact information: EQTEC Iberia S.L. c/ Princesa 2 3ª 08400 Granollers (Barcelona) Spain, Tel +34938702462, fax +34938702650, email: bcn@eqteq.es, http://www.eqtec.es.
Energía Natural de Mora S.L. Crta N-420, km 821,3 43040 Mora d'Ebre (Tarragona) Spain, tel +34 977 400141, fax +34 977 401112, email: enamora@energiaverde.com, http://www.energiaverde.com.

Gasbi (Gasificación de Biomasa) S.L. – Downdraft gasification systems from 500 kWe. Contact information: Plaza Easo, 3, 20006 Donostia-San Sebastián (GUIPÚZCOA), Spain,

phone # +34 943 469 246, fax +34 943 460973, Mr. Alvaro Senderos, manager, email gasbi@euskalnet.net

Guascor Group – Gasification systems for biomass (between 8000 and 60000 tons per year) and used tires. Contact information: see www.guascor.com (information available in english).

TAIM-TFG S.A. – Downdraft gasification of biomass for heat and power production. Contact information: Crta. Castellón, km 6.3, Zaragoza (Spain), phone # +34 976 50 00 06, Mr. Jorge Gutierrez, jgutierrez@taim-tfg.com.

5. Projects

CIEMAT – CFB gasification of biomass at laboratory, pilot and demonstration plant scales. More information at: http://www.ciemat.es/eng/proyectos/pdcfbiomasa.html

University Complutense of Madrid-University of Zaragoza. Laboratory and pilot plant research on gasification in fluid bed and circulating fluid bed of biomass and wastes with catalytic hot gas cleaning and upgrading of gasification gas.

University of Zaragoza. Hydrogen production from catalytic gasification of biomass. Pyrolysis and gasification of animal residue.

6. Implementations

500 kWe almond shell gasification plant in Mora d'Ebre. This plant gasifies almond shell in a fluidized bed reactor (patented) and is provided with three Gas engines with a total capacity of 500 kWe. It is in operation since 1997.
Actual operating time is 4000 hours/year, with a total time since start-up of 20000 hours. Electric efficiency is 1 kWe/kg biomass (with 3800 kcal/kg and 12% humidity). Initial design and operation has been carried out with almond shell.
Tests have been performed with residue of wood matter from pressed oil-stone (WPSO) with an efficiency of 1.2 kWe/kg WPSO. The plant has been working 200 hours with this material. Other biomasses as wood chips, demolition wood, bagasse from alcohol factories, greenhouse residues, etc. have been sucesfully tested. The company is also starting a R+D program to adapt the gasification plant to handle other residues as dried waste sludge from municipal water treatment plants, scrap tires and others.

More information can be downloaded (in English) at
http://www.energiaverde.com/Demo67in.pdf

600 kWe downdraft gasification plant. The plan is under construction by TAIM-TFG S.A., the start-up period will begin during fall 2002. It is provided with a gas cleaning system and a Jenbacher internal combustion engine.

Poligas Gasification Plant. The plant, located in Ribesalbes (Castellon) and owned by a Spanish consortium in which EIE SL is a majority shareholder, has been designed to gasify up to 25000 tons/year of residual industrial plastics (PE and PP). The synthetic gas, once conditioned, is used in internal combustion engines (GE Jenbacher) to generate electricity. The plant completed the start up in the Fall 2002. GE Jenbacher announced last year that, after installing a Wet Electrostatic Precipitator, the gas engines were running satisfactorily.

Unfortunately, in March 2004 Environmental International Engineering and Poligas Ambiente, the company in charge of the plant, were put into receivership, and currently the plant is not in operation.
Last year Environmental International Engineering had three projects for future plants in Spain:

- Vilaseca Energía. The plant, that would be located in Mora la Nova (Tarragona), would gasify 20000 tons/year of plastic residues to obtain 7 MWe, and 700 kWth for exportation to a nearby industry .
- Totana plant (Murcia). The aim is the energetic valorisation of 42000 tons/year of trimmings of skin and leather, biomass, vegetable wastes and non-dangerous plastics, producing 7.3 MWe.
- Europac Energía (Palencia). This plant would gasify 40000 tons/year of plastic residues from the recycled paper production producing 7.2 MWe and steam for the paper mill.

More details can be consulted at EIE web site www.eiegasif.com.

Guascor Used Tires Recycling Plant. Guascor has built a 12.000 ton/year recycling plant, with an investment of around 12 Million €. The plant, located in As Somozas (La Coruña, Galicia), and is a batch process, designed to operate 8000 hours/year, 2700 batches/year and 4500 kg/batch. Start-up of the plant finished at the end of 2002.
Currently the plant is operating at around 30% of its capacity, gasifying 9 ton/day in two batches. Weight product distribution obtained, based on dry tire fed (not taking into account gasification air, is:
28% of carbon black, sold for asphalt sheet manufacture.
22% of oil, sold for heating purposes in boilers.
75% fuel gas, used to feed two 425 kW Guascor gas engines. About half of the electricity produced is self-consumed and the rest sold to the grid.
20% of steel, which is sold as scrap iron.

Gasification Survey Country: **Sweden**

By: Lars Waldheim and Michael Morris, TPS
Date: July 2004

1. Policy

The main state organisation responsible for energy in Sweden is the Swedish National Energy Agency (STEM), Box 310, 63 104 Eskiltuna. Telephone: +46 16 5442000. E-mail: stem@stem.se. Website: www.stem.se. The aim of STEM is to establish an ecologically and economically sustainable energy system by:

- supporting R&D on renewable energy sources, and
- technology procurement of energy-efficient products, and
- providing investment support for the development of renewable energy

Capital investment grants

In lieu of an international agreement on CO_2 taxation, the Swedish parliament decided in 1991 to support investments promoting renewable energy and biomass-fuelled CHP plants. The total amount of investment support available was about € 450 million, and was designed as a subsidy of € 473/kW installed electric capacity. The programme ended in 2002. Taking advantage of this investment support over the last ten years, a significant number of new CHP plants fuelled by biomass were built, adding several hundred MW capacity to the system. The support led to installation of state-of-the-art technology combustion boilers featuring reduced operating costs, higher efficiency and higher availability than previously installed systems.

A national seven year renewables RD&D programme was started in 1998 by STEM to make nuclear phase out feasible. A general multi-billion SEK national programme for investments in sustainable technology on the local level (i.e. LIP) was in place up until 2001. It has now been replaced by a new programme, KLIMP, which has a greater focus on energy.

Targets of energy policy

Energy policies that still have a bearing on the Swedish situation were enacted in the 1960's when the decision on the programme of rapid expansion of nuclear power was taken, which up to the early 1980's led to the construction and commissioning of twelve nuclear power plants. The oil crises in the 1970's and 1980's caused a rapid change over from fuel oil to other fuels including also an extended use of coal.

In the 1970's, the nuclear programme was debated increasingly, and after the Harrisburg accident, the labour party government consented to a referendum on the future of nuclear energy. The referendum held in 1978 decided that nuclear power should be phased out completely by 2010, starting in 1986. Public distrust in that the referendum decision would not be implemented also led to a law in the beginning of the 1980's that prohibited development of nuclear reactors and the engineering of new plants.

From the late 1980's, the goal of the energy policy become two-fold, to replace both fossil fuels and nuclear power. This led to a policy of promoting renewable power and heat, as manifested by the introduction in 1991 of the environmental taxation and the investment grant scheme discussed above in Section 0.

In 1996, the electricity market was deregulated, followed by successive changes to metering requirements and other legal aids to also allow household customers to choose the type of contract and supplier.

In 1997, a new energy policy was agreed for Sweden. The objective of the energy policy was to ensure, in both the short- and long-terms, a reliable supply of electricity and other forms of energy on

competitive terms. The programme consisted of two parts: the short-term programme, which was concerned primarily with replacing the loss in electricity production capacity resulting from the closure of Barsebäck 1 nuclear power station, and the long-term programme which concentrated on research, development, demonstration and politically justified measures intended to counter climate change. The short-term programme was concluded in 2002 by the closure of this first nuclear power plant, while the long-term programme continues until 2004. In concrete terms, the policy consisted of a strategy for continued restructuring of the country's energy system by investment subsidies (approx. 25% biomass CHP, 15% wind, microhydro), landfill tax followed by the EU directive prohibiting landfilling of organic materials as well as a programme to demonstrate electricity from biomass by novel technologies, "FABEL".

A new energy policy agreement for Sweden, under the name "Working Together for a Reliable, Efficient and Environmentally Aware Energy Supply" was put in place in 2002. This new energy policy programme intended, among other points, to replace the concluded short-term programme of the 1997 energy policy. Changes in the 2002 energy policy agreement are concerned primarily with the thrust of the guide measures intended to influence developments in the shorter term. The agreement incorporates a longer-term element intended to restructure the energy system through encouragement of electricity production from renewable sources and of more efficient use of energy. A new guide measure, in the form of trading in certificates of electricity production, was introduced in 2003 in order to encourage the production of electricity from renewable sources and with minimum environmental impact. The overall objective is that the use of electricity from renewable sources should increase by 10 TWh/year between 2002 and 2010.

The so-called flexible mechanism for CO_2 was introduced in the climate change bill, that stated that Sweden would decrease the emissions of greenhouse gases by 4% of the level in 1992 by 2012. This implies joint implementation projects in Eastern Europe, five CDM projects and, as mentioned earlier, also trading of emission rights from 2005.

A number of investigations of changes to the tax structure have been made to equalise the taxation between sectors and allow taxation of CHP plants, and also to harmonise with the EC gas and electricity market directives. These have not yet been implemented as some of the consequences would be contrary to other policy goals, e.g. the increased use of biomass.

A special investigator has been nominated to supervise if the power supply conditions in Southern Sweden are such that also the Barsebäck 2 nuclear power plant could be decommissioned, to arrange by negotiations with the owners of nuclear power plants a phase out programme similar to that used in Germany, whereby the total production is capped and the plants could be phased out according to lifetime and economic considerations, and also to consider abandoning the time limit of 2010 set by the referendum. This is the first time the verdict of the referendum has been revisited, and following the Finnish decision in 2003 to start the construction of a new nuclear power plant, also a review of this issue has been seriously voiced. In addition, the introduction of natural gas has been strongly advocated recently, as a result of proposed tax changes, which would have a strong impact on the market potential of biomass.

All these investigations and future uncertainties has decreased the willingness to invest in new biomass capacity in recent years.

In September 2003, the Commission on Energy Technology and Development submitted its report on evaluation of the long-term elements of the 1997 energy policy agreement. The report states that although the various research, development and demonstration projects that have been carried out are both relevant and of good quality, they are not alone sufficient as a driving force for restructuring the country's energy system. The report includes proposals for a broader long-term energy policy programme, starting in 2005.

In 2003, the Swedish Government introduced a pilot scheme to introduce biofuels in the transport sector by allowing tax and duty exemptions for quota imports of such fuels, notably ethanol and RME. It also appointed an investigator to propose national objectives and strategies for continued work on the introduction of renewable motor fuels, in accordance with the EU Renewable Motor Fuels Directive. The investigator will look at the requirement for petrol

stations to supply at least one renewable-based motor fuel by 2005, and will also investigate the feasibility of introducing some form of motor fuels certificate, similar to that used for electricity produced from renewable sources. An interim report was due to be submitted in February 2004, with the final report at the end of December 2004. In this field, an interagency (National Energy Administration, EPA and Road Transport Authority) published a policy document in 2002 on renewable transport fuels emphasising the need for RD&D in oxygen-blown gasification to synthesis gas, being a key technology to accomplish policy targets.

Fuel and Energy Prices, Taxes, Fees and Other Fiscal Instruments

Fuel and energy prices

The price of different fuels in Sweden, as of 2002, for various customers is given in Figure 1. The commercial energy prices, including taxes, in Sweden from 1970 through 2002 are given in Figure 2.

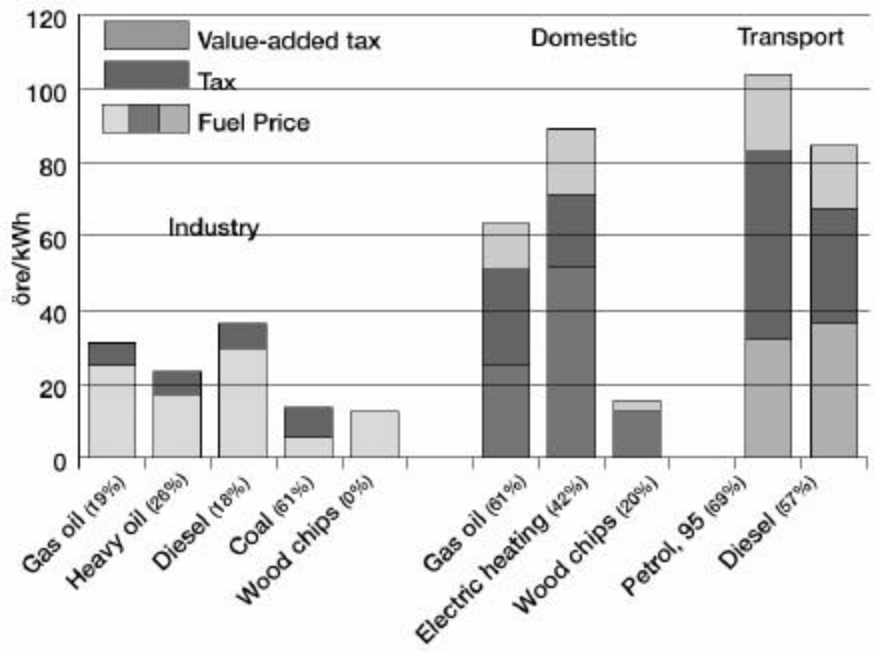

Figure 1 Fuel prices for various customers, 2002 (1 Swedish crown, SEK2 = 100 öre)

2 as of July 2004, € 1= 9.3 SEK

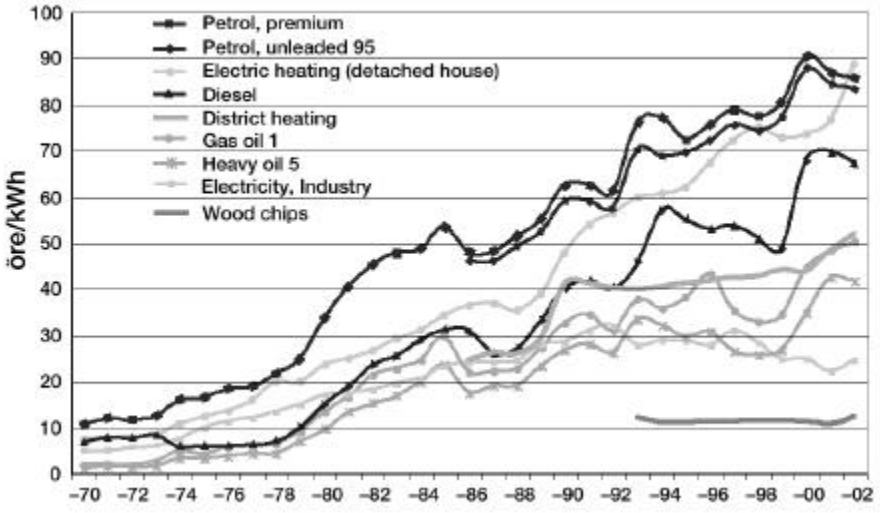

Figure 2 Commercial energy prices in Sweden, including tax, 1970-2002, öre/kWh

The rise in the price of energy in Sweden that occurred from the early 1970's to the mid. 1980's was mainly due to the increase in the price of oil, whilst the rise since then is primarily the result of higher taxation, see below. It is worthwhile to note that the price of electricity for the industrial sector has been stable and low (€ 20-30/MWh) for a long period, this being a result of the production system, deregulation, grid interconnections and last but not least, the policy of not enforcing the same taxes and levies on industry as on other sectors.

The price of wood fuel has been stable in nominal value since the beginning of the 1980's, which means that the price in real value has been falling over the last twenty years.

TAXES AND FEES

In recent years, substantial changes have been made to the taxation system, partly to move from a traditional tax system to a more market-based system (e.g. the introduction of the green electricity certificate system on 1 May 2003).

During the oil crises of the 1970's, the aim of the taxation policy was to reduce the use of oil and increase the use of electricity. The environmental element of energy taxation was given greater importance in the beginning of the 1990's and was introduced in 1991, mainly with the purpose of reducing greenhouse gas emissions. Since Sweden's accession to the EU, there has subsequently been a need to bring taxation into line with EU requirements, and in recent years this has provided the drivers to various studies and proposals.

Present energy taxation policy is aimed at improving the efficiency of energy use, encouraging the use of biofuels, creating incentives for companies to reduce their environmental impact and creating favourable conditions for indigenous production of electricity.

A recent environmental policy is the so-called "green shift" in taxation. The aim of the green shift, introduced in 1999 by the Environmentalist Party forming part of the current Labour Party government parliament majority, is to increasingly tax production of raw materials to increase the efficiency of use of limited resource materials and energy, whilst in proportion decrease the direct and indirect taxes on labour, thereby favourably influencing employment.

The present energy taxation system is relatively complex. There are different taxes on electricity and fuels, on CO_2 and sulphur emissions, and a levy system on NOx emissions. The taxes can then vary, depending on whether the fuel is being used for heating or as a motor fuel, whether it is being used by industry, domestic consumers or the energy sector and, in the case of electricity, whether it is being used in northern Sweden or in the rest of the country (Table 1 and Table 2). Value added tax on energy was

introduced in 1990, and is at present levied at a rate of 25%, but is deductible for companies and industry.

Table 1 Energy spot taxes for industry from 1 January 2003, excluding VAT (note. changes from 1 January 2004)

Fuels	Energy tax	CO_2-tax	Sulphur tax	Total tax	Tax, öre/kWh
Gas oil, < 0.05% sulphur, SEK/m³	-	544	0	544	5.5
Heavy fuel oil, 0.4% sulphur, SEK/m³	-	544	108	652	6.2
Coal, 0.5% sulphur, SEK/tonne	-	473	150	623	8.2
LPG, SEK/tonne	-	572	-	572	4.5
Natural gas, SEK/1000 m³	-	407	-	407	4.1
Crude tall oil, SEK/m³	544	-	-	544	5.5
Peat, 45% moisture, 0.3% sulphur, SEK/tonne	-	-	50	50	1.8

The general energy tax, which has existed for several decades, and with varying purposes, is payable on most fuels, and is independent of their energy content.

The CO_2 tax, which was introduced in 1991, is levied on the emitted quantities of CO_2 from all fuels apart from biofuels and peat. In 2003, the general level of CO_2 tax was 76 öre/kg of CO_2. The CO_2 tax on fuels was raised by 19% on 1 January 2003, which was intended to increase its impact in relation to the energy tax, and to help to reduce CO_2 emissions. A simultaneous change in the tax reduction rules has had the effect of ensuring that CO_2 tax remains unchanged for manufacturing industry, etc.

A sulphur tax was introduced in 1991, and is levied at the rate of SEK 30 per kg of sulphur emission from coal and peat, and at SEK 27 m³ for each tenth of a percent by weight of sulphur in oil.

Table 2 Energy spot taxes from 1 January 2003, excluding VAT (note. changes from 1 January 2004)

	Energy tax	CO_2-tax	Sulphur tax	Total tax	Tax, öre/kWh
FUELS					
Gas oil, <0.05% sulphur, SEK/m³	720	2 174	0	2 894	29.0
Heavy fuel oil, 0.4% sulphur, SEK/m³	720	2 174	108	3 002	28.4
Coal, 0.5% sulphur, SEK/tonne	307	1 892	150	2 349	31.1
LPG, SEK/tonne	141	2 286	-	2 427	19.0
Natural gas, SEK/1000 m³	233	1 628	-	1 861	18.6
Crude tall oil, SEK/m³	2 894	-	-	2 894	29.5
Peat, 45% moisture, 0.3% sulphur, SEK/tonne	-	-	50	50	1.8
MOTOR FUELS					
Petrol, 95 octane, environmental class 1, SEK/l	2.94	1.77	-	4.71	52.1
Diesel, environmental class 1, SEK/l	1.00	2.17	-	3.18	32.5
Natural gas/methane, SEK/m³	-	1.09	-	1.09	10.9
LPG, SEK/kg	-	1.32	-	1.32	10.3
ELECTRICITY USE					
Electricity, northern Sweden, öre/kWh	16.8	-	-	16.8	16.8
Electricity, rest of Sweden, öre/kWh	22.7	-	-	22.7	22.7
ELECTRICITY, GAS, HEAT OR HOT WATER SUPPLY					
Northern Sweden, öre/kWh	16.8	-	-	16.8	16.8
Rest of Sweden, öre/kWh	20.2	-	-	20.2	20.2
ELECTRIC BOILERS > 2 MW, Nov 1-Mar 31					
Northern Sweden, öre/kWh	19.2	-	-	19.2	19.2
Rest of Sweden, öre/kWh	22.7	-	-	22.7	22.7

The environmental levy on the emission of NOx was introduced in 1992, at a rate of SEK 40/kg of NOx emissions from boilers, gas turbines and stationary combustion plant supplying at least 25 GWh per annum. However, it is intended to be fiscally neutral, and is repaid to plant operators in proportion to their energy production and in inverse proportion to their NOx emissions so that only those with the

highest emissions are net payers. The system therefore provides a strong financial incentive for investments in equipment intended to reduce NOx emissions. The effect has been quantified to a reduction in NOx emissions by 50% on the basis of supplied energy to customers and by 35% on the basis of thermal energy input.

In 2001, an environmental tax ("green shift") was introduced. This environmental tax does not result in a higher overall tax bill but includes increased environmental-related taxes balanced by a reduction in taxes on labour. This transfer of taxation is intended to continue over a ten-year period, to a value of about SEK 30 billion.

Fuels that are used for electricity production are exempt from energy and CO_2 tax, although they are subject to the sulphur tax and NOx levy in certain cases. However, the use of electricity is taxed, at rates that vary depending on in which part of the country the electricity is used, and on what it is used for.

Fuels used for heat production pay energy tax, CO_2 tax and, in certain cases, sulphur tax, as well as the NOx levy. The use of heat, however, is not taxed. In principle, biofuels and peat are tax-free for all users, although the use of peat attracts the sulphur tax. Heat production is taxed differently depending on if it is produced in heat and electricity (CHP) plants, district heating plants or within industry. For CHP plants, the portion of the fuel used for production of the electricity receives a full rebate of energy and CO_2 tax. That part of the fuel which is regarded as producing electricity for internal use is subject to full taxation, while the fuel used for the net beneficial heat pays only half the normal energy tax rate. Manufacturing industry is exempt from energy tax, and pays only 25% of the CO_2 tax (Figure 3). District heating plants pay 100 percent energy- and environment tax (Figure 4). As a result of this taxation, the effective price of oil used in district heating plants is more than tripled and the coal price is increased six-fold compared with the fuel prices without taxes. The cost of biomass ranges from as low as SEK 100/MWh for waste bark to approximately SEK 150/MWh for fuel chips. Refined biofuels are of course more expensive. For the small consumer, all fuels are more expensive than for a larger consumer on a contract basis.

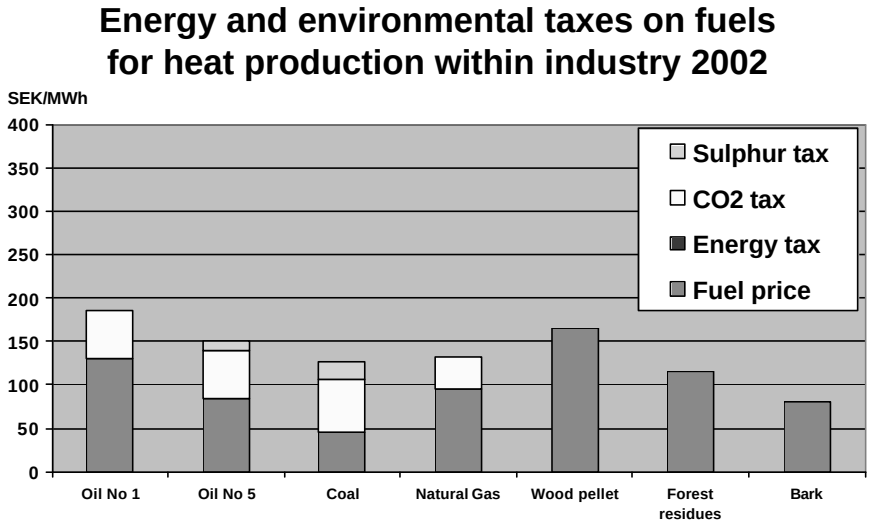

Figure 3 Taxes on fuels for heat production within industry, 2002

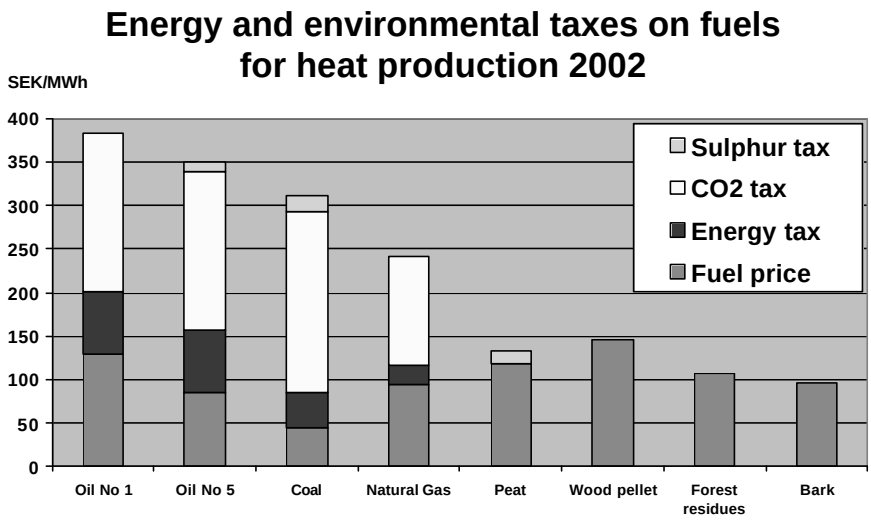

Figure 4 Taxes on fuels for heat production, 2002

In its 2002 energy policy agreement, the Swedish Government proposed changes in the taxation of CHP production in the form of increased tax relief on fuels used in CHP plants for heat production. The effect of these changes would be to bring them into line with tax on industry, and would encourage electricity production in CHP plants rather than in cold condensing power stations, in which a large quantity of the process heat is rejected. The EU Commission has approved this proposed changed, which came into force on 1 January 2004. This means that all the fuel(s) used will be assigned to the respective taxation regime in proportion to the total amounts of electricity and heat produced.

The environmental taxation was strengthened in January 2004 by increasing the CO_2 tax by 18% to 91 öre/kg, the energy tax on electricity by 1 öre/kWh for non-industrial users and introducing a modest 0.5 öre/kWh electricity tax also for industry, whilst the rise in taxation for diesel fuels was 10 öre/litre.

The Taxation Reduction Committee (SNED), submitted a report to the Swedish Government in April 2003, which included a proposal for a new energy taxation model, giving equal treatment in terms of taxation to all commercial activities. It was suggested that two sectors, the energy conversion sector and the services sector, which were previously taxed on the same basis as domestic households, should instead be taxed on the same basis as industry. This proposal was however rejected prior to reaching parliament.

To stimulate the introduction of biofuels for transport purposes, in view of EU Directive 2003/30/EC, quotas have been given for the period 2003-2006 to importers and producers of liquid fuels, etc. that give them permission to import ethanol and RME without being charged import duties. These fuels are also exempt from energy taxes and, since they substitute fossil fuels, deprive the state of income from the CO_2 tax equal to approx. SEK 9 billion (€ 1 billion) for the period. For this reason, other methods to enhance the use of biofuels for transport purposes are discussed, as otherwise the cost of meeting the EU target of 5.75% at 2010 would be prohibitive, see Section 0.

OTHER NON-FISCAL INSTRUMENTS

Recently, the use of taxes has been complemented by so-called “market-based mechanisms”. One of the drivers of this system is that, in comparison to subsidies on specific technologies, etc. that have been the main policy instruments in the past, market-based mechanisms are technology neutral and hence more apt to give an optimal resource allocation by competition. Another factor that should not be overlooked in the light of the EU Stability and Growth Pact that caps public spending and budget deficits is that such subsidies and costs no longer form part of the government budget as trading is made externally on the market. Three such non-fiscal instruments have been introduced or are discussed in Sweden.

Green electricity certificates

Since 2003, a scheme and organisation for electronic registration and trading with electricity certificates has been in force in Sweden. The purpose is to stimulate the production of renewable electricity by providing the producers an additional income on top of the revenues for electricity sold on the market. The basis for the system, that will continue in this form until 2010, is that the buyers of electricity are obliged to have a certain quota of the electricity bought, 8% in 2004 and 16.9% in 2010, as renewable electricity verified by certificates. This is expected to give an additional 10 TWh of green electricity.

As most buyers are small, the quota obligation is normally automatically transferred to the seller of the electricity, but e.g. industries may register as providing certificates. The certificates are issued monthly to the accounts of the producers on the basis of reported production from facilities that have been validated and registered as green producers of electricity. Certificates have an unlimited time validity and are issued on the basis of one certificate per MWh. When sold, they are transferred from the sellers account to the buyers account.

The buyers of electricity must declare their balance of required certificates and bought certificates for each calendar year in March the following year, and certificates are removed from their accounts and annulated. If their account shows a deficit, there is a penalty payable to the certificate authority of the average traded cost of the certificates that particular year plus a surcharge of 50%. Initially, there is also a guaranteed floor price for the certificates to give the suppliers a secure level of income.

Certificates in 2003 were traded at 20-25 öre/kWh (approx. € 22-27/MWh), i.e. approximately the same price as the average feed-in rate on the electricity market.

Following complaints that the insecurity of an end date of 2010, with no indications of what kind of prolongation is foreseen, limits the bankability of new projects, the minister in charge has declared that this will be addressed shortly.

Emission right trading

Following the EU directive on emission trading, such a system is to start in Sweden in 2005. The first section, 2005-2008, includes energy and industrial plants above 20 MW thermal. A new section is planned for 2008-2112, but no details of this are published yet.

In the preliminary plan of distribution of rights, existing installations have been given rights for 80-90% of their emissions, while planned installations have received less, typically only 60%. The final distribution will be decided in September 2004. The EU penalty for not achieving the balance of emission rights is € 40/tonne until 2008, when it rises to € 100/tonne.

Renewable transport fuel certificates

Based on the discussion above regarding the high “cost” of the present promotion system for transport fuels in force to 2006, as well as from the general aspects of subsidies as a policy instrument in relation to technical neutrality and economic efficiency, other means to achieve the EU targets on use of biofuels in transport are under investigation by a parliamentary committee. A certificate system similar to that used in the electricity sector system is one of the suggestions that will be studied.

SUMMARY OF THE ROLE OF ENERGY TAXES AND FEES

The energy market in Sweden is to a great extent governed by fees and taxes. The Swedish incentives for biomass in industry and for power generation are still rather weak. The Swedish state has chosen to put the strongest tax burden on the domestic heating sector, including district heating since this can be applied without the risk of this sector moving abroad, or that the competitive strength of industry is diminished, resulting in loss of employment. However, the need for convergence of Swedish policies with those of the EU, and also the collectively self-imposed restrictions on government budgetary practices and discipline being implemented jointly within the EU, has caused other more market-like modalities to be considered, and this will probably continue in the future.

Commercial Biomass Gasification Activities, 1997-2003

General overview

Limited commercial development of biomass gasification in Sweden has taken place in different markets during different periods.

In the mid. 1970's, and influenced by similar development in the USA, a waste gasification plant (Motala Pyrogas) was built.

After the second oil crisis, a new process for methanol from biomass "MINO" was developed at pilot scale but not commercialised.

Replacement of oil in existing kilns, e.g. lime kilns and dryers, led to the installation of fixed bed and circulating fluidised bed gasifiers (CFBG). One plant for district heating was also built. As a result of falling oil prices after 1986, no further gasifiers for these applications were built.

During the 1990's, expected future higher power prices led to the development of gasifier/gas turbine combined-cycle (BIG-CC) both at pilot plant and semi-commercial scale.

Figure 5 and Table 3 give an overview of existing "commercial" gasifiers in Sweden. Further details on these gasifiers are given below, as well as descriptions of other technologies related to biomass gasification such as waste and black liquor gasification.

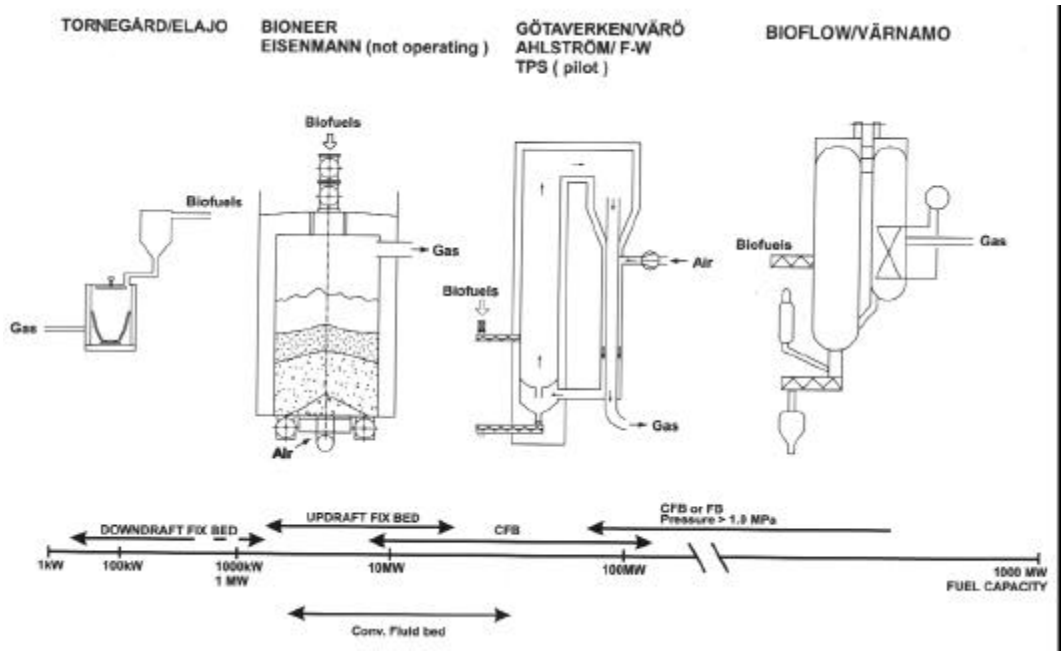

Figure 5 Commercial biomass gasifiers in Sweden

Downdraft gasifiers

The well-known Swedish "World War II" downdraft experience is kept alive to some extent at "Statens Maskinprovningar". This is today a part of SP (the National Institute for Standards and Testing) and collaborates with the Agricultural University in Umeå. Until a few years ago, some downdraft gasifier development and testing still took place related to its use for substituting diesel in modern turbocharged engines.

Some development of small-scale downdraft gasifiers coupled to Otto engines for use in developing countries took place in the early 1980's at the Royal Institute of Technology, Stockholm (Kungl Tekniska Högskolan or KTH) and the Beijer Institute in Stockholm (Kjellström). At Luleå Technical University, a small downdraft gasifier was coupled to an Otto engine, where filter tests were carried out,

but today there are few activities. A few private persons are still engaged in small-scale demonstration activities.

Table 3 "Commercial" gasifiers in Sweden (1985-2004)

Process	Location	Type	Size (MW fuel)	Fuel	Commissioned date	Application	Status
Komako	Filipstad	DD	2	green chips	1986-90	boiler	n.o.
WGE	Oskarshamn	DD	2	RDF, pellets, wood		boiler	n.o.
Eisenmann	Rättvik	UD	6.5	chips, rubber, peat	1986-90	lime kiln	n.o.
Bioneer	Lid	UD	10 (6+4)	wood chips	1986	boiler/dryer	operating
Bioneer	Vilhemina	UD	5	sod peat	1986	boiler	operating
Foster Wheeler	Norrsundet	CFB	20	bark/wood chips	1983	lime kiln	operating
Foster Wheeler	Karlsborg	CFB	25	bark/wood chips	1985	lime kiln	operating
Kværner (Götaverken)	Värö	CFB	35	bark/wood chips	1987	lime kiln	operating
BIOFLOW	Värnamo	PCFB	18	wood chips	1994-96	IGCC	operating (test unit)
Kværner	Frövifors	EF	4	black liquor	1993	boiler	operating (test unit)
Chemrec	Piteå	EF	0.5	black liquor	-	pilot	planned

DD = downdraft reactor
UD = updraft reactor
EF = entrained flow reactor
n.o. = not in operation

Another effort in Sweden related to downdraft gasifiers is from the inventor Olle Tornegård. One test unit and two commercial units have been built (Table 3). Poor operational results, mainly related to fuel quality and bed performance led to plant shut down.

Updraft gasifiers

Three updraft gasifiers have been installed in Sweden (Table 3). One gasifier, Eisenmann of Austria, was sold as a multifuel gasifier ready to accept "all" fuels such as rubber, peat, sawdust, green chips and so on. It was installed as oil replacement in a lime kiln (rotation tray type) in Rättvik, Sweden. Start-up problems in the tray dryer as well as in the gasifier delayed continuous operation for several years. Examples of the problems are gas explosion and ash sintering on the reciprocating ceramic grid. After four years of joint efforts from the manufacturer and the plant owner, the plant was finally shut down in 1990.

A more successful updraft gasifier is the "Bioneer" from Finland (Figure 6 and Table 3). The Bioneer gasifier installations have, despite some problems, e.g., with feeding and varying gas quality, been running well on both peat and wood chips. The feeder hopper design has been changed in one of the plants. The major emission problem is NOx with fuels such as peat with a high nitrogen content (250-350 mg/MJ). As a result of extensive experience, the manufacturer, now a subsidiary of Foster Wheeler, seems to know and respect the limits of the downdraft technology. No further units have been sold in Sweden due to the low oil prices after 1986.

CFB gasifiers

The CFB lime kiln gasifiers sold in Sweden were ordered before 1986 when the oil price was high, and ash enrichment in the black liquor recovery cycle was a problem at the powder combustion plant at ASSI, Piteå, Sweden. The three plants, two from Foster Wheeler and one from Kværner (Table 3), are still in continuous operation.

All the CFB gasifiers suffered from start-up and related problems. Gas leakages and explosions in the feed hopper were major problems in the Norrsundet gasifier. Sintering problems led to a special design of the lower part of the gasifier, with easy access to clean out sinters (Foster Wheeler). Multiple gas uses in lime kiln and boiler and "hot dirty gas" valves have been a problem in the Kværner Värö gasifier. Erosion in the valves led to a short valve lifetime. Expansion problems in the hot gas duct were caused

by settling of dust, which then required unforeseen insulation of the lower part of the duct. Problems in the “hot gas” fired dryer were related to the high dust content partly in the hot flue gas furnace and partly in the flue gas cleaning. The low BTU gas combustion characteristics “longer and cooler flame” might, depending on the original design of the rotary lime kiln, necessitate the need for oven and/or burner modification. Recently, in 2003, this gasifier was operated with enriched air to debottleneck the lime kiln in order to increase pulp capacity.

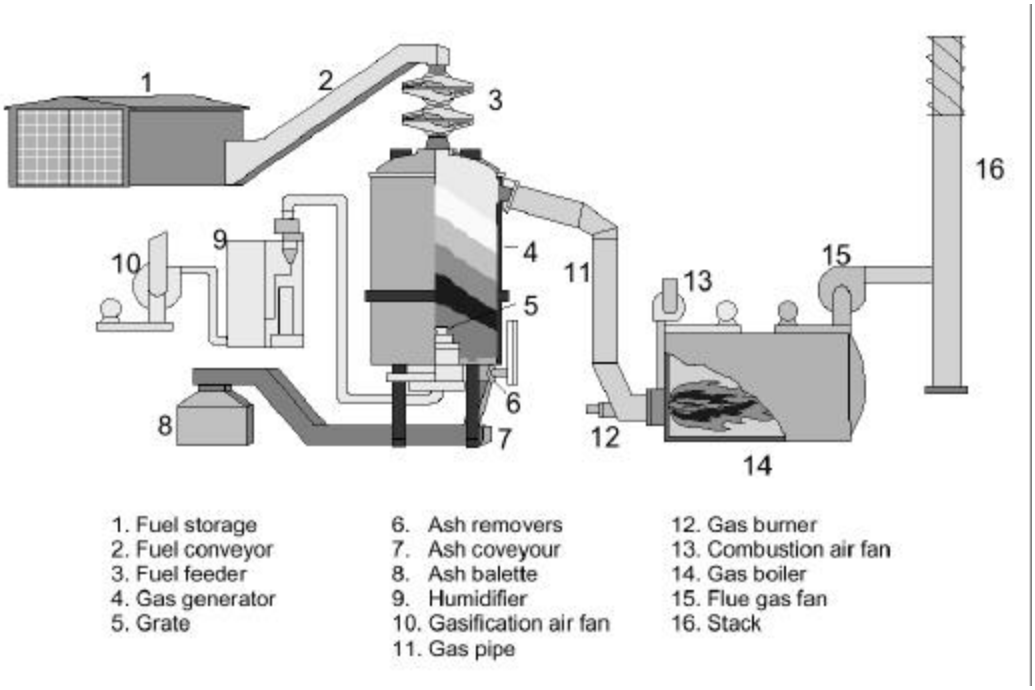

Figure 6 Bioneer updraft gasifier

Despite some operational problems, the CFB gasifiers for lime kilns have been in continuous operation for more than fifteen years and have accumulated more operating hours than any other biomass gasifiers in the world.

Power generation with biomass gasification

Three main routes for power generation from biomass by using gasification have been studied in Sweden:

1. atmospheric gasification coupled to dual fuel engine (3-10 MWe, TPS Termiska Processer AB, TPS)
2. pressurised gasification with hot gas cleaning and IGCC. Either relatively small-scale demonstration (6 MWe, Sydkraft/Foster Wheeler, see Section 0) or large-scale (> 40 MWe, Vattenfall; see below)
3. atmospheric gasification coupled to cold gas cleaning and IGCC at moderate size (10-100 MWe, TPS, see Section 0)

Tampella Power Inc. and Vattenfall AB made a joint effort through Enviropower to develop a biomass-fuelled IGCC system. This system is based on a simplified IGCC process which applies the gasification technology originally developed by the Institute of Gas Technology (IGT), Chicago and an advanced hot gas clean-up system. Enviropower’s gasification pilot plant of 15 MW thermal input (80 tpd on biomass) in Tampere, Finland, was used for research, development and component testing of the gasification and gas clean-up process. Gas turbine combustion tests, using low BTU gas, were carried out at General Electric Power Generation Development Laboratory in Schenectady, USA. Biomass fuel drying tests were executed at commercial facilities of different dryer manufacturers. A novel fuel feeding system was

developed and tested by Vattenfall for the direct feeding of mainly biomass type fuels to pressurised systems.
Full-scale demonstration plants in Sweden and Finland were studied but could not be realised due to high costs and low electric price. Vattenfall then decided to withdraw from the co-operation and later on Kværner bought Tampella Power. A special licence arrangement gave Carbona Inc., the rights to utilise and commercialise the Enviropower/IGT technology.

Waste gasification

Gasification of waste is an interesting option due to the potentially higher yield of electricity, a more stable residue and cheaper gas cleaning as a result of the lower gas volume to be treated.

In ordinary combustion plants, the yield of electricity is limited to approximately 23% by high-temperature corrosion of the superheaters. Cleaning the gas before combustion could increase the electricity yield in a steam cycle to 28%, and, if coupled to a gas turbine, up to 35-40%. TPS has tested the gas cleaning at pilot plant scale. The test indicated that despite a relatively high tar load in the gas due to the fuel's chlorine content, the bag house filters at about 200°C could be used to recover dust, HCl and mercury.

Two TPS CFB gasifiers, without fuel gas cleaning but integrated with a hot gas combustor and advanced flue gas cleaning, have been erected by Ansaldo Aerimpianti and operated outside Florence, Italy (Section 0).

For hazardous waste, a special plasma supported process "ScanArc" has been developed (see later).

Black liquor gasification

Tomlinson boilers have been used and developed continuously for more than 100 years in kraft pulp chemical recovery processes. Their performance is very good in many ways, but there are some limitations in the process, such as a fixed ratio between sulphide and sodium in the melt. To increase the process flexibility and power output, new process concepts such as black liquor gasification are considered. A future black liquor gasification IGCC system could be combined with bark/chips gasification for a power system with high yield of electricity in the pulp and paper industry.

Two different processes have been developed in Sweden. One is from former SKF Plasma Technology and has been developed by Chemrec. The basic idea of the process is to use a suspension gasifier at atmospheric pressure for boosting capacity in the soda recovery cycle instead of installing a new large black liquor boiler. A first demonstration plant (4 tonnes/hour dry substance) was erected at the Frövifors Mill in Sweden and was started up in 1992-93 (see later). A test unit in Karlstad has been operated and plans exist to erect a new demonstration plant including a gas turbine at Assi, Piteå. A grant for this demonstration plant has been awarded by the Swedish State, but has been staged to start with a research programme involving a smaller pilot facility which is currently under construction, and for which there is also paper and pulp industry co-financing. Further details of the process development are given later.

ABB has developed a low temperature CFB gasifier for black liquor. Tests in a small-scale fluidised bed gasifier showed that the carbon content could be reduced to an acceptable level. The fluidised bed has also been shown to work well without any additional fuel except for the black liquor organic. ABB also operated a pilot plant gasifier in Västerås, Sweden, with a fluidised bed reactor both under atmospheric and slightly pressurised conditions. This development is continued by Mälardalens Högskola, Västerås.

PROCESS AND PLANT DESCRIPTION

Commercial plants before 1990 (not in operation today)

See previous reports for details of these older plants.

Commercial plants still in operation

CFB gasifiers for lime kilns

In total, three commercial plants based on atmospheric CFB-gasification with a lime kiln have been erected in Sweden, with the pulp industry as gas customer. All three gasifiers are still in operation today.

The first unit was erected by Foster Wheeler. They proved in practice that by drying the fuel, "flash pyrolysis" and pre-heated air, a rich enough gas could be produced to achieve the desired high temperature in the lime kiln. Other Swedish companies developed similar gasifiers for the same application, e.g. Fläkt/TPS and Kværner. The technical description below concentrates on the Kværner technology and the plant in Värö. The TPS technology is described elsewhere in this report.

Värö plant

The Värö gasifier plant was delivered by Kværner and commissioned in 1987. The plant includes a rotary drum dryer, fuelled by biogas, and fuel pre-treatment (Figure 7). Crushing of the fuel, both bark and wood wastes, takes place in a primary and a secondary hammer mill to achieve the fuel size specification necessary for the gasifier. The feed system consists of two pressurised rotary feeders enabling gasifier pressure balance with cooled transport screws to the gasifier.

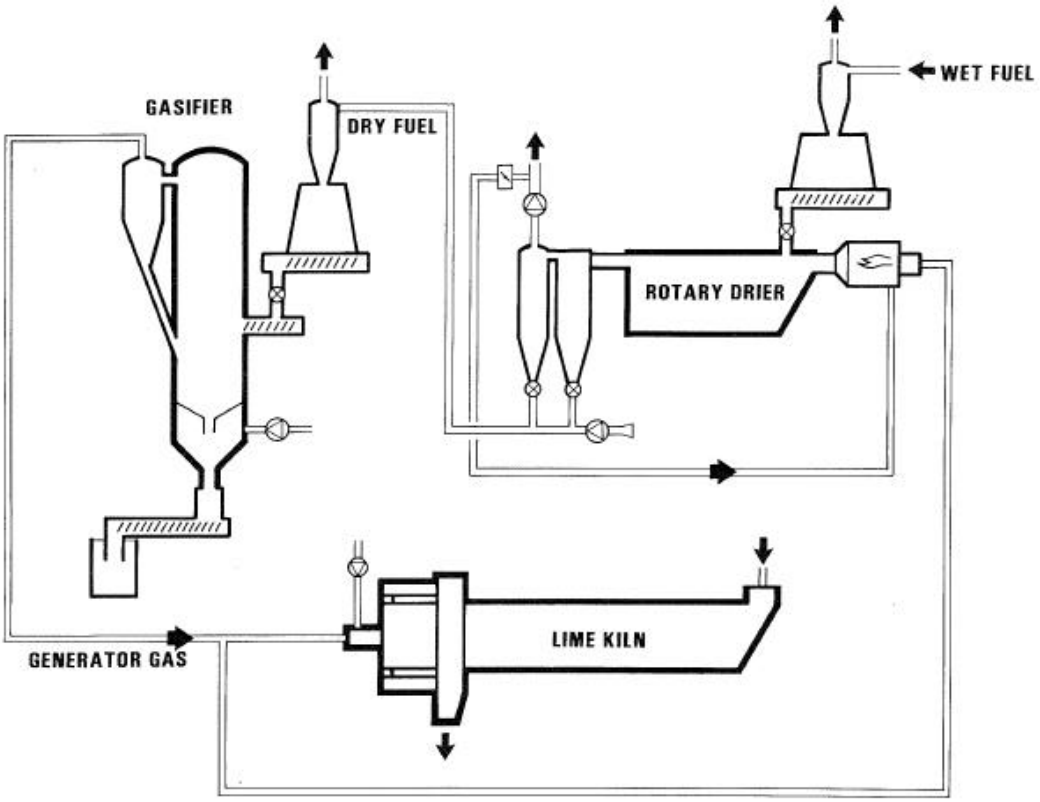

Figure 7 Biomass gasification plant at Värö Mill

The gasifier was developed based on Kværner's CFB combustion experience and gasification experience from KTH. A 2 MW pilot test unit proceeded the erection of the Värö plant. The Värö gasifier is a CFB of 30 MW fuel capacity with the fuel feed placed a few metres above the bottom of the bed to create two distinct reaction zones. In an upper zone, the fuel reacts via flash pyrolysis in the hot bed/inert flue gas atmosphere to a gas rich in C_2:s and also tar.

The lower reaction zone is essentially for char combustion (recycled char) and, to some extent, char gasification. In theory, char combustion/flash pyrolysis should be balanced if the fuel has a small particle size. In practice, and with coarser particles, the zones will be less well defined and separated. To limit the amount of heavy hydrocarbons in the gas and to allow for carryover of bed material to the lime kiln, dolomite is used as gasifier bed material.

The gasifier is a refractory-lined free-standing vessel with solids recycling (Figure 8) and air/gas heat exchange. The product gas is piped to the dryer furnace and the lime kiln controlled by valves.

Operational experience

Normally, the product gas quality is better (HHV) than design figures (

Table 4).

Figure 8 Värö gasifier

Table 4 Physical and chemical data from the Värö gasifier

Temperature (°C)	645
LHV (MJ/nm³)	7
Char (mg/nm³)	12 600
Ash (inorganic) (mg/nm³)	2 500
Al in ash (%)	3
Si in ash (%)	10
Chemical analysis (% vol)	
CO	15.1
H_2	10.3
CH_4	5.1
C_2H_4	1.9
C_2H_6	0.3
CO_2	15.9
N_2	43.5
H_2O	7.9

Due to conservative design of the heat exchangers and pipes (i.e. low velocities), a tendency for char/tar adhesion to the surfaces and settling of dust in the lower region of the horizontal pipes occurred. This led to mechanical problems when restarting the unit (i.e. differential expansion). After a few years, a smaller transport pipe was installed which mainly solved the problem. Severe erosion/corrosion of high temperature control valves occurred and led to a reduction of the number of delivery points for the gas from three to two. Stopping the fuel feed and burning off the depositions every week or second week cleaned the heat exchangers sufficiently.

A single hot gas cyclone is a rather inefficient dust cleaning device when applied to a “dust generator” such as a CFB bed (

Table 4). The high dust content is still a problem that is not completely solved despite many years of operation. To reduce the dust coming from the gasifier a wet scrubbing system has been installed after the cyclones.

During operation of the plant over a period of more than ten years most of the initial problems have been solved. Due to the low oil price in industry (i.e. since it is not subject to environmental tax), the owners of the plant are not interested in extending the plant as no substantial additional investment can be justified.

Status of the technology

Kværner has not built any CFB gasification units since 1987 and are not actively marketing or developing CFB gasification technology. In 2003, the Värö gasifier was operated with enriched air to increase the capacity of the plant. S.E.P. Scandinavian Energy Project AB, Gothenburg, assisted the owner of the gasifier with advice as to its optimal operation.

Development activities

The BIOFLOW (Sydkraft/Foster Wheeler) concept in Värnamo

Sydkraft AB has built the world's first complete IGCC power plant which utilises wood as fuel (Figure 9). The plant is located at Värnamo, Sweden, and the technology used is based on gasification in a pressurised CFB. The gasification technology was developed in co-operation between Sydkraft and Foster Wheeler Energy International Inc. The plant can be operated as a co-generation plant and is cooled by a district heating system or by separate air coolers. The air coolers were installed so that the plant could be operated independently of the heat load while test runs were being performed.

Figure 9 World's first complete IGCC power plant at Värnamo

The Värnamo plant (6 MWe/9 MWth) was constructed during 1991-1993, operated 1993-1999 and was an important step forward in developing highly efficient and environmentally acceptable technologies based on biomass. The aim of the project was to demonstrate the complete integration of a gasification plant and a combined-cycle plant, fuelled by biomass. The idea was to demonstrate the technology rather than to run a fully optimised plant. Flexible and conservative solutions were chosen for the plant layout and design to ensure the success of the project and to make the plant suitable for RD&D activities. The accumulated operating experience at the plant per 1999 amounted to about 8 500 hours of gasification runs and 3 600 hours of operation as a fully integrated plant. The test runs were successful and the plant was operated on different wood fuels as well as straw and refuse-derived fuel (RDF).

The demonstration programme was concluded in 2000 and the plant has been mothballed since then as it is not economical to operate given the commercial conditions prevailing in Sweden. However, significant

efforts have been made to make use of this research facility and for this purpose a new company Växjö Värnamo Biomass Gasification Centre (VVBGC) has been established, see Section 0.

A detailed summary report of the demonstration programme has been published in Swedish and English: Krister Ståhl, Värnamoverket - Demonstrationsprogrammet 1996-2000 (The Värnamo Plant, The Demonstration Program 1996-2000) Sydkraft Miljö och Utveckling, 205 09 Malmö, www.sydkraft.se.

Process description

A simplified process diagram and the components of the gasification plant are shown in Figure 10 and Figure 11.

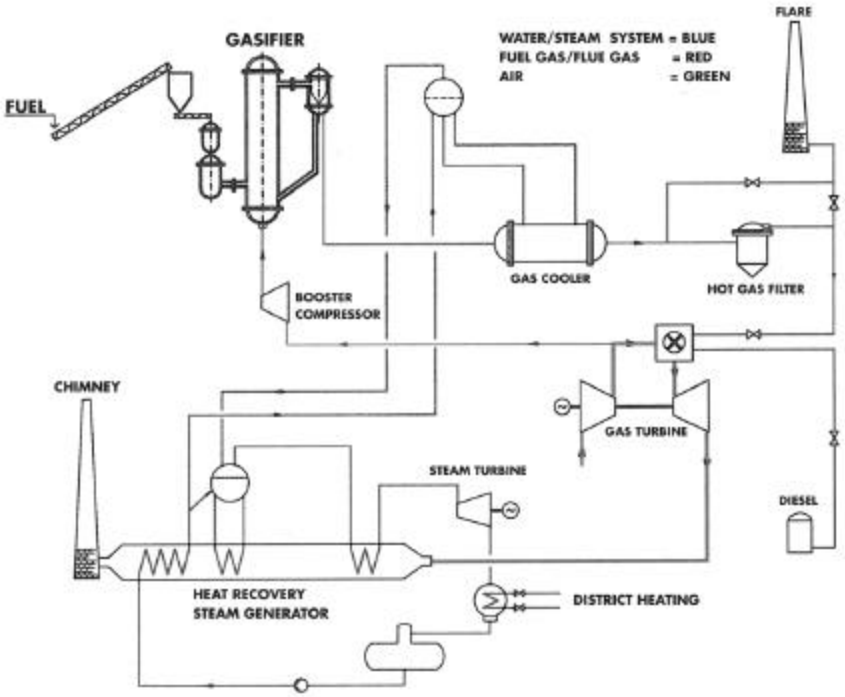

Figure 10 Process diagram of Värnamo plant

The dried and crushed wood fuel is pressurised in a lock hopper system to a level determined by the pressure ratio of the gas turbine, and fed by screw feeders into the gasifier a few metres above the bottom. The operating temperature of the gasifier is 950-1 000°C and the pressure is approximately 18 bar.g. The gasifier is a CFB and consists of the gasifier itself, cyclone and cyclone return leg. All these three parts are fully refractory-lined.

The gasifier is air-blown. About 10% of the air in the gas turbine compressor is extracted, further compressed in a booster compressor, and then injected into the bottom of the gasifier.

The fuel is dried, pyrolysed and gasified on entering the gasifier. The gas produced transports the bed material and the remaining char to the top of the gasifier and into the cyclone. In the cyclone, most of the solids are separated from the gas and are returned to the bottom of the gasifier through the return leg. The recirculated solids contain some char, which is burned in the bottom zone where air is introduced into the gasifier. Combustion of the fuel and gas maintains the required temperature in the gasifier.

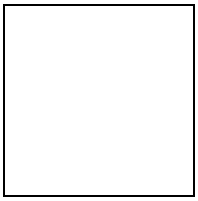

Figure 11 Cross section of the Värnamo gasification plant

After the cyclone, the gas produced flows to a gas cooler and a hot gas filter. The gas cooler is of a fire tube design and cools the gas to 350-400°C. After cooling, the gas enters the candle filter vessel where particulate clean-up occurs. Ash is discharged from the candle filter, as well as from the bottom of the gasifier, and is cooled and depressurised.

The gas produced is burned in the combustion chambers and expands through the gas turbine, generating 4.2 MW of electricity. The gas turbine is a single-shaft industrial unit. The fuel supply system, fuel injectors and the combustors were redesigned to suit the low calorific value gas (5 MJ/m³).

Table 5 Technical data of the Värnamo plant

Power/heat generation	6 MWe/9 MWth
Fuel input	18 MW fuel (85% ds)
Fuel	Wood chips (Several other fuels have been tested with good results.)
Net electrical efficiency (LCV)	32%
Total net efficiency (LCV)	83%
Gasification pressure/temperature	18 bar.g/950ºC
Lower calorific value of product gas	5 MJ/m³n
Steam pressure/temperature	40 bar.a/455ºC
Plant owner	Sydkraft AB

The hot flue gas from the gas turbine is ducted to the heat recovery steam generator (HRSG), where the steam generated, along with steam from the gas cooler, is superheated and then supplied to a steam turbine (40 bar, 455°C), generating 1.8 MWe.

The plant is equipped with a flare on the roof of the gasification building, which is used during start-up and to protect the gas turbine when testing less well known conditions.

Demonstration/development programme

An extensive demonstration/development programme was carried out during 1996-2000. The work was partly performed in collaboration between Sydkraft, Foster Wheeler, Electricité de France and Elkraft. The overall aim of the programme was to verify the status and future potential of the biomass IGCC concept from both technical and economical points of view. In order to achieve this, it was important to identify and verify the status of different parameters e.g. operability, maintainability and availability. Of particular interest to the success of the gasification technology was verification of the quality of the gas produced in the gasifier, as well as operation of the gas turbine.

Experience gained during test operation

The first gas was generated at low pressure in June 1993.

Tests with different bed materials, temperatures and pressure levels, caused deposits to occur at times. During the tests with limestone and dolomite as bed material, recarbonisation of the limestone/dolomite resulted in deposits in the gas cooling system which in turn provided insufficient cracking of high molecular by-products, which caused fouling on the cooler tubes. The use of magnesite (MgO) as bed material in the gasifier proved to be very successful. As magnesite is more expensive than dolomite, tests were carried out to check the feasibility of re-circulating bottom ash, and thus reusing the magnesite drained from the system, these tests proved to be successful. Whilst it was concluded that significant deposits can be handled with a suitable design of gasifier and downstream components, it is still believed that it will be useful to continue testing different bed materials or mixtures of bed materials to further optimise the gasification process i.e. achieve minimum of deposits, cost and best possible gas quality.

Gas quality

During the commissioning as well as the demonstration programme, the gas quality was checked regularly. The hydrogen content in the gas turned out to be slightly lower than predicted, but the heating value was maintained as a result of an increase in methane. A typical range of dry gas composition is shown in Table 6. Gas heating values in the range 5.0 - 6.3 MJ/m³n were recorded.

Table 6 Typical range of dry gas composition in the Värnamo plant (% vol.)

CO	H_2	CH_4	CO_2	N_2
16-19%	9.5-12%	5.8-7.5%	14.4-17.5%	48-52%

Different operating conditions in the gasifier as well as a change of fuel produced different amounts of light tars and benzene, as can be seen in Table 7. Bark tends to produce less benzene and tars than ordinary wood chips.

Table 7 Light tars and benzene content in product gas in the Värnamo plant (mg/m^3n)

Fuel	Benzene	Light tars
Bark 60% and forest residues 40%	5 000 - 6 300	1 500 - 2 200
Pine chips	7 000 - 9 000	2 500 - 3 700

Due to the relatively low combustion temperatures in the gas turbine combustors when burning product gas, thermal NOx was very low. Total NOx emissions could however be higher than on operation on liquid fuel with steam injection due to the conversion of fuel bound nitrogen, mainly ammonia, into NOx. The recorded levels of alkalines were below 0.1 ppm wt.

Hot gas filter performance

The idea behind the hot gas filtration system is to allow gaseous tars to pass through the filter and other tars to stick to the filter cake and not pass into the fine pore structure of the filter itself.

Originally, a ceramic hot gas filter was installed. The ceramic filter showed good filtration efficiency, with stable pressure drop. However, after more than 1 200 hours of trouble free operation, two ceramic candles suddenly broke. The complete set of candles was changed to a new design of ceramic candles and this was installed in the plant. After less than 350 operating hours, one of the new type of candles broke. The breakdown was determined by the supplier to be caused by mechanical fatigue since micro cracking was found in all tested elements.

During summer 1998, it was decided to install metal filter candles in the main hot gas filter instead of the ceramic candles. The metal filter candles were installed in the original filter vessel but with a new tube sheet and back-pulsing arrangement. The metal filter has, like the ceramics, shown very good filtration efficiency, with stable pressure drop. This filter has been in operation for more than 2 500 hours without any filter breakage or other damage during operation. Investigations carried out after the end of the last test indicated that there was no degradation of these elements although they had been exposed to gas and ash not only from wood chips but also from RDF and straw.

Gas turbine experience

The gas turbine installed in the plant is almost a standard Typhoon from ABB Alstom Gas Turbines in Lincoln, England (now operating as Demag Delaval Industrial Turbomachinery Ltd, a wholly owned subsidiary of Siemens). Modified components are the combustors, the burners and the addition of an air bleed from the compressor. A special design gas control module was also developed to control the product gas, steam and nitrogen to the unit.

Already prior to being supplied to Värnamo, the special combustors and burners were tested in a rig in England utilizing synthetic gas. Combustion has always been reliable in the turbine whether operating on gas fuel or liquid. The relatively low heating value of the gas (about 1/10th of natural gas) caused no problem for the gas turbine and a stable flame was always maintained even when the heating value was lower than normal. Not even during earlier operation was it necessary to maintain a pilot flame of liquid

fuel and thus operation during all 3 600 hours as a fully integrated plant was on 100% gas for the LCV gas operating range, i.e. from 40% to full load.

Complete combustion of the hydrocarbons was always achieved with emissions between 1 and 4 ppm only, whereas a slightly high figure of CO was observed with figures up to and sometimes even above 200 ppm on part load.

As mentioned before, levels of NOx around 150 ppm were recorded when operating on gas produced from biomass with high nitrogen content (such as bark), whilst the lower nitrogen content of hardwood considerably reduces the NOx, down to as little as 50 ppm.

Fuel flexibility

During commissioning and the first years of testing, forest residue and wood chips were the fuels generally used. A variety of fuels have however been tested in the plant during the demonstration programme, such as:

- Wood chips
- Forest residue (bark, branches, etc.)
- Sawdust and bark pellets
- Willow (salix)
- Straw
- RDF

All these fuels proved to be easy to gasify without causing deposits or sinter in the systems. Bark has proved to be an excellent fuel and even with feed rates up to 100% bark is easily gasified and the gas is suitable for filtration and gas turbine operation. The high levels of alkalines in willow (salix) did not cause any problems in any part of the system and the amount of sintered/agglomerated material in the bottom ash was very small.

Straw has always been considered a very difficult fuel to burn/gasify due to its high levels of alkaline and large amount of ash in the fuel. Also, the chlorine level is very high in comparison to wood fuels. Tests were carried out with straw mixed with bark, and with 100% straw. About 200 tonnes of straw were gasified without any problems or sintering, and a gas was produced with a hydrogen content slightly higher than normal, which proved to be excellent for gas turbine operation.

Encouraging results were achieved in the tests on RDF, including gas turbine operation on the gas produced.

Conclusions from the demonstration programme

The difficulties encountered initially in the Värnamo project were overcome after a couple of years of intense commissioning and testing.

The Demonstration Programme, started up during 1996, was very successful and proved that pressurised biomass IGCC technology works. The complete plant has been in operation in excess of 3 600 hours with the gas turbine operating solely on product gas produced by the gasifier. Huge experience has been gained from more than 8 500 hours gasifier operation. Results achieved can be summarised as:

- High pressure gasification technology works
- Gas produced can be burnt in a gas turbine under stable conditions
- Hot gas filtration is efficient and reliable
- Technology is capable of gasifying “difficult fuels”
- No harmful effects identified on gas turbine or other components
- NOx emission slightly high at present for some fuels, but solutions available
- Emissions of HC very low and emissions of dioxins below detection level also for chlorine-rich fuels
- The biomass gasification technology is very suitable for retrofit to existing natural gas fired combined-cycle (NGCC) plants

The market potential for the pressurised gasification technology developed at Värnamo can be summarised as follows:

- Industrial back-pressure CHP generation plants, such as for process steam in the pulp and paper industry, will have the highest competitiveness
- The high fuel flexibility shown opens the way for building plants for more difficult fuels, such as straw, RDF and bagasse
- An interesting application may be to supplement a NGCC plant with a gasification plant, so that part of the natural gas flow can be replaced by product gas
- The competitiveness compared to conventional biofuel-fired condensing power plants is promising
- In the shorter perspective, the market will be dependent on political measures for reducing CO_2 emissions

Future activities in the Värnamo plant

During 2000 and 2001, TPS, together with Volvo, LRF, the Municipality of Växjö and others, studied the possibilities of further developing the biomass-based motor fuel DME (DiMethyl-Ether). This is a new, environmentally-friendly diesel motor fuel with extremely low exhaust emissions. In 2001, these companies put together a proposal to use the Värnamo plant to produce 10 000 tonnes/year of bio-DME. However, it was concluded by the industrial companies involved that the risks involved (in economic terms) were too large to be borne by themselves alone.

Since 2000, further efforts to create new partnerships to maintain and utilise the Värnamo plant have been made and two such efforts have met with success.

In 2000, an application was submitted to DG TREN aiming to demonstrate IGCC operation on RDF and to some extent operation on used Tyres Derived Fuel (TDF). The project (the so-called VÄRNAMO - WASTE project) involves Helector S.A., Greece, Sydkraft and CRES, Greece. This contract was signed in 2004.

In 2003, applications were made by several consortia to the EC for financial support for projects aimed at generating a hydrogen-rich gas that can be upgraded to commercial quality hydrogen or a synthesis gas, or for producing methanol, hydrogen, ammonia and DME or Fischer-Tropsch diesel from renewable fuels. One application that was successful concerned a project based on the use of the Värnamo plant, i.e. the CHRISGAS project.

In order to guarantee the availability of the Värnamo plant by public funding, a non-profit project-based company was established at Värnamo by Växjö Energi AB and Värnamo Energi AB, local publicly-owned energy companies, on behalf of Växjö University. This company, named Växjö Värnamo Biomass Gasification Centre (VVBGC) was incorporated in December 2003. The plant and associated IPR were taken over from the previous plant owner in 2004. This arrangement safeguards access to and availability of the plant, including the use of qualified staff for projects interested to use the Värnamo plant. The major projects planned for VVBGC that will use the Värnamo plant in the near future are:

- development of IGCC application for RDF and other waste fuels, including waste tyres, i.e. the VÄRNAMO - WASTE project, see below
- production of clean hydrogen-rich synthesis gas, i.e. the CHRISGAS project, see below
- rebuild of pilot plant to incorporate the production of alternative motor fuels

The VÄRNAMO - WASTE Project

Helector S.A., Sydkraft and CRES have signed a contract with the EU, within the Framework 5 programme, aiming to demonstrate IGCC operation on RDF and to some extent operation on TDF. The Värnamo plant will be refurbished and re-started. Some modification of the plant is also necessary in order to limit the emissions of e.g. sulphur. As a measure to handle this problem, additional testing in a pilot plant will be conducted to test an innovative H_2S removal device and the performance of this system will be evaluated and reported. Also, a new fuel feeding and pressurisation will be considered to be installed to handle fluffy RDF, which is expected to decrease the plant's nitrogen consumption compared to previous operation of the Värnamo plant.

The CHRISGAS Project

Gasifying biomass to a hydrogen-rich synthesis gas and cleaning of the gas by steam reforming and upgrading promises higher efficiencies in the production of hydrogen or liquid fuel for transport purposes. The achievable yield of motor fuel from cellulosic biomass is higher for fuels derived via the gasification/synthesis gas route than via the hydrolysis/fermentation route.

In 2003, the application to DG Research for part funding of the CHRISGAS project met with success. The project is aimed at establishing the necessary design basis for each process step, including test work in the Värnamo plant. The project is scheduled to start on 1 September 2004, and pilot plant tests are to begin in 2006.

During the period 2004-2006, the Värnamo plant will be utilised in the VÄRNAMO - WASTE project, as described above. In parallel, and extending through to 2009, the CHRISGAS project will be operated, using the plant for oxygen-blown gasification to generate synthesis gas from biomass. During 2004 and 2005, the planning of the modification of the plant for the CHRISGAS project will be made. After the VÄRNAMO - WASTE test programme is complete, plant alteration will commence and once the plant is ready for operation again, test work in the CHRISGAS project will begin. Use of the site for gas turbine developments and addition of downstream units to utilise the synthesis gas produced for production of liquid fuels, fuel cells, etc. are also planned to commence in 2006-2007.
The primary objective of the CHRISGAS project is to demonstrate in the Värnamo plant the manufacture of a hydrogen-rich gas from a renewable feedstock, i.e. biomass. The demonstration part of the project consists of a number of tasks for which the objectives are:

- Conversion of several solid biofuels into a medium calorific value gas by gasification at elevated pressure using a steam and oxygen mixture
- Cleaning of the generated gas from particulates in a high temperature filter. Note that hot gas cleaning is advantageous for the overall energy balance when a reformer is applied directly after the cleaning section because reforming requires a high inlet temperature
- Purification of the generated gas by catalytic autothermal steam reforming of not only tars, but of methane and other light hydrocarbons, to generate a raw synthesis gas consisting mainly of carbon monoxide and hydrogen as energy carriers

In order to provide a sound technical background to the process to be installed at Värnamo, a supporting R&D programme on various technical aspects of the proposed process will be conducted, the objectives of which include:

- Studies of the conditioning of the hydrogen-rich raw synthesis gas to the quality stipulated for synthesis gas suitable for manufacture of DME or other potential products
- Studies of the production of these fuels from various biofuels, at the scale and cost representative of typical biomass fuel chains in various regions in Europe
- Development of a feed system based on a piston feeder. The advantages of piston feeding are that the total energy consumption is much lower than that of lock hoppers, the feeder is more compact and the capacity of one feeder can be very large

The proposed modifications to the Värnamo plant can be seen in Figure 12. The most important changes proposed are:

- The gasifier is blown with pressurised oxygen and steam
- A new hot gas filter is positioned directly downstream of the cyclone, and is therefore exposed to a much higher temperature than the previous hot gas filter
- A catalytic high temperature reformer is installed

The partners in the CHRISGAS project are:

from Sweden: Växjö University, TPS, KTH, VVBGC, S.E.P. Scandinavian Energy Project, KS Ducente, Växjö Energi

from Denmark: TK Energi

from Finland: Valutec

from Germany: Pall Schumacher, Forschungszentrum Jülich

from Italy: Università di Bologna

from the Netherlands: TU Delft

from Spain: CIEMAT

The EU will support the CHRISGAS project with a grant of € 9.5 million as part of its Framework 6 programme. STEM will also contribute to the realization of VVBGC as well as financially support the CHRISGAS project and in 2004, € 8 million was allocated for this purpose for the initial two years of the project.

The hydrogen-rich gas can, by means of more or less conventional processing, be upgraded to commercial quality hydrogen or a synthesis gas suitable for the production of liquid fuels. These include a system for the removal of acid gases, notably CO_2 from the raw synthesis gas, followed by compression of the gas to the level of synthesis processes of interest, i.e. 60-100 bar. Such process steps will be studied with the purpose of installing also the downstream upgrading and gas cleaning units at Värnamo at a later date (as an extension of the CHRISGAS project). After completion of case studies, it is likely that three fuel production routes will be considered for this follow-up project, i.e.:

- Hydrogen
- DME/methanol process
- Fischer-Tropsch synthesis

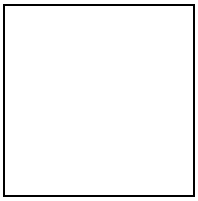

Figure 12 Värnamo biomass-fuelled IGCC process scheme, after proposed rebuilding (Phase 1)

Note. the gas turbine is still in place as VVBGC intends to maintain the capacity to engage in IGCC projects. Assuming that development of a new piston feeding system is successful, and that the feeder prototype is suitable for installation at Värnamo, it may also be installed and demonstrated.

The TPS/Ansaldo RDF Gasification Process - Grève-in-Chianti plant

General

Since the mid-1980s, TPS has worked on the development of an atmospheric-pressure gasification process. The initial driving force for such development was the possibility of fuelling lime kilns with biomass-derived gas. Although TPS was successful in developing a CFB gasifier, no commercial units for this particular application were sold. However, TPS licensed their CFB gasifier technology in the late 1980's to Ansaldo of Italy and provided the design for two RDF-fuelled CFB gasifiers for a commercial plant in Italy (Figure 13). The total process layout (Figure 14) was designed by Tavolini s.r.l. and built by Ansaldo Aerimpianti. The plant is owned by S.A.F.I. (Servizi Ambientali Area Florentina).

Process description

RDF fuel is delivered to the plant in pelletised form. The pellets are fed into the lower sections of the two CFB gasifiers, each of 15 MW fuel capacity. The gasifiers operate at close to atmospheric pressure and at a temperature of approximately 850°C, employing air as the gasification/fluidising agent. Part of the air is injected into the gasifier vessel through the bottom section, the remainder being 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 maximum length of the RDF pellets delivered to the plant is 150 mm (note. TPS has stated that its gasifier can operate on unpelletised RDF fluff and that from the gasification point of view there is no need to pelletise the fuel).

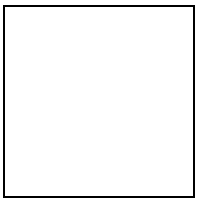

Figure 13 TPS/Ansaldo RDF gasification plant in Grève, Italy

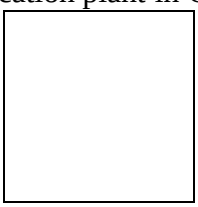

Figure 14 Process scheme of TPS/Ansaldo RDF gasification plant in Grève-in-Chianti

The raw gas from each gasifier passes through two stages of solids separation before being fed to a furnace/boiler. Alternatively, part of this raw gas stream can be led to a nearby cement factory to be used as fuel in the cement kilns. The gas heating value is high, averaging 8 MJ/Nm³. The flue gas exiting the boiler is cleaned in a Research-Cottrell three-stage dry scrubber system before being exhausted through the stack. Steam produced in the boiler drives a 6.7 MWe steam condensing turbine. Due to local restrictions, no flaring of the gas is permitted.

Status

The Grève plant was turned over to the customer in 1993. Pilot tests at 2 MW fuel capacity on RDF pellets were carried out at TPS during 1989-90.

Operational problems in the Grève plant were mainly related to combustion of the gas with high dust content. At times, fuel supply to the plant has been limiting for the operation of the plant until a RDF pellet production factory was commissioned in 1996.

Present situation and future

The original process layout of the plant included a dedicated furnace/boiler and flue gas cleaning system for each of the two gasifiers. To date, only one such line has been installed.

In 1998, the plant was modified to include a second combustion line and a product gas cleaning system comprised of a new cyclone solids separator, a high-temperature acid gas/dechlorination unit, a second cyclone solids separator, and a gas cooler and ceramic filters. The cost of the modification was estimated at € 9.7 million, of which € 1.5 million was provided through the EU THERMIE programme. Information on the plant modifications and the performance of the modified plant and plans for future operation on the plant are not readily available.

In the Italian section of a recent IEA Task 33 Country Report, it is reported that 4 000 and 5 000 tonnes of RDF were processed in 2000 and 2001, respectively. This was presumably prior to any modifications of the plant.

The TPS gasification and hot gas cleaning process - incl. ARBRE plant

During the latter part of the 1980's, TPS worked on the development of a hot gas cleaning process for application to biomass and waste-derived gases based on the use of dolomite as a tar cracking catalyst and absorbent for chloride. This hot gas cleaning technology was first demonstrated over long operational periods at pilot scale in the late 1980's, the gas being fired successfully in a dual-fuel engine. At that time, it was thought that a sizeable market existed in Sweden for the commercial application of TPS's gasification/hot gas cleaning technology to small-scale electricity production plants (say 5 to 20 MWe). Although TPS did not succeed in selling any small-scale plants based on this gasification/hot gas cleaning technology, TPS continued to develop this application for IGCC systems and were successful in having its technology selected for several important projects aimed at proving the technical and commercial viability of biomass-fuelled IGCC systems (see below).

Process description

In the view of TPS, there are three main applications for cold tar-free biomass-derived gas for electricity production:

1. firing of the gas in a furnace/boiler without further flue gas cleaning (Figure 15)
2. firing of the gas in a gas engine/dual-fuel engine
3. firing of the gas in an IGCC system (Figure 16)

The TPS process is described in detail later in the section on the IGCC plant installed in Yorkshire, England (i.e. the so-called ARBRE plant), and is typical of the gasification/gas cleaning technology developed by TPS.

Status

In 1987, the existing 2 MW CFB gasifier at TPS was extended by the construction of a catalytic tar cracker, gas quench and cold gas cleaning equipment, as well as by a 0.5 MW shaft power turbo-charged eight cylinder diesel engine.

By the spring of 1990, the gasification plant had been operated on wood fuel for about 1 700 hours in total. During these tests, the gas cleaning by means of dolomite cracking was successfully demonstrated. The engine was run for more than 700 hours with the expected efficiency, but yielded an exhaust gas with a relatively high concentration of carbon monoxide and hydrocarbons in comparison to combustion boilers.

The main advantage with gasification/dual-fuel engine is that a high yield of electricity can be achieved in small-scale systems (≈ 30% efficiency, 3-10 MW). No commercial or demonstration plants have yet been built.

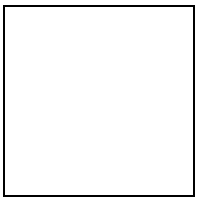

Figure 15 TPS gasification and gas cleaning process scheme

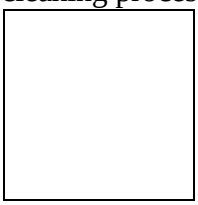

Figure 16 TPS CFBG integrated gasification combined-cycle process scheme

As a part of the Brazilian project (see below), the pilot plant was operated during ten separate one-week tests. In April 1997, the gasifier and cracker was operated continuously for four weeks with an availability better than 90%. Further tests have since been carried out on RDF and on sugar cane bagasse and trash, and mixtures of these two fuels.

As of the early 1990's, two major projects were underway to demonstrate TPS's technology in IGCC application. Both of these projects, the World Bank/Global Environmental Facility (GEF)-sponsored Brazilian BIG-GT project and the EU-sponsored ARBRE project, were due to start-up within the following two years.

Brazilian BIG-GT Project

In 1992, TPS was awarded a contract to further develop gasification technology for application in a 30 MWe eucalyptus-fuelled IGCC plant to be built in North-eastern Brazil (Figure 17). The development work was sponsored by, amongst others, the World Bank and the Swedish National Board for Industrial and Technical Development (NUTEK).

In 1995, the gasification development work was successfully completed and after an evaluation of this technology and a competing pressurised gasification technology proposed by BIOFLOW based on their experience from the Värnamo plant, TPS's technology was selected for use in the proposed plant. The General Electric LM 2500 gas turbine, which will be modified to accommodate the product gas from the gasifier, was also selected for use.

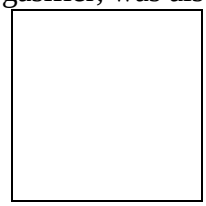

Figure 17 Artist's impression of the Brazilian BIGCC plant

A consortium for carrying out the project, SER, Sistemas de Energi Renovavel, comprising of Shell Brasil, Eletrobrás and CHESF, was established but never became fully operative. With time, company policies and perspectives changed and Shell Brazil withdrew from the project.

Because Eletrobrás is also formally an owner of CHESF, an agreement was made in 2001 with the Ministry of Mines and Energy of Brazil that CHESF would be solely responsible for the implementation of the project. CHESF accepted this responsibility, as far as the World Bank (WB) and GEF concurred in supporting it with the loan and the grant as discussed in the past. The WB was informed of these developments, but ultimately rejected the proposal in favour of the project being pursued by a private company. In early 2004, a private company in Brazil interested in pursuing the project had been found and the World Bank had once again been approached for its approval of this new arrangement.

The capital investment of the plant (equal to approximately US$ 100 million) will be provided by the GEF and the World Bank. The World Bank formally approved the GEF grant in June 1997. A contract is also in place with the EU for them to provide a small part of the required financing (as part of the EU-BR-IDGE project).

Sugar cane biomass application in Brazil and elsewhere

Apart from woody biomass, a huge potential for power generation from waste fuels exists within the sugar cane industry. 1 200 million tonnes of sugar cane is harvested annually, which corresponds to a worldwide electricity production potential of 40 000 MW or 300 TWh/annum in the eighty countries where sugar cane is grown on a significant basis.

Project BRA/96/G31 - "Biomass Power Generation: Sugar Cane Bagasse and Trash" was initiated in 1997 to evaluate and develop the technology required in the complete fuel-to-electricity chain; starting with cultivation and recovery of sugar cane by-product fuels to electric power generation with advanced systems (i.e. BIG-GT) integrated with a sugar mill. Technical needs and other requirements necessary to proceed into large-scale demonstration of a combined-cycle power plant fuelled by sugar cane wastes were to be addressed.

The first phase of the project, organised as an extension of the eucalyptus-based Brazilian BIG-GT project, was estimated to be of 30 months duration with a budget of US$ 7.4 million, financing being roughly split equally between Copersucar and GEF, through UNDP who appointed the Ministry of Science and Technology of Brazil as the project executing agency. In 2000, additional support for an extension of the work was received from the EU ENERGIE programme and STEM as part of the EU-BR-IDGE project.

The participants in the project are Copersucar Technology Center (CTC) of Brazil and TPS. CTC is the technology branch of Copersucar, a cooperative of 36 sugar/ethanol mills in Brazil producing three million tonnes of sugar, 3.2 million cubic metres of ethanol and crushing 65 million tonnes of cane per season. Most of Copersucar's affiliated mills are in the State of São Paulo, Brazil.

The project work plan covered the following five topics:

- evaluation of agronomic routes to green cane harvesting with trash recovery
- evaluation of sugar cane bagasse, and in particular, sugar cane trash availability and quality
- use of bagasse and cane trash in a BIG-GT plant incl. tests in the TPS 2 MW gasification pilot plant
- technical and economic evaluation of the integration of a combined-cycle system in the combined heat and power (CHP) system of a typical Brazilian sugar mill and optimisation of the overall mill facilities
- identification and evaluation of environmental impact

Availability of future agricultural residues from the main producing areas of Brazil was showed to be approximately 40 million dry tonnes, most of it nowadays being burned before harvesting. Based on the assumption that the majority of the sugar cane production will be harvested in the future without burning and, taking into account the recovery factors of cane trash, approximately 20 million tonnes of biomass will be available. This is in addition to the 40 million dry tonnes of bagasse available.

Pilot plant tests on bagasse pellets were performed under two contracts, during 1998 and 1999, and the success of these tests led to an extension of the project, this extension also being a part of the EU-BR-IDGE project, which was to include test work on loose sugar cane trash. These latter tests were made in 2000 and 2001. The availability of the gasification system increased with time to over 90% in the tests, and in the case of bagasse, to an even higher figure. The high chemical reactivity of the organic part of the bagasse and trash results in a high carbon conversion to gas, above 95%. The carbon content of the bottom ash was low. Although agricultural fuels are known to have low ash fusion temperatures leading to operational problems, with careful selection of the operating conditions, no such problems occurred in the tests. The quality of the gas produced indicated that the use of bagasse and cane trash in a BIG-GT process would be possible. The gas generated from cane trash has slightly lower heating value than when using bagasse and other biomass as it has a higher ash content. Also, there are more fuel contaminants in the trash.

On the basis of these tests, conceptual engineering of a bagasse and cane trash-fuelled combined-cycle power plant integrated with a typical sugar mill in Brazil was performed. It was shown that when a gasification plant, based on a General Electric LM 2500 gas turbine, is integrated with a typical mill in Brazil, the net exported power will be 28 MW (or more than 160 kWh/tonne cane), and when a gasification plant twice the size is integrated, the net exported power will be 290 kWh/tonne.

The follow-up step to this project was to evaluate the possibility of demonstrating the BIG-GT technology at commercial scale within a sugar mill in Brazil. MCT in early 2001 gave CTC instructions to develop a proposal for such a demonstration project including capacity of the project, a mill site host, participants, organisation, cost, time schedules, etc. This work was concluded in 2004.

In early, 2004, TPS concluded an UNDP-sponsored feasibility study of the installation of BIG-GT systems in the ageing sugar mills in Cuba.

Project ARBRE

In 1993, the EU agreed to part-finance the construction of at least two short rotation coppice-fuelled combined-cycle plants in Europe, each of 8 to 12 MWe capacity, including Project ARBRE in the UK. Figure 18 shows a simplified process flow diagram of the plant.

In December 1994, the proposed generating plant became the recipient of an UK NFFO3 (Non-Fossil Fuel Obligation, 3rd tranche) contract providing an index-linked price of 8.75 p per kWh (1993, linked to the UK retail price index) guaranteed until 2013.

In December 1995, ARBRE Energy Limited (AEL), the majority owner being Yorkshire water plc, later to be renamed Kelda plc, was formed to implement the generating plant based on the following understanding of the role of AEL:

- to contract with local farmers to cultivate, harvest and transport short rotation coppice (SRC) to the generating plant
- to contract with reputable fuel suppliers to deliver forestry residues to the generating plant
- AEL to award turnkey contract to third party for design, construction, commissioning and performance testing of the IGCC plant
- AEL to award 15 year O&M contract to third party

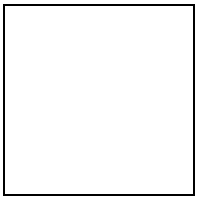

Figure 18 Project ARBRE process flow scheme

In the preparatory work for the RFP documentation, several important technical decisions were made, including:

- based on its proven use in similar applications, the Typhoon gas turbine from Demag Delaval Industrial Turbomachinery Ltd. would be used
- the plant would have a significant amount of supplementary firing in order to achieve the desired 8 MWe output
- the feedstock to the plant would be dried with the waste heat in the flue gas from the gas turbine
- the process design of the gasification plant would be supplied by TPS through a sub-contract to the turnkey contractor, the contract terms of which would be included in the RFP documentation

The ARBRE plant is an IGCC plant comprised of the following major components:

- wood delivery, weighing, reception/storage, drying and feeding
- TPS atmospheric-pressure gasifier, including air supply
- TPS hot gas conditioning vessel (so-called “tar cracker”)
- fuel gas cooling
- fuel gas cold cleaning (i.e. bag filter and wet scrubber)
- fuel gas compressor
- “Typhoon” gas turbine
- waste heat boiler
- steam turbine

The plant was to consume 43 000 dry tonnes of wood per year and its net electrical efficiency was projected to be c. 30%. This relatively low efficiency was a result of the requirement of eligibility for the EU grant that net generation must reach 8 MWe, which after selecting the technically proven Typhoon gas turbine of 4.5 MW could only be achieved by increasing the contribution of the steam turbine cycle to the overall output by firing a third of the gas produced directly into the HRSG, thereby bypassing the gas turbine, such that the plant configuration was not an example of a typical generic combined cycle.

Following the submission of an Environmental Statement in May 1996 and widespread consultation with the local planning authority, local residents, the UK Department of Energy and many other organisations, planning permission for the project was granted in February 1997.

During 1996, the RFP documentation was issued and several companies submitted preliminary offers. During 1996 and early 1997, detailed discussions took place with two companies and in September 1997, a conditional turnkey contract, valued at c. £23 million, was awarded to Schelde Engineers & Contractors BV, the Netherlands. At that time, the planned start-up date for the plant was

early 2000. McLellan and Partners, UK was appointed as consulting engineer to the project and were responsible for managing the turnkey contract.

In April 1998, and only after the plans for project financing had been abandoned and replaced by majority financing by Kelda, could the turnkey contract be made unconditional. At the same time, SEC signed the gasification process design sub-contract with TPS. The plant's O&M contract was awarded by AEL to Schelde Heat and Power (SHP) UK Limited.

Technical Description of the ARBRE Plant

Fuel supply, preparation and feeding

The wood is delivered in chipped form to the plant by truck. The fuel supply, preparation and feeding system consists of a weigh-bridge, a reception pit, an A-frame storage building (providing three days bulk storage), a dryer (which dries the fuel to around 10% moisture content with flue gases leaving the waste heat boiler) plus travelling screws, screws and elevator and conveyors interconnecting these latter three units and also leading to the two gasifier fuel feed silos.

Gas generation and tar cracking

The wood is fed to a TPS air-blown CFB gasifier operating at around 850°C and close to atmospheric pressure, and converted into a low calorific value gas.

The gas produced in the gasifier is cleansed of tars in a tar cracker; a second CFB operating at a slightly higher temperature. By catalytically cracking the tar to simpler compounds in this vessel, the gas can be cleansed of particulates and alkalis in downstream conventional gas cleaning equipment. In addition, this catalytic process means that there is no significant reduction in the chemical heating value of the gas, as would be the case if the tar was thermally cracked at higher temperature.

Gas cooling, cleaning and compression

After leaving the tar cracker, the gas is cooled before passing through bag filters at 200°C to remove fine particulates (fly ash, alkalis condensed on fly ash and chloride as $CaCl_2$). The gas is then cooled further before the final cleaning stage. The heat removed during the gas cooling stages is recycled for boiler feedwater pre-heating and steam raising. The final cleaning stage is a wet scrubbing procedure to condense out any remaining tars and water vapour and remove traces of alkali metals, as well as to remove ammonia using a dilute sulphuric acid solution.

Power plant

The resulting clean gas is then split into two streams and fed to the combined-cycle generating plant.

The main gas stream is compressed and fed to a Typhoon gas turbine with a rated output of 4.75 MW. The hot gas turbine exhaust gases then pass to a boiler for heat recovery and steam generation. The Typhoon single-shaft industrial gas turbine is designed specifically for electrical power generation and cogeneration applications. Its application to biomass-produced fuel gas was proven in the Värnamo plant.

The second gas stream is combusted in the boiler to supplement the gas turbine exhaust heat and generate additional steam. The steam raised in the boiler is combined with that produced in the gas cooler and used to drive a 5.25 MW steam turbine. The steam leaving the steam turbine is condensed in a hybrid cooling plant and returned to the boiler.

Construction and Commissioning of the Plant

Construction work on the site in Eggborough, North Yorkshire began in the spring of 1998.

During 1998, SEC's parent company in the shipbuilding industry, encountered such serious economic difficulties that it was sold, and SEC was ultimately declared bankrupt. SEC's obligations in relation to AEL gradually became impossible to meet and as a result, construction of the plant suffered significant delays during 1998 and 1999. This led to the cancellation of the O&M contract with SHP in 1999, and to AEL and SEC agreeing in 2000 to terminate the turnkey contract. Prior to agreeing to terminate, the start-up date for the plant had slipped to October 2000.

Following the departure of SEC from the project, AEL assumed direct responsibility for plant construction as well as start-up and operation (the plant's O&M activities were to be managed by a team

of 25 persons directly employed by AEL) and, at relatively short notice, had to muster an engineering and site team to finalise the design and construction of what was then found to be ill-documented and poorly designed systems, the true extent of which only became fully evident once SEC's contract had been terminated. The consequential difficulties in completing the work meant that hot start-up could only be commenced in the beginning of 2001, and was then further delayed by inadequate documentation and co-ordination between sub-contractors. Figure 19 shows the ARBRE plant in June 2001.

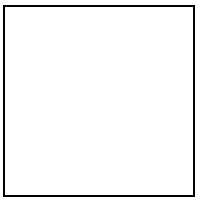

Figure 19 The ARBRE plant in June 2001

Commissioning to mid. 2002

During the commissioning period, the plant suffered operational delays as a result of mechanical problems. However, as of mid. 2002, no long term process problems had been identified. Most mechanical problems encountered were those associated with the movement of solids, including fuel and ash. Most of these teething problems were easily resolved, requiring only small modifications to the systems.

The fuel dryer operated without problems although its integrated operation with the rest of the plant did lead to some difficulties. As more experience with its operation was gained, the drying operation became more easily controllable.

The gasifier and tar cracker operated according to design, although operation in gasification mode did not exceed 70% load, partly because of the limitation set by the gas cooler (see later). The switchover from combustion mode to gasification mode was rapid and trouble-free. The gasifier operated smoothly for a total period of more than 1 000 hours over ten test periods, each of varying duration. The fuels gasified included many different wood species, including that from several of the SRC plantings.

The gas quality data collected from the tar cracker, from the short periods when operating reasonably close to design conditions, indicated that expected LCV and quality could be met (Figure 20).

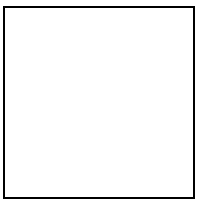

Figure 20 Tar levels in flue gas

Mechanical problems were encountered with the fire tube heat exchanger that cools the gas leaving the tar cracker. As the result of an error in the design calculation and from mal-distribution of the water flow beneath the tube sheet due to being designed with only one riser, the upper tube sheet of the cooler evaporator overheated such that it often limited the load at which the plant could operate. As a result of this design error, it was planned to replace this cooler in mid. 2002 with a cooler of new design. This gas cooler also suffered from clogging, in particular during combustion/start-up conditions, due to recalcination of CaO to $CaCO_3$, but was free from any tar condensation.

No operational problems were encountered with the filter. The wet scrubber was operated over long periods and, other than the need for the inclusion of a system for separation and separate removal of hydrocarbon phases formed, the wet scrubber operated according to design. After passing through the wet scrubber, the LCV gas had a heating value of c. 5.7 MJ/Nm³.

In the beginning of 2002, the gas compressor and gas turbine were operated on LCV gas for the first time, the gas turbine operating on 70% product gas at 80% load for a number of hours at 3.6 MW. Emissions were as expected. During this same period, the gas compressor appeared to operate with seemingly no problems but afterwards it was discovered that two impellers suffered mechanical damage (thought to have been caused by debris left in the compressor during its installation) and needed to be replaced.

The waste heat boiler worked satisfactorily but the burner for firing the second gas stream, necessary to reach 100% load and also to allow fresh air firing mode operation at 5 MW, had been operated only up to 50% of its design capacity. The operational difficulties encountered were not helped by the absence of the burner supplier during its commissioning as a result of a contractual dispute. The problems with the burner had been resolved by mid. 2002.

Other problems encountered with plant commissioning and operation, and the solutions applied, can be summarised as follows:

- over-integration of safety system (cautious approach): rationalisation underway
- insufficient integration of digital controls: rewriting software
- expansion joint failure (wrongly positioned and specified): repositioned and improved specification
- flare clean-up design insufficient: cyclone added

Lessons learned

Project ARBRE was an ambitious project that incorporated many novel aspects. As maybe could be expected, the project encountered many obstacles during its implementation but overcame all of these to the point where the gas turbine operated on LCV gas from gasified purposely-grown SRC. During the implementation of the project, the following very important project requirements were reinforced:

- dedicated technical and managerial personnel
- sufficient financial resources

The main lessons learned during project implementation were:

- for innovative projects, a turnkey contract may not be the best form of contract (however, this depends on the knowledge of the contractor of the process involved)
- the control system should be properly integrated

Project ARBRE has many positive operational aspects, the following being particularly worthy of note:

- fuel supply development demonstrated
- process scale-up proven to be possible
- no operational problems with CFB gasifier
- no operational problems with catalytic tar cracker
- LCV gas according to design specification
- no operational problems with bag filters
- no operational problems with gas turbine

Liquidation of ARBRE Energy Limited

ARBRE Energy Limited was placed in liquidation in the summer of 2002.

Ultimately, Project ARBRE failed as the result of insufficient dedicated managerial personnel. Both SEC and Kelda became involved in Project ARBRE as a result of their management's wish to expand or change their core business, SEC moving from a manufacturing basis to a project company in the new area of renewable energy and Kelda expanding their none-regulated businesses and investing in renewables projects. Changes in the management of both SEC and Kelda during the duration of Project ARBRE led to both company's changing their company strategy and ultimately withdrawing from Project ARBRE.

During 2000, Kelda failed to receive permission from the regulatory authority for requested price increases for water. This resulted in Kelda changing its strategy, and deciding it would no longer invest in environmentally-oriented commercial development. A consequence of this was that AEL was sold. From May 2002, AEL was owned by Energy Power Resources (EPR) Limited of the UK, but the final takeover was conditional on the success of operational trials at the end of 2002. The sale agreement between Kelda and EPR included an effective write-off of a significant part of the loan provided by Kelda to AEL, together with promised further write-offs once replacement financing was put in place. The agreement also included a promise from Kelda to finance the plant's commissioning activities to the end of 2002.

In July 2002, Kelda withdrew its promise of support for plant commissioning to the end of the year and despite the promising outlook for Project ARBRE as a result of the reduction in loan debts, the preferential NFFO3 contract and the imminent commercial operation of the plant, EPR indicated that they wished to place AEL into immediate liquidation, citing reasons of short term cash flow problem and long term economic viability. The EU, the Department of Trade and Industry, UK (DTI) and STEM all expressed their concern over the proposed liquidation of AEL and offered their assistance (including monetary support) to prevent such a prospect. Despite these efforts and those made by other parties, EPR placed the company in voluntary liquidation on 7 August 2002.

During the period September to November, TPS had many contacts with companies showing interest in "buying" Project ARBRE, most of which expressed the wish to see the project completed as originally intended. Several of these companies also held discussions with the EU and the DTI on likely financial support.

In November 2002, bids were received from a number of companies and during December and January 2003 serious discussions were held with interested parties, following which new bids were to be received by mid. February 2003.

In April 2003, the sale of the assets of AEL to DAS Green Energy UK Ltd. (a subsidiary of BDI of USA) was completed. Talks held in 2003 and 2004 between TPS and DAS Green Energy to complete Project ARBRE were unsuccessful and today TPS has withdrawn from the project. The possibility for the plant to receive funding from the EU under existing contracts is no longer available as these contracts have now expired. The fate of the ARBRE plant is not clear today as very little reliable information is available publicly as to the detailed plans of the new owner.

CHEMREC - www.chemrec.se

The Chemrec company was formed from the earlier SKF Plasma team. Earlier, it was part of the Kværner group but today it is privately owned.

Technology

A major task of a kraft recovery system is to recover cooking chemicals in a form suitable for subsequent use in the delignification process. A conventional recovery system has some limitations in this respect. Concepts such as split sulphidity pulping and other sulphur-modified processes are difficult and costly to implement in existing recovery systems.

The gasification-based recovery systems are more flexible, and cooking liquor compositions ranging from sulphur saturated to low sulphidity or even sulphide-free liquor may be obtained in quantities suitable for use in bleaching operations or for sulphur-modified cooking.

The core of Chemrec Kraft Recovery is the Chemrec gasifier - a refractory-lined entrained bed reactor in which concentrated black liquor is gasified under reducing conditions at around 900°C (Figure 21). The liquor is decomposed in the reaction zone into melt droplets consisting of sodium compounds, and a combustible gas containing H_2 and CO.

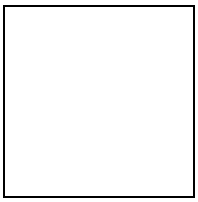

Figure 21 CHEMREC™ black liquor gasifier

The smelt droplets and the combustible gas are separated in a quench dissolver, in which they are simultaneously brought into direct contact with a cooling liquid. The melt droplets dissolve in the liquid to form a green liquor solution. The gas leaving the quench dissolver, now essentially free of melt droplets, is scrubbed for H_2S removal, and then used as a clean fuel.

The three major applications for the CHEMREC™ Recovery technology are:

1. CHEMREC™ Booster
- Relieve overloaded recovery boilers
- Capacity expansion projects

2. CHEMREC™ IGCC - BLGCC
- Replace old recovery systems (Tomlinson boiler)
- Recovery technology for green-field mills with improved power yield

3. CHEMREC™ BLGMF/H2
- Replace old recovery systems (Tomlinson boiler)
- Recovery technology for green-field mills
- Production of synthesis gas for generation of Black Liquor Gasification Motor Fuels

Emerging recovery technologies based on gasification and energy recovery in advanced gas turbine cycles promise substantial improvements in energy and environmental performance. Besides a higher power to heat ratio, the CHEMREC™ IGCC system (Table 8 and Figure 22) has a higher thermal efficiency relative to a recovery boiler/steam cycle. This has a beneficial impact not only on emissions but also on the supply of steam and power to the mill.

Table 8 CHEMREC™ vs. Recovery boiler, energy flows co-generation

	Modern recovery boiler	**CHEMRECÔ IGCC**
Electricity	12%	24%
Steam	54%	53%
Losses	34%	23%

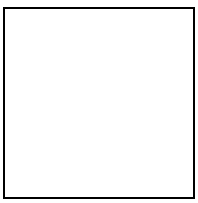

Figure 22 The CHEMREC™ steam/power cycle

The increased thermal efficiency and higher power to heat ratio in a CHEMREC™ IGCC system increases the potential for power generation to the range 1.8-2.0 MWh/ADMT from substantially lower figures in today's most advanced recovery boiler steam cycle systems. The current CHEMREC™ IGCC concept is based on air as oxidant. However, oxygen-blown gasification would be a logical development, particularly in light of the increasing use of oxygen chemicals in the modern mill. For the BLGMF concept, this is a prerequisite.

When considering synthetic motor fuels, the combination of synthesis gas generation with the heat sinks available in the pulp mill means that not only can a good conversion efficiency be achieved from black liquor, but more importantly, the extra biomass fuel required to compensate for the loss of fuel value in the motor fuel product gives a 60%+ efficiency of conversion. The cost of production of motor fuels is claimed to be low in spite of the high investment cost of the gasification and GTL plant.

Chemrec commercialisation

A CHEMREC™ Booster atmospheric-pressure demonstration plant has been operating successfully for some time at AssiDomän's Frövifors mill in Sweden (Figure 23). The capacity corresponds to 75 tpd of black liquor solids. The CHEMREC™ Booster system is targeted to relieve overloaded recovery boilers, and unlike retrofitting a recovery boiler, this system can be installed without any interruption in pulping operations.

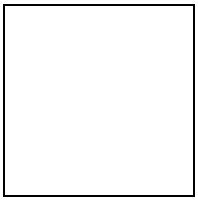

Figure 23 Demonstration plant at Frövifors

A commercial facility of 300 tds/day capacity has been in operation at the Weyerhauser New Bern pulp mill in USA since 1996. In the initial stage of operation, refractory lining cracks led to corrosion of the shell, but the refractory has been modified and the plant is again in operation.

Gasification of black liquor under pressurised conditions, a pre-requisite for IGCC operation based on the CHEMREC™ concept, has been performed and tested in a large pilot plant in a mill in Karlstad.

Future

A commercial-sized demonstration was planned in Piteå and, despite long delays in this process, a final investment decision is still pending. A grant from the Swedish state has been allocated to the project.

A part of this grant, together with co-financing from the paper and pulp industry, has been diverted to the construction of a smaller pressurised demonstration/pilot plant, DP1 at 100 kg ds/hr capacity (Figure 24). DP-1 is at ETC (Energy Technology Center), Piteå and is scheduled for start-up in 2004. The entire programme is budgeted at SEK 130 million

Commercialisation of black liquor and biomass gasification with combined-cycle technology might double the future power output from pulp mills and be a major market for biomass gasification technology.

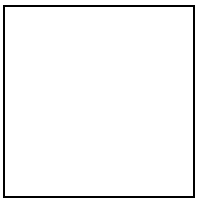

Figure 24 Pressurised pilot plant DP-1 at ETC, Piteå

Table 9 CHEMREC™ development

Plant	Capacity	Location	Date
Atmospheric pilot plant	3 tds/day	SKF, Hofors	1987-1990
Booster demonstration plant	75 tds/day	AssiDomän, Frövifors	1992-
Pressurised air-blown pilot plant	6 tds/day	STORA, Karlstad	1994-
Commercial Booster plant	300 tds/day	Weyerhaeuser, New Bern, USA	1996-
Pressurised pilot plant	2.4 tds/day	ETC, Piteå	2004
Financing and engineering, pressurised demonstration plant	?	AssiDomän, Piteå	pending

Scanarc/Pyroarc (plasma) process - www.scanarc.se

General

The Plasma Gasification technique evolved from the metallurgical process developments by SKF Steel in Sweden. In attempts to produce reducing gas for iron manufacture, a plasma was introduced in the bottom of the shaft producing H_2 and CO from coal and air. The effectiveness of the plasma in this application was high, leading to a number of proposed processes.

Two of these processes were installed at full-scale: the PlasmaZinc and the PlasmaChrome for handling zinc dust and chrome materials. Several processes for coal gasification using the Plasma Gasification technique were designed during the early 1980's, however none were realised.

Following the fall in energy prices, the interest during the 1980's focused on Plasma Gasification as a tool in waste handling, in particular, for special types of waste such as hazardous wastes, medical wastes, etc.

The ScanArc (former "SKF Plasma") process is a fixed bed, high temperature process producing a molten slag. The gasification is carried out in an updraft shaft. Differences to other processes are in the means to achieve the high temperature and in the cleaning of the raw gas. In the ScanArc process, the gas cleaning is achieved in a plasma where the gas is heated to very high temperatures, causing a decomposition of tar, chlorinated hydrocarbons and ammonia.

Process description

The ScanArc process (Figure 25) uses a shaft reactor and is fed in the middle with a mixture of air and oxygen. Oxygen is needed when the effective heat content of the wastes is too low to achieve a temperature of 1 200°C or more. For fuels to the reactor with heat contents above 10-15 MJ/kg, this constitutes no problem. These heat contents are, however, not always met with MSW unless other wastes are added.

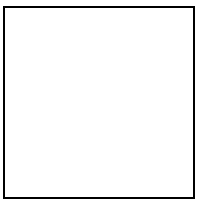

Figure 25 SKF Plasma/ScanArc

The raw gas is fed to a second reactor, which is more or less an empty shaft with a plasma generator on top. The electric plasma generates a theoretical temperature of more than 15 000°C through which the gas is passed (thus, lowering the temperature) into the shaft. The fuel to the plasma is composed of electricity and air for combustion (oxidation). After the second reactor, chlorine is present as Cl_2 or HCl, nitrogen as N_2, etc., i.e. all organic compounds and several others are decomposed.

The gas after the plasma reactor is cooled and washed. The fly ash is collected and may be sent for recovery of some metals since they are separated in a reduced state. Besides the wash water, a "clean" gas and hot water is obtained. Available data do not provide information as to what extent flue gas treatment is required after combustion.

The molten slag is tapped from the bottom of the first reactor, and it is claimed to be non-leachable and easily disposable.

Only few data are revealed from the process. The power consumption for the plasma is reported as 200-400 kWh/tonne of feed - depending on the heating value of the feed. These figures imply an energy efficiency of roughly 65-80%, calculated on the gas and the hot water.

Status

The ScanArc gasification is tested on MSW in a pilot unit. The gasification is designed for capacities of 50-100 000 tonnes per year and in this range the investments are indicated as US$ 700-1 000/tonne of feed (1997 figure).

Up until now, offers have been made for MSW but no unit has been installed. At present, the ScanArc gasification focuses on hazardous wastes where higher requirements on the process can more easily afford the technique.

Biomass Gasification R&D Activities

Swedish activities in the R&D field are based on programmes, each having an area of interest with delimitations and stated objectives. The programmes are operated on a three-year cycle and under the control of a steering committee representing various stakeholders.
The main programmes in relation to gasification are Energy in the Forest Industry, Thermal Processing, Fluidised Bed Combustion and Gasification and FALT (Research Programme on Alternative Motor Fuels).
The Energy in the Forest Industry programme is supporting work in the area of black liquor gasification.
The Thermal Processing programme is relatively newly established, has an academic profile and is largely devoted to modelling of furnaces and combustion processes, and traditional thermodynamic cycles. However, there are some examples of projects related to gasification in the area of modelling of thermodynamic cycles involving gasification at Lund University (LTH) and Chalmers Technical University, and at the Royal Institute of Technology (Kungl Tekniska Högskolan, KTH) the catalytic combustion of LCV gases from biomass gasification in a gas turbine combustor is studied experimentally, with the goal of achieving low NOx emissions from nitrogen-containing fuel without upstream ammonia removal or downstream SCR.
From having a profile of applied R&D in separate combustion and gasification programmes in the 1980's and 1990's, during build-up of know-how and of industrial expansion in this field, the merged programme Fluidised Bed Combustion and Gasification Programme has now a more fundamental research orientation. The funding level has been reduced as industrial relevance to the boiler and power industry has decreased. The Fluidised Bed Combustion and Gasification Programme has a long history of supporting R&D at LTH, KTH and TPS, amongst others.
FALT was initiated in 2003 to look at the production and use of all alternative motor fuels with the exception of ethanol, where a dedicated programme has been ongoing for a number of years. The programme is currently planned for a three-year period, having a funding level of SEK 75 million, half of which is dedicated to co-financed industrial research and development activities. The programme is largely the result of the interagency (National Energy Administration, EPA and Road Transport Authority) policy document of 2002 on renewable transport fuels. RD&D in oxygen-blown gasification to synthesis gas was highlighted as a key technology, concerning which a number of relevant projects have been initiated. Projects looking at the conversion of synthesis gas to liquid fuels, and innovative routes to hydrogen by other means than gasification have also been initiated.
In 2003, an investigator evaluated the energy R&D programme. The verdict was that the quality of the work was generally good, but that measurable deployment of results in society or by industry was low. This was claimed to be the result of an often extended time to implement R&D results into products.
In 2004, but with the exception of FALT, there is an interregnum between two government planning periods, coinciding with an interregnum also of the programme cycles, and therefore it is not clear exactly how the programme structure will look for the next period.

Other funding sources in Sweden, but at a smaller level, are Värmeforsk (Thermal Research Foundation) and Elforsk AB (the joint research agent of the power utilities).

OVERVIEW OF INSTITUTIONS/COMPANIES INVOLVED IN BIOMASS GASIFICATION R&D

Royal Institute of Technology (Kungl Tekniska Högskolan, KTH) - www.kth.se

The Department of Chemical Engineering at KTH has long-time experience in thermochemical conversion of solid fuels, starting with MSW pyrolysis in the early 1970's. A gasification research programme has been in continuous operation since 1974. Early studies of waste, biomass and peat

gasification (1975-85) were very process oriented. The results were utilised to develop a pressurised oxygen-blown process known as MINO, a process subsequently evaluated in a pilot plant at TPS, and later also CFB gasification systems (TPS and Kværner). During the period 1985-1990, a gradual re-orientation towards a more fundamental scientific approach was supported by funding agencies. Today, fundamental experimental gasification studies are prioritised. The research today mainly concerns gasification of biomass, predominately chemical issues in fluidised bed gasification. Examples of such research are the course of events in pyrolysis, gasification kinetics, tar analysis, tar decomposition, alkali analysis and gas cleaning. The main fuels studied are wood, miscanthus, straw and olive kernels, and to some extent, coal. Co-gasification of coal and wood has also been studied. Black liquor, a lignine-containing liquid by-product from the pulp and paper industry has also been studied in a dedicated programme. KTH are a partner in the Framework 6 CHRISGAS project, described earlier.

Another important part of the research at KTH has been the development of sampling methods and methods for analysis of tar. Sampling procedures for tar, identification and analysis of tar components are seen as important issues to be studied further. A method for quantification of phenolic and neutral compounds in the tar has been developed. Research activities have also consisted of charting the possibilities for analysing tars in the gaseous phase and also methods for increasing the speed of tar analyses have been studied. One of them is the so-called SPME technique. SPME is a single-step sampling and sample preparation method that can be classified as a GLC-technique (gas-liquid chromatography) or a VPC technique (vapour-phase chromatography). The SPME device is quite unique since it is used both for sampling and subsequent introduction of samples into a gas chromatograph. The second technique, which seems suitable for most applications, is a solid phase absorption (SPA) technique. The method of SPA comprises the collection of a sample by adsorption and condensation at room temperature on an SPE (solid phase extraction) column containing an amino phase. This method is suitable for intermittent trapping of tar compounds ranging from benzene to asphaltenes which are common in product gases from thermal decomposition of biomass at 700-900°C. The sampling step enables collection of 1-3 samples/min compared to 1-2 samples/hr using conventional cold trapping techniques. Correspondingly, it is possible to obtain more information. As a result of this improvement, the progress of pyrolysis and gasification processes in terms of molecular distribution is easily followed. Furthermore, the method can readily be applied under industrial and field conditions, as the sample column can be stored and also sent for analysis at a different site by normal mail services, while cold trapping is sometimes difficult under field conditions without proper laboratory resources, and liquid samples are not transportable as readily as SPA columns.

Experiments at KTH are primarily conducted in a pressurised bubbling fluidised bed having a downstream filter and reformer and in an isothermal fluidised bed, equipped with two filters in series. In the CHRISGAS project, KTH shall perform experimental research in the pressurised fluidised bed gasifier unit and an atmospheric-pressure fluidised bed gasifier. The pressurised fluidised bed is depicted in Figure 26, and the small fluidised bed reactor system is shown in Figure 27.

TPS Termiska Processer AB (TPS) - www.tps.se

TPS is a privately-owned research, development and design company working in the field of energy technology. The company offers product and services and performs research and development on gasification and combustion. The research is based mainly on experiments in the laboratory and on computerised flow simulation. Commercial exploitation of the new techniques developed by the company normally progress through large-scale demonstration plants to commercial operating plants. This type of exploitation has been achieved through technology licensing and joint venture activities. Research and development projects of TPS are often funded by STEM, the EU and by private companies.

TPS was, or is, the designated technology supplier for the Grève-in-Chianti project in Italy, the Brazilian BIG-GT project and the ARBRE project, all of which have been described earlier. TPS is also a partner in the Framework 6 CHRISGAS project.

TPS's R&D work on biomass gasification began in the late 1970's. During the early 1980's, the work concentrated on the development of the MINO process for gasification of wood and peat to synthesis gas. This oxygen-blown process featured a high temperature filter and a catalytic gas cleaning step, a pilot plant of 2.5 MW capacity was operated at up to 28 bar. During the latter part of the 1980's,

research and pilot plant test work concentrated on the air-blown atmospheric-pressure CFB gasification process and its application to the thermal processing of biomass and waste fuels, featuring a patented gas cleaning step. TPS has a 2 MW atmospheric-pressure gasification pilot plant (Figure 28) on its premises. This plant includes a CFB gasifier, CFB tar cracker, filter, wet scrubber and diesel engine. Over the last fifteen years, many hours of test work in this pilot plant using biomass and RDF as feedstock have been completed.

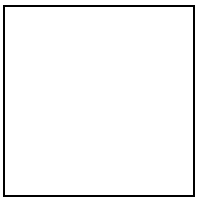

Figure 26 Pressurised bubbling fluidised bed gasifier at KTH

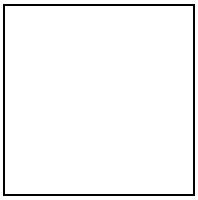

Figure 27 Isothermal fluidised bed reactor

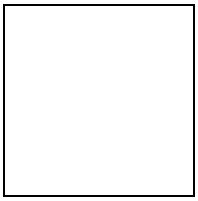

Figure 28 TPS's ACFBG 2 MW pilot plant

A small fluidised bed gasifier was installed at TPS in the mid. 1990's (Figure 29). Here a realistic gas is produced at laboratory scale, i.e. a fuel input of 20-50 kWth. Because the gasifier has external electric heating (approx. 10 kW) it is possible to achieve calorific values of the gas corresponding to that normally found in commercial scale equipment (5–6 MJ/m³ dry gas). The gasifier system is equipped with a cyclone and a heated ceramic filter for removal of particulates.

A flexible pressurised apparatus, operating at up to 30 bar, was also designed and installed in the mid 1990's. The purpose of this apparatus was to perform investigations of high temperature gas cleaning by means of thermal, catalytic or chemical procedures. A semi-continuous fuel feeding concept, at a maximum rate of 700 g/h, allows constant formation of a gas product at 700°C. The gas product, or gas from another external source, e.g. gas bottles, is subsequently introduced into a fixed bed secondary reactor where the gas clean-up or reforming takes place. The apparatus consists of two externally heated pressure vessels (Figure 30). The first vessel contains the pyrolyser. A piston levers a fuel container into the pyrolysis zone by means of a DC motor. The gas produced is quickly removed from the reactor by the carrier gas and enters the top of the secondary reactor, this reactor containing a fixed catalytic bed. This unit is now used for the study of tar and methane reforming for FALT projects and, in future, in the CHRISGAS project.

Lund University (LTH) - www.lth.se

Gasification research started at the Department of Chemical Engineering II, LTH in 1975 with work focused on oil shale gasification. The research group worked in close co-operation with Swedish mineral industries, and apart from TGA experiments, the majority of the work was directed towards development, construction, and operation of a laboratory-scale fluidised bed gasifier.

In 1978, pyrolysis and gasification experiments started, using biomass and other domestic fuels as feedstock. In these experiments, the gasification and pyrolysis kinetics of straw, sawdust, bark, peat, and lignite were investigated.

In 1981, a high-pressure TGA was built in which characterisation studies on peat and biomass were carried out. Gasification studies using a conventional fluidised bed gasifier were also performed. These activities were followed in 1985 by biomass thermochemical conversion studies in a specially-designed high temperature entrained phase reactor.

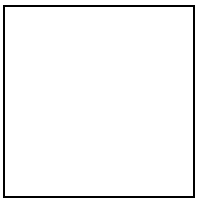

Figure 29 The 20 kWth air-blown bubbling fluidised bed gasifier at TPS

In 1991, a government-supported evaluation of Swedish gasification research recommended expansion of pressurised biomass gasification research at the Department of Chemical Engineering II, and, as a result, a biomass PICFB (Pressurised Internal Circulating Fluidised Bed) gasifier test rig was installed at the Chemical Center at LTH. The installation work was essentially made by the workshop at the Department and by PhD students involved in the project. This made it possible to keep investment in the installation low, the total investment cost for the equipment being estimated at less than SEK 6 million. Financial support for the first phase of the project was made available by NUTEK (now STEM), SEU/Elforsk and Sydkraft.
The test rig was used for R&D on an assignment basis as well as in postgraduate research education. In addition, the test rig programme was supported by a variety of bench-scale test equipment for solid, liquid, and gas phase investigations.

The biofuel PICFB gasifier test rig consisted of four main parts (Figure 31):

- feeder
- PICFB
- hot gas filter
- reactor for the catalytic/thermal treatment of dust-free gas

Operating parameters that gave a stable circulation of the bed material during the gasification mode were very difficult to achieve. After a comprehensive investigation involving more than 500 hours of test runs, the decision was made to abandon the internal circulating bed concept and to focus on bubbling bed operation.
From the mid. 1990's onwards, the project group was involved in several EC-sponsored R&D projects where the PFB test rig played an important role in the experimental investigations.

However, by the end of 2000 all the gasification activities at LTH had been terminated.

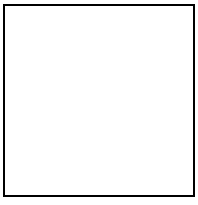

Figure 30 10 kWth nominal fixed bed gasifier/pyrolyser reactor

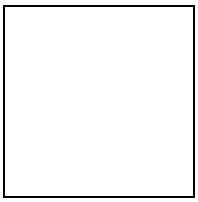

Figure 31 The biofuel test rig at LTH

Växjö University - www.vxu.se

The Municipality of Växjö has a declared ambition to become a fossil-free-community.

Växjö University is the second largest University in southern Sweden with more than 12 000 students. 75% of the 800 persons employed are researchers. Environmental and process technology is one of three strategic research platforms with focus on energy research for development of new technology and knowledge at the University. The Division of Bioenergy, having two professors, eight graduate students and a post-doctorate position, has research activities in the field of biomass combustion and projects with the scientific activities directed towards aerosol science in combustion aerosols, drying and handling of biomass, and studies concerning catalytic deactivation processes. At the School of Industrial Engineering, the R&D programme "Wood Design and Technology" aims at stimulating, supporting and developing industrial systems from forestry. Research within the programme is directed towards forestry, logistics, industrial production economy for forestry and marketing of wood and wooden products.

Växjö University is the host research organisation for VVBGC and also the co-ordinator of the CHRISGAS project. Hence, the University will be increasingly involved in gasification research in the coming years.

Mitthögskolan - www.mh.se

The School of Engineering at Mitthögskolan (Mid-Swedish University) in Härnösand has recently engaged in biomass gasification activities. This is supported by local and regional organisations, which include forest industries, communities and a regional environmental initiative, Biofuel Region North.
Based on funding from EU regional support grants, grants from FALT and from other local sources, a pilot gasifier for oxygen-free generation of synthesis gas is planned to be constructed in 2005. The aim is to develop, jointly with other regional stakeholders, a small-scale Fischer-Tropsch concept for local use. To support the scientific work in the gasification area, assistance is provided by KTH.

Umeå University - www.umu.se

Umeå University is engaged in research in gasification and combustion, mainly specialising in the inorganic chemistry of ash constituents and its impact on bed materials and agglomeration, slagging and fouling properties. Through the Biofuel Region North, Umeå University also collaborates with Mitthögskolan, and with ETC on black liquor inorganic solids, see below.

Luleå Technical University - www.luth.se

Luleå Technical University is the parent organisation of ETC, and collaborate with ETC on some activities in black liquor gasification. Previously, a small-scale BIG-GT CHP concept was developed, consisting of a cyclone gasifier to be used as a combined gasifier and solid separator integrated with a combustor of a small, low inlet temperature gas turbine. Both atmospheric and pressurised tests were made on this concept. However, the most recent project in the unit has been completed and the development is on hold.
Energy Technology Center (ETC), Piteå - www.etcpitea.se

ETC, a foundation based in Piteå, was formed in 1988. The activities at ETC were boosted in 1993, when Assi Domän Kraftliner (presently Kappa Kraftliner) made their old laboratory available to ETC. The laboratory was rebuilt and re-equipped, and was inaugurated in 1994, after which a close collaboration was started with the universities in Umeå and Luleå. The research activities soon focused on combustion and gasification of biofuels. In the gasification area, ETC is the host organisation of the pressurised black liquor demonstration/pilot plant DP1 and is responsible for its operation.

Chalmers Technical University - www.chalmers.se

Chalmers Technical University in Gothenburg has some activities in the area of black liquor gasification in association with other organisations involved in such activities, and are also engaged in modelling of gasification energy cycles and catalysis research on the Fischer-Tropsch process.

Mälardalens Högskola - www.mdh.se

Mälardalens Högskola in Västerås has some limited activity on black liquor gasification based on the fluidised bed process of ABB.

Gasification Survey Country: **Switzerland**

By: R. Bühler, Umwelt + Energie; Th. Nussbaumer, Verenum Research
Date: 27.4.2004

1. Policy

In Switzerland, biomass contributes with 44 PJ or 5.1% to the total end energy consumption of 861 PJ (table, 1, [1,2,3,4]. The biomass potential allows an increase by nearly 100 %, which is to the aim of the Swiss energy policy.

The main source of bioenergy in Switzerland is wood. It contributes to 21 PJ or 2.4 % of the total energy. The main part of wood fuel is used in boilers and stoves for household heating. Furthermore, automatic furnaces are widely used in industry for wood residues and in district heating plants for forestry wood chips. A few plants allow the combustion of urban waste wood and demolition wood and are equipped with respective technologies.
All other biomass beside wood contributes with 23 PJ or 2.7 % to the energy consumption and it includes biomass contained in municipal solid waste, sewage sludge, paper sludge, agricultural residues, and organic residues for the production of biogas, which is used for electricity production and as a fuel for cars.
In Switzerland, energy production from biomass is supported in different programmes by the government (Energie Schweiz / Swiss Energy) and the cantons. The installation of both, manual and automatic furnaces is funded under certain conditions. To ensure a high standard of the introduced technologies, different quality control instruments are applied. For small scale furnaces up to 70 kW a type test has been introduced which ensures good combustion quality and high efficiencies. For biomass heating plants, a quality management system «*QM Holzheizwerke*®» has been developed and introduced which accompanies the planning, installation and operation of biomass district heating systems. Several tools as the "Planungshandbuch" [3] facilitate the task of the planning engineers.

Table 1 Consumption and potential of wood and other biomass as energy source in Switzerland.

	1998	1999	%	Potential (medium-term)		%
	Mio m^3	PJ		Mio m^3	PJ	
Forestry wood	1.1 [2,3]	9.5 *	1.1 %	3.2 [2,3]	27.6 *	3.2 %
Wood residues from industry	1.1 [2,3]	9.5 *	1.1 %	1.1 [2,3]	9.5 *	1.2 %
UWW** and DW** (Altholz)	0.2 [2,3]	1.7 *	0.2 %	0.7 [2,3]	6.0 *	0.7 %
Wood	2.4 [2,3]	20.6 [1]	2.4 %	5 [2,3]	43.2	5.0 %
Other biomass ***		23.2 [4]	2.7 %		35.0 [4]	4.1 %
Total biomass		43.8	5.1 %		78.2	9.1 %
Total end energy		861 [1]	100 %		861	100 %

* 1 Mio m^3 = 2400 GWh = 8.64 PJ (2000 GWh for pine wood and 2800 GWh for leave wood, [2,3]).
** UWW = urban waste wood, DW = demolition wood, UWW and DW = „Altholz"
*** Other biomass = biomass in waste, sewage sludge, paper sludge, agricultural residues, and organic residues for biogas production.

Literature:

[1] Swiss Federal Office of Energy (Bundesamt für Energie): Schweizerische Gesamtenergiestatistik 1999, Bern 2000, www.admin.ch/bfe/d/wirtscha/gesamt/gesamt.htm
[2] Holzenergie Schweiz 8008 Zürich, www.holzenergie.ch
[3] Good, J et al.: QM Holzheizwerke: Planungshandbuch, Arbeitsgemeinschaft QM Holzheizwerke, Straubing 2004, www.qmholzheizwerke.ch
[4] Hersener, J.-L.; Meier, U.: Energetisch nutzbares Biomassepotenzial in der Schweiz, Swiss Federal Office of Energy, Berne 1999

2. Programs

R&D&D program of the Federal Office of Energy. The cantonal governments (district governments) also financially support demonstration projects. The total amount for the promotion of biomass by the Federal Government is about 5 Mio/a.

According to the bilateral agreement between EU and Switzerland, additional support comes directly through the EC 6th framework.

3. R&D Institutes

Paul Scherrer Institute, CH-5232 Villigen
Verenum Research, CH-8006 Zurich
Umwelt + Energie, CH-8933 Maschwanden

4. Industries

- ***Pyroforce***, CH-6020 Emmenbrücke.
  Pyroforce is the Manufacturer of the PYROFORCE gasifier, based on AHT technology.
- ***DASAG***, CH-8472 Seuzach.
  DASAG is selling the IISc-DASAG open top gasifier in Europe
- ***Xylowatt***, CH-1052 Le Mont s/Lausanne.
  Xylowatt is manufacturer of CHPP by gasification and licenses of the IISc technology
  Xylowatt is the owner of the 60 kWe demonstration plant at Bulle
- ***Procone GmbH***, CH- 4617 Gunzgen.
  Procone is the manufacturer of the Prometheus (former HTV/Juch) gasifier.

5. Projects

R&D projects

- On-line tar measurement with FID. ***Verenum Research***
- CH_4 production from woody biomass via conventional gasification ***Paul Scherrer Institute***
- Adaptation and Optimization of the Xylowatt CHPP in Bulle. ***Xylowatt***

- Optimization of the Pyroforce gasifier system installed at Spiez ***Pyroforce, CTU Concepte and GE Jenbacher***
- Direct methane production from wet biomass by catalytic gasification in supercritical water. ***Paul Scherrer Institute***
- CHP via high temperature fuel cell (B-IGFC) ***Paul Scherrer Institute***

6. Implementation

200 kW_{el} Pyroforce gasifier

Installation of a 200 kW_{el} *Pyroforce gasifier* with a Jenbacher engine at a military research centre at Spiez 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 down draft moving bed gasifier maintains a temperature of 1200 to 1300 C in the combustion zone.

Operation experience

Plant commissioning: From autumn 2000 to March 2001 (incl. the engine).

– Commissioning of the total system (incl. the engine): March 2001.
– Several test runs in 2001, some difficulties and failures.
– Improvement of some parts. New start In Mai 2002.
– The plant runs more or less continuously from Monday to Friday each week at part load of 100 kW with only smaller problems. Each week a detailed report of the operating experience is available.
– Operating hours (total system with engine) until April 2005: more than 5'000 hours
– Availability June 03 – August 03 (Monday afternoon to Friday afternoon is equivalent to 100%): 70 – 100% per week

Although pilot tests were conducted with demolition wood, uncontaminated wood chips will be used as the gasification feed material. Contact: Mr. W. Gemperle, Pyroforce Energy Technology, Reusseggstrasse 17, CH-6020 Emmenbruecke, Phone: 0041 41 420 44 33, Fax: 0041 41 420 44 76, e-mail: welcome@pyroforce.ch

60 kW_{el} Xylowatt gasifier

The gasifier is based on the Indian Institute of Science (IISc) technology. It is an air suction, a low pressure, open-top, co-current, downdraft, moving bed system with a specially designed lateral air inlet to reduce tar production.

A pilot demonstration plant designed for 130 kW_{th} and 55 kW_{el} capacity is in operation in the sawmill Despond in Bulle (FR). The gasification feed material is uncontaminated woody biomass materials. Total engine hours 1'940 (March 2004).

The plant is composed by:

- Reactor of gasification (included wood silo, screws, ash extraction),
- Gas treatment devices: cyclone, heat exchanger, scrubbers, polyester filter and blower
- Condensate treatment devices: decanter, flocculation, cooling system, and pumps,
- Naturally aspirated gas engine and generator.

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, 14% H_2, 53%N_2, 300 mg/Nm^3 Particle, and 700 mg/Nm^3 Tar.

Contact: Xylowatt SA, En Budron A12, CH-1052 Le Mont s/Lausanne, P. Giordano; Phone: +41 21 651 69 69, Fax: +41 21 651 69 68, Home Page: http://www.xylowatt.ch, e-mail: info@xylowatt.ch

Gasification Survey Country: **United Kingdom**

By: Nick Barker, Future Energy Solutions
Date: May 2004

Changes since the last update

- After disruptions following the ARBRE project failure the project with Siemens in the UK to develop gas turbines for gasification applications is now progressing well.

- 20 MW installation using FERCO technology has been announced as a result of the UK Bio-energy capital grants scheme. The project is now in the planning and permitting phase. Two other projects using other gasification technologies have also been announced in this scheme.

- ARBRE project still not resolved.

1. Policy

Extract from DTI web site.

"Our energy future – creating a low carbon economy" defines a long-term strategic vision for energy policy combining our environmental, security of supply, competitiveness and social goals. It builds on the Performance and Innovation Unit's Energy Review, published in February 2002, and on other reports that have looked at major areas of energy policy.

Because energy requires very long term investment we look ahead to 2050 to set the overall context. We set out the challenges we face on the environment, the decline of our indigenous energy supplies and the need to update our energy infrastructure and the policies we need to pursue over the next twenty years and beyond to meet these challenges. As we address these challenges we will have four goals for our energy policy:

- To put ourselves n the path to cut the UK's carbon dioxide emissions by some 60% by about 2050 with real progress by 2020;
- To maintain the reliability of energy supplies;
- To promote competitive markets in the UK and beyond, helping to raise the rate of sustainable economic growth and to improve our productivity; and
- To ensure that every home is adequately and affordably heated.

The Government has set itself a target of securing 10% of electricity from eligible, renewable sources by 2010. There are four elements to the new 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 has been announced:

- The Renewables Obligation target has been increased to 15% by 2015.
- The DTI Innovation Review of Renewable Energy has been published on the DTI Web Site at http://www.dti.gov.uk/energy/renewables/policy/renewables_innovation_review.shtml .
- This review concluded that developing biomass fuel supply chains was the key barrier to progress and that the preferred Programme is to develop the energy crops option and exploit heat markets to kick-start fuel chains
- DEFRA (Department for Environment, Food and Rural Affairs) has recently announced a £30 million scheme to support the development of new technologies as part of the Waste Implementation Programme. Funding is in two tranches and is targeted on pilot installations in the four advanced technology areas of Gasification, Pyrolysis, Anaerobic Digestion and, Mechanical and Biological Treatment. Details can be found on http://www.defra.gov.uk/environment/waste/wip/newtech/index.htm

2. Programs

The Renewables Obligation

1. The Renewables Obligation means that licensed electricity suppliers will have to provide a specified proportion of their sales from renewable energy in future years. In this way the Government will actively encourage the increased supply of renewables electricity while leaving the choice of technologies to the market. The Government intends that the Obligation will form the framework for the development of renewable energy in this country up until at least 2027.

2. Under the Obligations, electricity suppliers can comply by:
    - buying ROCs from an accredited renewable generator; and / or
    - buying ROCs from other suppliers / traders who have bought more than they need (through the trading of ROCs);

and / or, as an alternative to supplying renewable energy, by:

- paying the regulator the "buy-out price" of (currently) £30/MWh for each unit the supplier is under obligation.

The August 2001 consultation document http://www.dti.gov.uk/renewable/consultations.htm explains how the Obligation is structured and how they will encourage compliance through ROCs rather than the buy-out.

The Renewable Obligation has a number of interesting developments relevant to gasification.

- The definition of biomass has been widened to include all material from plant and animal sources.
- Mixed wastes, containing fossil elements are only eligible if pyrolysis or gasification is used. They are not eligible if they are incinerated. Only the electricity generated from the renewable fraction can be claimed.
- Renewable fractions separated from wastes could be eligible using any technology.
- Co-firing in existing installations is eligible up to 2011 but only if the biomass comprises 75% energy crops after 2006.

The UK government has recently amended the Renewable Obligation to extend the provisions for co-firing. This amendment should provide energy crop growers with a more secure long-term market and more time to exploit improvements in cultivation.

Climate change levy exemption
From 1st April 2001, a climate change levy has been payable on the use of energy by all non-domestic (industrial, commercial and public sector) customers throughout the UK. The rate for electricity is 0.43p/kWh. Renewable generation (excluding hydro over 10MW) is exempt from the CCL. This means that suppliers who sell eligible renewable electricity to non-domestic customers are exempt from the Climate Change Levy for that supply.

Capital Grants
Biomass technologies, in particular energy crops, will find it difficult to compete in the short term. Recognising this a series of capital and support grants has been put in place that could bring down the costs of generation (p/kWh) to within the expected price cap.

There are three broad aims for the scheme, which are sub-divided into the technical priorities below:

1a - Large scale, state of the art electricity generating installations.
1b - Electricity generating, or CHP, installations over 1MWe.

2. - Large scale installations using technologies with much higher electrical generating efficiencies than current state of the art, and significant future development potential.

3a - Projects comprising clusters of heat or small CHP installations.
3b - Larger industrial heating units with outputs over 0.5MW for process or space heating.

Two projects within priority 1b are expected to be gasification projects. One project in Priority 2 will be a gasification project using FERCO technology. The project list in this document has been updated to reflect these.

Research and Development

Department of Trade and Industry New and Renewable Energy Programme
DTI's UK budget for R& D into renewable technologies is £18m per annum for the 3 years from 2001/2. This covers a wide range of renewable energy technologies – including wind energy, hydro, solar, biofuels and fuel cells. Further funding of £3.5m per annum to support R&D activities is also available from the Engineering and Physical Sciences Research Council (EPSRC), and other Research Councils are spending small amounts on renewables projects. The biofuels budget is some £2M per year and is set to rise in the future.

Reports are now published on the web at http://www.dti.gov.uk/publications/ go to "Browse" then select Renewable Energy - Biomass.

The Carbon Trust - Low Carbon Innovation Programme
The Carbon Trust is a body set up by DEFRA to implement carbon saving technologies. It also has R & D activities which it pursues through a series of open calls on the World Wide Web. Small scale biomass energy is seen as a priority but there is also an interest in larger scale power generation. The Carbon Trust also operates a venture capital scheme that has supported some biomass businesses. Www.thecarbontrust.co.uk .

Supergen
Sustainable Power Generation and Supply (Supergen), part of the EPSRC Infrastructure and Environment Programme. This is a programme of basic research which 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 utilisation is one of four themes for this Programme. Within this theme the potential for power generation systems utilising energy crops and agricultural crops will be examined, and the research is striving for a carbon neutral cycle. Aston University is the lead contractor for this Programme with five further Universities and research institutes and five industrial partners. The work programme comprises six work packages

- Process and techno-economic assessment
- Fuel specification and matching to conversion
- Thermal reactor modelling
- Minimisation of engineering risk
- Co-firing and co-processing biomass
- Network (British Biomass and Bio-energy Forum)

Web site http:// www.supergen-bioenergy.net

3. R&D Institutes

Industry Research

Mitsui Babcock Technology Centre, Renfrew, Scotland

Mitsui Babcock has played a leading role in the development of environmental technologies, from emissions reduction to clean waste disposal. Their environmental reduction and control systems enable plant to operate within legislative limits – ensuring a cleaner future. The Mitsui Recycling R21 pyrolysis system provides a highly efficient solution to the disposal of municipal solid waste with low emissions, metal recovery and added power generation capability.

Demag Delaval Industrial Turbo machinery Ltd. (Siemens) Lincoln, England

An extensive test facility for gas turbines including a full size test rig for alternative fuels. The services provided by the facility also allow non-power generation work to be undertaken. Investigations of large combustion systems operating at high pressures, high temperatures and with a variety of fuels can be carried out on various rigs contained at the centre.

Powergen Technology, Ratcliffe

Extensive combustion and power generation test facility

Universities working in this area

Aston University
Cardiff University
Cranfield University
Imperial College
Leeds University
Newcastle University
Queens University Belfast
Sheffield University
University of Manchester Institute of Science and Technology
University of Ulster

4. Industries

- ***Advantica Ltd*** Consultancy and microturbine dev.
- ***Demag Delaval Industrial Turbomachinery (Siemens) formerly Alstom Power*** Gas turbines
- ***Exus Energy Ltd.*** Downdraft gasifiers for heating and CHP
- ***Biomass Engineering Ltd.*** Downdraft gasifiers for heating and CHP
- ***Bowman Power Systems*** Micro-turbines for biomass gasification
- ***Novera Ltd*** Indirect rotary kiln gasifier
- ***Compact Power Ltd.*** Indirect gasifier for wastes
- ***EPRL Ltd.*** Biomass and waste power plant developers
- ***James Engineering Turbines*** Micro turbines for biomass
- ***JND Ltd*** Indirect kiln gasifier for wastes
- ***Mitsui Babcock Engineering*** Engineering contractors. Waste gasification
- ***Rural Generation Ltd***. Downdraft gasifiers for heating and CHP
- ***Ventec Ling Developments Ltd.*** Downdraft
- ***Wellman Process Engineering Ltd.& Wellman Bronzeoak*** Updraft gasifiers with catalytic cracker and IC engines

Contact details can be made available on request

5. Projects

Current biomass R & D projects in the DTI Programme relevant to gasification are:

- Next Generation BIGCC, Demag Delaval Industrial Turbomachinery Ltd (Siemens) – a £6.9 million project to develop the gas turbines that will be necessary for future applications in biomass and waste gasification. After considerable disruption following the failure of the ARBRE project we are now making good progress with this project. The objectives are to develop burner technology for both MCV and LCV gasses plus a new power turbine design capable of the higher mass flows that we will have with gasification applications.
- Micro turbines and biomass Gasification. Two projects with Biomass Engineering and Rural Generation to investigate the use of new turbine types and burners with small gasifiers. These were reported in the proceedings of the London Task Meeting in May 2003. Biomass engineering final report will soon be posted on the DTI web site.
- A 2.5 MW demonstration of green wood gasification. A £6.7 million demonstration of Wellman gasification and tar cracking technology. Design stage started March 2003 and is still progressing through permitting.
- 250 kW downdraft gasification demonstration. Biomass Engineering Ltd. Scale up issues moving from sub 100kWe units. Plant commissioning.
- Extension of the Compact Power process to clean biomass feedstocks. This project will install a preconditioning stage ahead of the indirect gasification step of the Compact Power waste gasification process. The aim is to make the most cost effective use of the high temperature stage, improve efficiency by recycling waste heat to the front of the process. and to improve the specific throughput. Work has just started on this.

In addition to the technical projects the UK Program will fund a series of comprehensive monitoring projects. These will deal with environmental impacts and technical performance. We still intend to cover the ARBRE project and will cover plant performance, ecological and

other environmental impacts. We will collect sufficient data for life cycle carbon and energy balances.

Other biomass projects will also be monitored in more or less detail depending on the novelty and size of the scheme and the environmental sensitivity of the site.

6. Implementations

The projects below are a selection.

ARBRE Project: as built the ARBRE project employs the low pressure TPS gasifier. The fuel gas is compressed and burned in a gas turbine heat recovery steam generation system to produce 8 MWe employing a Typhoon gas turbine.
The project has been put into receivership by its current owners EPR Ltd. It is not possible to give more details at this time as to the future of the unit. We understand there are plans to re-activate the project but details must wait until the next update. The energy crop part of the project has been a success and farmers are actively looking to grow more material to supply the co-firing market.

Brook Hall Estate, Londonderry. This 100 kWe downdraft gasifier has been generating electricity onto the Northern Ireland grid for the past five years and accumulated over 20,000 hours of operation. The reported load factor is approximately 0.6, which is very close to the design figure. The fuel, short rotation willow coppice, is grown on the farm.
Recently a small micro-turbine has been installed on site and trials are going on to develop this to a commercial concept.

Contact: Mr. Michael Doran, Rural Generation Ltd, Brook Hall Estate, 66 Culmore Road, Londonderry, Tel: +44 (0) 28 7135 8215,
http://www.ruralgeneration.com/index.htm

Ecos Millenium Centre. Balymena, Northern Ireland.
A complete 75 kWe net gasification system, with wood preparation and modified diesel engine, was been sold to Ballymena Borough Council, Northern Ireland in 1999 to provide the heat and electricity for the ECOS Millennium Centre, demonstrating a range of renewable energy technologies.

Over 2000 hours operation on a wide variety of wood types have been obtained, with continuous test runs of up to 10 hours coupled to a converted diesel engine. The gasifier has been run on a variety of feedstock including: willow, poplar, sawmill residues, pine, spruce and oak. The gasifier operates unattended and is subject to routine filter and engine maintenance as scheduled. Biomass Eng. Ltd. has a service contract on the unit.
Contact Mr Andy Connor, Biomass Engineering Ltd.
Tel +44 (0)1925 220338
andrewc@shawton.co.uk www.biomass.uk.com

This installation was described in a presentation to the IEA Task Meeting in London and a paper is posted on the Task Web site.

Beddington Zero Emissions Development. Exus Energy Ltd. The Beddington Zero Energy Development Project (Bed Zed) is an innovative mixed workspace and housing development.

The objective of the development is to provide a working example of a sustainable development and to act as a demonstration for other new housing and workspace developments. The scheme is owned by the Peabody Trust, London's largest housing association.
Exus Energy has designed, installed and commissioned a 130 kWe CHP unit and this now provides the sites domestic heat and electricity demand with over 2,000 hours of operation. In addition BP solar, have installed photovoltaic cells to provide electricity for an electric vehicle pool. After some teething problems the unit is reported to be operating eighteen hours per day. A further two projects, in Northern Ireland and England, are under development.

Contact: Ms. Debra Jenkins, Exus Energy Ltd, Derry City Co. Londonderry, Ph: +44 (0) 28 7127 1520, e-mail: d.jenkins@exusenergy.com

Compact Power Ltd, Avonmouth. This project has been operating commercially for 3 years. It processes 800kg of clinical or municipal waste per hour. The waste is first pyrolysed in an externally heated tube. The char residue is steam gasified in a close coupled gasifier with the product gas mixed directly with the pyrolysis gas. The combined gas is then burned in a cyclone burner with the exhaust providing heat for the pyrolysis chamber and a steam boiler. A small amount of power is generated from the steam. The unit is a demonstration for larger capacity units in the future that will be built on a modular system with multiple pyrolysis tubes. The emissions performance is exceptionally good because of the good control of the gas combustion process and the high temperature.

The unit shows the potential of gasification in this respect bettering the current EC limits for waste incineration by a very wide margin. Dioxin levels have been measured at less than 0.003ng/nm3. The unit is fully licensed for commercial use by the UK Environment Agency and was included in their annual report as an example of excellence.

Web site http://www.compactpower.co.uk/

Demonstration and pilot projects

To be included in the list the project has either a firm electricity contract or hardware on the ground.

	Owner/ Location	Type of Gasifier	Fuel	Gas Use	Plant size	Status	Support
1	ARBRE Energy / Yorkshire	CFB/TPS	SRC	GTCC	8 MWe	Uncertain Company in Liquidation	THERMIE and NFFO 3
2	NFFO 3 Suffolk	Rotating kiln	Forest residue and Energy crops		5.5 MWe	No progress	NFFO 3
3	NFFO 3 Wiltshire	Not known	Forest residue and Energy crops		5.5 MWe	No progress	NFFO 3
4	Mid Wales Energy	Not known	Forest residue		250 kWe	No Progress	NFFO 4
5	Enniskillen College / Northern Ireland	Downdraft	SRC	Dual Fuel Engine	100kWe	1992 started Test operation only	VALOREN NI Gov. ETSU
6	Rural Generation Ltd. Northern Ireland	Downdraft	SRC	Dual Fuel Engine	100kWe	*Operating.daily on a commercial basis 20k hours*	NI NFFO Reg. Dev Fund
7	Rural Generation Ltd. Newark, Notts England	Downdraft	Forestry residue and sawmill chips	Dual Fuel Engine	100kWe	*Operating, intermittently as demonstration unit hours unknown*	Reg Dev fund.
8	Exus Energy Biomass Blackwater Valley Northern Ireland	Downdraft	SRC	Dual Fuel Engine	204kWe	*Rebuild*	NI NFFO Reg. Dev Fund
9	Exus Energy Biomass Beddington ZED, London	Downdraft	Waste wood	Spark ignition engine	120kWe	Operating March 2003 500+Hours	Private. Charity
10	Biomass Engineering. Warrington, England	Downdraft/	Waste wood / various	SI Engine Micro turbine	100kWe	Operating as test unit	UK Local Gov. and Private
11	Biomass Engineering Ecos Millenium centre Balymena NI	Downdraft	Coppiced Willow	SI Engine	60kWe CHP	Operates on demand	Reg Dev fund
12	*Biomass Engineering Ltd Lancashire Farm*	*Downdraft*	*Willow and other woods*	*SI Engine*	*250kWe*	*Commissioning*	*DTI R & D*
13	Waste to Energy Ltd	Downdraft	Waste Wood	SI Engine	35 kWe	1995 Started	Private
14	British Leather Research	Downdraft	Leather and meat processing wastes	Heat	100 kw thermal	2000. *Moved to Biomass engineering as test unit*	Private
15	Compact Power	Indirect/ Compact Power	Municipal, Industrial and clinical waste	Steam Boiler	1 MWth	2001 Commercial operation 20+k hours	Private
16	Waste Gas Technology. South Wales	Indirect/ WGT rotating drum	Sewage sludge	Combustion in dryer	500 kW thermal	*Status unclear*	Private
17	Novera (formerly CPL Industries)	Rotating drum	Various wastes and energy crops	Combustion to flare	200kwth	2000 Trials. *Report DTI web site*	Private, DTI
18	Graveson Environmental South Wales	*Indirectly heated agitated vessel*	Wastes	Engine	250kW?	2000 Pilot trials	Private
19	Global Energy/Fife	BG Lurgi	Sewage sludge/coal	Gas turbine	80MWe	Noprogress	Private
20	*Charlton Energy*	*Windforce , indirectly heated rotating kiln*	*Energy crops, Ag & forestry residues*	*IC Engines*	*7 MWe*	Permitting	*DTI Capital Grants Scheme*
21	*Castle Cary*	*Wellman*	*Ag & forestry residues, Energy crops*	*IC Engines*	*7 MWe*	Permitting	*DTI Capital Grants Scheme R&D Programme*
22	*Winkleigh*	*FERCO*	*Energy crops, Ag & forestry residues*	*GTCC*	*22MWe*	Permitting	*DTI Capital Grants Scheme*

(Additions May 2004 in italics)

Gasification Survey Country: **U.S.A.**

By: Richard L. Bain
National Renewable Energy Laboratory
Date: Spring 2004

STATUS OF BIOMASS ENERGY SYSTEMS IN THE UNITED STATES

Renewable energy represented 5.6% of the primary energy flow in the United States in 2002, Table 1. Renewable energy consumption in 2002, Table 2, was 6.38 EJ; biomass comprised 46%, conventional hydrothermal comprised 45%, and other (wind, geothermal, and solar) comprised 9%. Total electricity generation in 2002, Table 3, was 3831 billion kilowatt-hours; of this renewable energy represented 8.9%. Renewable electricity generating capacity is shown in Table 4. Renewable electricity capacity and generation is predominantly conventional hydroelectric. In 2002 hydroelectric represented 77% of renewable capacity; of the remaining 23% biomass represented 77%. Table 5 gives renewable energy generation; hydroelectric generation comprised 76% of the total. Of the remaining 24%, biomass represented 71 %, geothermal 16%, and wind 13 %.

Table 1: U.S. Total Energy Supply

	2001	2002
Production	EJ	EJ
Crude Oil and Lease Condensate	12.83	12.57
Natural Plant Gas Liquids	2.69	2.70
Dry Natural Gas	21.34	20.64
Coal	25.29	23.95
Nuclear Power	8.47	8.60
Renewable Energy	5.54	6.16
Other	0.56	1.19
Total	**76.72**	**75.80**
Imports		
Crude Oil	21.37	20.93
Petroleum Products	5.32	5.01
Natural Gas	4.28	4.33
Other Imports	0.62	0.55
Total	**31.60**	**30.82**
Exports		
Petroleum Products	2.12	2.14
Natural Gas	0.40	0.55
Coal	1.33	1.09
Total	**3.85**	**3.78**
Discrepancy	2.20	-0.25

Ref: Energy Information Agency, Annual Energy Outlook 2004

Table 2: U.S. Renewable Energy Consumption

	2001 EJ	2002 EJ
Marketed Renewable Energy		
Residential Wood	**0.38**	**0.41**
Commercial Biomass	**0.09**	**0.11**
Industrial		
Conventional Hydroelectric	0.03	0.04
Municipal Solid Waste	**0.01**	**0.01**
Biomass	**1.68**	**1.69**
Transportation, Corn Ethanol used in Gasoline	**0.15**	**0.18**
Electric Generators		
Conventional Hydroelectric	2.42	2.90
Geothermal	0.31	0.32
Municipal Solid Waste	**0.35**	**0.36**
Biomass	**0.00**	**0.00**
Dedicated Plants	**0.13**	**0.12**
Cofiring	**0.03**	**0.06**
Solar Thermal	0.01	0.01
Solar Photovoltaic	0.00	0.00
Wind	0.08	0.14
Total Marketed Renewable Energy	5.67	6.34
Non-Marketed Renewable Energy		
Residential Solar Hot Water Heating	0.04	0.02
Commercial Solar Thermal	0.02	0.02
Total Renewable Energy Consumption	5.73	6.38
Total Biomass (including MSW and Ethanol)	**2.82**	**2.93**

Ref: Energy Information Agency, Annual Energy Outlook 2004

Figure 3: U.S. Electricity Generation

	2001 Bil kWh	2002 Bil kWh
Electric Power Sector		
Power Only		
Coal	1852	1875
Petroleum	113	77
Natural Gas	427	450
Nuclear Power	769	780
Pumped Storage/Other	-9	-9
Renewable Sources	259	304
Distributed Generation (Nat Gas)	0	0
Non-Utility Generation for Own Use	-20	-34
Total	**3391**	**3443**
Combined Heat and Power		
Coal	31	32
Petroleum	6	6
Natural Gas	128	148
Renewable Sources	4	5
Non-Utility Generation for Own Use	-9	-11
Total	**160**	**183**
Net Available to the Grid	**3551**	**3626**
End-Use Sector Generation		
Combined Heat and Power		
Coal	21	21
Petroleum	6	5
Natural Gas	83	84
Other Gaseous Fuels	4	5
Renewable Sources	29	30
Other Gaseous Fuels	9	11
Total	**152**	**156**
Other End-Use Generators	3	4
Generation for Own Use	-129	-134
Total Sales to the Grid	**25**	**27**
Total Electricity Generation	**3734**	**3831**
Net Imports	**22**	**22**

Ref: Energy Information Agency, Annual Energy Outlook 2004

Table 4: U.S. Renewable Electricity Generating Capacity

	2001 GWe	2002 GWe
Electric Power Sector Net Summer Capacity		
Conventional Hydropower	78.13	78.29
Geothermal	2.88	2.89
Municipal Solid Waste	3.38	3.49
Wood and Other Biomass	1.79	1.83
Solar Thermal	0.33	0.33
Solar Photovoltaic	0.02	0.02
Wind	4.15	4.83
Total	**90.67**	**91.69**
End-Use Sector Net Summer Capacity		
Combined Heat and Power		
Municipal Solid Waste	0.21	0.25
Biomass	3.80	3.91
Total	4.01	4.16
Other End-Use Generators		
Conventional Hydropower	1.02	1.02
Geothermal	0.00	0.00
Solar Photovoltaic	0.03	0.04
Total	**1.05**	**1.06**

Ref: Energy Information Agency, Annual Energy Outlook 2004

Table 5: U.S. Renewable Electricity Generation

	2001 Bil KWh	2002 Bil kWh
Electric Power Sector Generation		
Conventional Hydropower	213.70	255.78
Geothermal	13.74	13.36
Municipal Solid Waste	19.22	20.02
Wood and Other Biomass	8.56	8.67
Dedicated Plants	7.22	6.32
Cofiring	1.34	2.35
Solar Thermal	0.54	0.54
Solar Photovoltaic	0.00	0.00
Wind	6.74	10.51
Total	**262.50**	**308.87**
End-Use Sector Net Summer Generation		
Combined Heat and Power		
Municipal Solid Waste	1.78	1.84
Biomass	26.91	28.16
Total	**28.86**	**30.00**
Other End-Use Generators		
Conventional Hydropower	3.21	4.11
Geothermal	0.00	0.00
Solar Photovoltaic	0.06	0.09
Total	**3.27**	**4.20**

Ref: Energy Information Agency, Annual Energy Outlook 2004

ONGOING

PROJECTS

The USDOE biomass thermochemical platform is concentrating primarily on producing clean intermediate products suitable production of fuels, chemical, and power from biomass and black liquor. The primary projects this year involve 1) a solicitation addressing cleanup issues, fundamental breakthrough research, utilization of biomass intermediate products in petroleum refineries, and black liquor gasification; 2) development and evaluation of fluidizable catalyst for tar cracking and methane reforming; 3) Commissioning and operation of a 200 ton/day black liquor gasifier at the Georgia Pacific Big Island, Virginia, semi-chemical pulp mill; and 4) small modular biomass.

DOE/USDA Solicitation

The U.S. Department of Agriculture (USDA) and the U.S. Department of Energy (DOE) are jointly soliciting projects for financial assistance addressing research, development, and demonstration of biomass-based products, biofuels, biopower, and related processes with the intent to promote greater innovation and development related to biomass, and to support Federal policy calling for greater use of biomass-based products, feedstock production, and processing and conversion. DOE intends to fund up to 10 million USD and USDA to fund up to 12 million USD for proposals under this solicitation. The maximum amount of Federal funding for an individual award is 2 million USD. Eight technical topic areas are being addressed:

DOE-1: Thermochemical Conversion – SynGas Cleanup & Conditioning and Pyrolytic Bio-Oils Handling and Blending characteristics
DOE-2: Thermochemical Conversion - Fundamental Breakthrough Research
DOE-3: Biomass – Petroleum Refinery Evaluations
DOE-4: Thermochemical Gasification – Kraft Black Liquor Gasification
USDA-5: Feedstock Development and Production
USDA-6: Biobased Products – Environmental and Economic performance
USDA-7: Biomass Focused Forest Management Training
USDA-8: Incentives

A more detailed description of the DOE topic areas is given below.

1. **Thermochemical Conversion – SynGas Cleanup & Conditioning and Pyrolytic Bio-Oils – Handling and Blending Characteristics**

   a. Required minimum cost share – 20%
   b. Syngas cleanup (tars, N, alkali, and sulfur)
      i. Catalytic conversion
      ii. Condensing cleanup
      iii. Non-condensing cleanup (including plasma tar destruction)
   c. Pyrolytic Bio-Oils
      i. Handling (toxicity, stability, transportation, storage)

ii. Blending characteristics

Description: Raw gases from biomass systems, including black liquor systems, do not meet strict quality standards for downstream fuel or chemical synthesis catalysts or those for some power technologies (fuel cells or fuel cell/turbine hybrids), and will require gas cleaning and conditioning to remove contaminants such as tar, particulates, alkali, ammonia, chlorine, and sulfur. Available cleanup technologies do not meet the cost, performance or environmental criteria needed to achieve the program goals or commercial implementation.

Applications are being solicited in the areas of 1) improved catalysts for tar, benzene, ammonia, and sulfur destruction or mitigation within the syngas, 2) improved reliability, ammonia separation/recovery and environmental performance of condensing syngas cleanup systems, 3) improved techniques for removal of particulates, volatile alkalis heavy metals, and sulfur in either condensing (low temperature) or non-condensing (high temperature) syngas cleanup systems, 4) methods for improving the handling characteristics of pyrolytic bio-oils (toxicity, stability) for safe transport and long-term storage, and 5) determining the blending characteristics of pyrolytic bio-oils with commercial petroleum fuels.

Barriers:
1. Feasibility, cost, environmental, and reliability concerns for cleanup and conditioning technologies.
2. Product properties: impact on downstream costs, fungibility of intermediate product

Desired outcomes: Development of processes meeting the required specification for downstream synthesis operations or meeting established commercial product specifications for the identified market.

2. Thermochemical Conversion and Conditioning – Fundamental Breakthrough Research

Required minimum cost share – 20%

Description: Thermochemical biomass conversion techniques—gasification, pyrolysis, and hydrothermal conversion—have been studied and developed over the past half century. While ongoing development shows significant technical innovation, the development results in incremental improvements in final product costs. Proposals may include R&D to improve the ability of the gasification or pyrolysis process to eliminate tars, sulfur, and particulates in process e.g. within the reactor. Proposals are being solicited that address the chemistry of thermochemical conversion that ultimately have the potential to result in greatly improved thermochemical conversion rates and greatly reduced costs. The goal is to greatly reduce the cost of producing clean fuels and chemicals from biomass. Projects should have in mind the ultimate goal of producing fungible intermediate or final products, and should identify the specific target and address the specifications required for commercial markets, such as cleanliness, physical properties, etc

Barriers: Cost and efficiency of biomass thermochemical conversion, and cost and efficiency of cleanup and conditioning.

Desired Outcomes: Innovative conversion and cleanup systems with the potential for order of magnitude improvements in processing costs or product value.

3. Biomass – Petroleum Refinery Evaluations

Required minimum cost share – 20% total - must include at least a 10% portion of cost share from oil or gas industry partner.

Description: Use of biomass has not been demonstrated for commercial use in the petroleum refining industry. Applications are being sought to perform detailed evaluations of using biomass as feed or co-feed to all potentially suitable refinery conversion processes, e.g., hydrotreaters, catalytic crackers, hydrocrackers, cokers, etc. The evaluations may be analytical or pilot-scale. If potential attractive results are obtained for any unit operation, the analysis should include approaches for tracking the amount of renewable product.

Barriers: Utilization of biomass for petroleum refineries

Desired Outcomes: Identification of opportunities for the use of biomass as petroleum refinery feed

Thermochemical Conversion – Kraft Black Liquor Gasification

Required minimum cost share – 20%

Description: R&D applications are being solicited to assist in Kraft black liquor gasification development thereby supporting the majority of United States' paper and pulp mills. Applications must identify the gasification or other thermal conversion system and provide data for black liquor conversions, including yields, temperatures, pressures, compositions, etc. used as the basis for defining the process efficiencies, environmental benefits, and system economics. Methodology to reduce capital intensity and minimize risks of commercial demonstration must be addressed.

Barriers: Develop a reliable gasifier to produce syngas and provide chemical recovery. The path forward sought is to demonstrate cost-effective, energy efficient, gasification technologies for integrated combined cycle (IGCC) or gasification/cogeneration applications. The technical barriers that must be surmounted before commercialization of these technologies are understood to be:
Materials of construction with known life expectancy;
Gas clean-up in the high sulfur-laden gas specific to the Kraft process; and
Integration of gasification, power cycle, syngas conversion, and pulp mill systems are critical technical areas.

Desired Outcomes: Implementation of cost-effective, energy efficient, gasification technologies for integrated gasification combined cycle (IGCC) or gasification/cogeneration applications yielding a syngas capable of use in a power generation cycle, or production of fuels and chemicals. Through this solicitation, DOE expects to support applications for the research and

development of Kraft black liquor gasification systems up to but not exceeding a pilot validation scale.

The following dates are relevant for the proposal:

Pre-application due:	January 30, 2004
Full application due:	March 26, 2004

NREL Core Thermochemical Research
The raw gases from biomass gasification systems do not meet strict quality standards for downstream fuel or chemical synthesis catalysts nor those for some power technologies (fuel cells or fuel cell/turbine hybrids), and will require gas cleaning and conditioning to remove contaminants such as tar, particulates, alkali, ammonia, chlorine, and sulfur. Available cleanup technologies do not meet the needed cost, performance or environmental criteria needed to achieve the Program goals or commercial implementation. To date, gas cleanup and conditioning technologies and systems are unproven in integrated biorefinery applications. As part of the Thermochemical Platform, this project addresses particulate removal optimization and catalytic tar reforming strategies to produce a clean syngas from a range of biomass feedstock. Validating gas cleanliness requirements is the final component.

Status: Three tasks are devoted to the catalytic steam reforming of tars produced biomass gasification at different scales. The 2003 efforts to install a full stream steam reforming catalytic tar conditioning reactor in NREL's TCPDU and slip-stream testing of novel, fluidizable catalysts in a 2" fluidized bed reactor was completed in January 2004. Additionally, fundamental catalyst studies will be conducted to evaluate tar reforming activity and destruction kinetics in a micro-scale reactor as well as catalyst surface characterization.

Recent Progress**:** The scheduled completion date with final delivery of all fabricated equipment was 11/30/03. Actual delivery of the vessel and ancillary equipment was on 12/12/03. Installation was completed in January 2004.

Five materials were evaluated in 2003 in the 2"FBR at multiple temperatures in an effort to determine effective kinetics for tar reforming in the raw, biomass-derived syngas produced in NREL's Thermochemical Process Development Unit. A commercial naphtha cracking catalyst (Sud Chemie C11NK) was used as a benchmark for performance and activity in these catalyst screening studies. A fluidizable Ni-based catalyst was made by depositing a catalyst formulation similar to the commercial naphtha cracking catalyst, but scaled to the surface area of the support, onto a commercially available ceramic material produced by CoorsTek Ceramics. The CoorsTek support material, a synthetic olivine, and a platinized catalyst made with the fluidizable support were also tested. The NREL Ni-based catalyst using the CoorsTek support contained ten times less Ni than C11NK yet performed nearly as well as the commercial material. As expected, the supports exhibited only slightly better than thermal cracking ability with the platinized catalyst activity falling between the supports' and Ni-catalyst's performance.

Recently we have focused on understanding and interpreting the catalyst deactivation kinetics. A detailed survey of the literature has been conducted to identify deactivation kinetic models that apply to our results. A study is also underway to evaluate initial catalyst deactivation for the

NREL 1 catalyst (potassium promoted nickel-magnesium on alumina). The initial deactivation represents the decline in fresh catalyst activity resulting in a pseudo-steady state activity where the majority of catalytic tar reforming data are measured. Understanding initial catalyst deactivation is important in evaluating potential catalyst regeneration. The preliminary evaluation involves developing relatively simple plug-flow reactor models based on 1st and 2nd order kinetic expressions with 1st and 2nd order catalyst activity functions incorporating a semi-empirical severity factor.

Black Liquor Gasification

The Department of Energy's Offices of Fossil Energy and Energy Efficiency and Renewable Energy (Office of Industrial Technologies) have awarded a contract through the National Energy technology Laboratory (NETL) to Georgia-Pacific to demonstrate Black Liquor Gasification at the Big Island facility. The project is a 5-year commercial scale demonstration designed to prove the viability of black liquor gasification technology in the forest products industry. The technology being demonstrated is the MTCI/Thermochem gasifier (steam reformer). The gasifier scale is 200 tpd (32.5 MW t).

The Big Island Mill is a non-sulfur, non-bleaching pulp and paper mill at Big Island, Virginia (about 12 miles west northwest of Lynchburg, VA). The facility produces corrugating medium from semi-chemical (sodium carbonate/sodium hydroxide) hardwood pulp and secondary fiber, and linerboard from fiber recycled from old corrugated containers, clippings and rejects from corrugated container manufacturing plants, and some mixed office waste paper. The production capacity of the semi-chemical pulp mill is about 860 tons per day and supplies only the medium machines. The Secondary Fiber or OCC mill produces an average of 950 tons per day and supplies 100% of the furnish for the linerboard mill and about 20% of the furnish for the medium mill. The paper mills produce an average of 870 tons per day of corrugating medium and 730 tons per day of linerboard. Corrugating medium is used to form the inner flute and linerboard to form the two outer surfaces of the board used to manufacture containers or cardboard boxes.

This partnership will enable the development, scale-up and commercialization of gasification technologies for the forest products industry providing domestic mills the opportunity to replace recovery boilers that are reaching retirement age with a new, more energy and environmentally efficient, technology. This technology offers great potential for improved capital effectiveness, energy efficiency, environmental performance, global competitiveness, and safer working conditions for the forest, wood, and paper industry. These advantages include:

- The ability to increase electrical power production capacity by over 200 percent.
- Providing the potential to reduce greenhouse gas emissions by over 30 million metric tons of carbon per year.
- Providing Unites States facilities with significantly more effective and efficient powerhouses compared to currently growing segment of the global industry.
- Pulp mill operating benefits include increased pulp yield per unit of wood, reduced pulping energy consumption, and increased pulp quality. In addition, this technology offers cross-cutting applications to other industries including agricultural, pharmaceutical, and petrochemical.

- Georgia-Pacific's Big Island facility in Virginia has been in operation for over 100 years and represents Georgia-Pacific's commitment to the program and the future of the industry. When completed, this project will provide the entire chemical recovery required by the facility.
- Georgia-Pacific and its technology partners will design, construct, and operate a black liquor gasifier integrated into the existing mill operations with deployment demonstration beginning in early 2003.

Status: During the overall commissioning phase of the G-P project, black liquor was fed initially on March 6, 2004 to the steam reformer unit. This feeding of black liquor was related specifically to the pulse heater commissioning integral to this unit and the overall process. Black liquor feed has been stopped and started several times since the initial feed period. The processing rate of black liquor has been equal to 40% of the design load for one vessel. Additional commissioning work around the pulse heaters is ongoing since the firing of these units has not yet reached sufficient load to induce pulsing.

Gas Technology Institute (GTI) Flex-Fuel Gasification Test Facility
Project Objective: GTI has built a unique gasification test platform to address the need for more thorough gasification technology evaluation and development. The Flex-Fuel Gasification Test Facility, located on GTI's research campus in Des Plaines, Illinois, is used to facilitate commercialization of advanced gasification and down-stream end-use technologies.
The Gas Research Institute (GRI) and the State of Illinois Department of Commerce and Economic Opportunity have provided valuable financial support for the construction of the facility. GTI began construction in early 2003 on the state-of-the-art, $12 million facility. This test platform will evaluate advanced and innovative gasification processes employing a variety of low-cost, solid carbonaceous fuels.
The Flex-Fuel Gasification Test Facility employs GTI's fluidized-bed gasifier as a primary platform for testing coal, biomass, or a variety of other solid fuels. The facility's flexible design will allow testing of a variety of cleanup systems that will be needed to condition the syngas from the gasifier. The facility can also be used to test other advanced gasification concepts. The facility is capable of operating over a broad range of conditions. Pressure up to 435 psia (30 bar)
Operation with either Air or Oxygen. Coal Feed Rates up to 1700 lbs/hr (771 kg/hr)
Biomass Feed Rates up to 4100 lbs/hr (1860 kg/hr)

Status: The facility is available for use by organizations conducting research on enabling technologies that have shown promise after laboratory and bench testing and that need to be proven at the next scale through long-duration tests. Syngas from the facility can be used to study the ability of advanced energy systems—such as solid oxide fuel cells—to operate on fuels other than natural gas. The facility is initially conducting a variety of tests where coal is the feedstock. GTI is actively seeking partners interested in developing advanced biomass applications.

Small Modular Biomass

Project Objective: This project is part of the department of Energy's (DOE) Office of the Biomass Program and is managed by the National Renewable Energy Laboratory (NREL). The primary objective of this project is to develop, through subcontracts with private sector companies, small modular technology capable of converting biomass to power in a range of 5 kW

to 5 MW. The project is currently in Phase II where the contractors are completing detailed engineering design, fabrication, or testing of prototype performance

Community Power Corporation

Project Objective: To develop a turnkey downdraft gasifier system capable of producing 5-50 kW of power. The major system components are a feed/dryer module, a gasifier/dry quench modules, and a commercial engine genset.

Micro Modular Biomass Home System – CPC is testing a 5 kWe system for home use

15 kW systems

Generation 1 – Aliminos, Panay, the Phillipines, 1999 – 2000
Generation 2 – Hoopa Indian Reservation, California, 2001-2002
Generation 3 – 2003 – present, jointly with USDA Forest Service

- Walden High School, Walden, Colorado (operating)
- SBS Wood Shavings, Ruidoso, New Mexico (operating)
- Zuni Indian Reservation, New Mexico (operating)
- San Bernadino National Forest Visitor Center, California (const)

50 kW system
Mt. Shasta, California
Approved/Planning
Funding from the California Energy Commission

FlexEnergy

Project Objective: To develop the Flex-Microturbine, uniquely suited to handle low Btu biomass gases, and to demonstrate its performance on landfill, digester and wood gas

Status:

1. **Progress in Past Quarter:**

The Prototype Shop Testing of the Flex-Microturbine has demonstrated that the Flex-Microturbine can be safely started up, brought to full power and operated continuously for long periods in an automated mode. The Flex-Microturbine can also be automatically restarted following a shutdown. NOx emissions from the Flex are about 0.02 to 0.03 ppm (20 to 30 ppb) and CO emissions are also extremely low.

The highlights of the Prototype Shop Test are provided below:

- The Flex has been started up and shutdown over fifty times. These starts and stops have demonstrated the resilience and thermal cycling tolerance of the new electrical heaters, the catalyst, the control system and the compatibility of the old system with the new.
- The Flex has achieved over 1,500 hours of operation (over two months) demonstrating that the catalyst is adequate and sturdy.
- Control of startup and ramp up to power proved to be a significant challenge. There are complex transients created by thermodynamic and heat transfer during startup. Sophisticated algorithms had to be developed to manage them.

- The catalyst was able to achieve essentially one hundred percent combustion. The fuel-air mixture flow has two small pathways that bypass the catalyst. These pathways result in small amounts of unburned methane. While this is not an emissions problem, we are evaluating means to reduce this bypass.
- The basic premise of the Flex-Microturbine is now established: fuel may be delivered at atmospheric pressure, and a fuel with only 13 to 15 Btu per cubic foot is adequate for full power operation.

Carbona Corp

Objective: Integrate a fluidized bed gasifier with a novel tar reforming catalyst and other gas cleanup devices into a modular biomass gasification gas engine (BGGE) power system at a capacity of 5 MW. The components of the system have demonstrated successful operation independently but not as an integrated process. The plant will be commercial status and owned by Skive Fjernvarme, the local cooperative that supplies heat and power to the community of Skive, Denmark.

Status:

1. **Progress in the Past Quarter:** Carbona has completed the process design of the plant in Skive. Skive finalized the contract with Carbona and an EPC contractor for the construction of the BGGE plant. The selection of the architectural firm will be complete in January 2004.

U.S. GASIFIER MANUFACTURERS AND DEVELOPERS

Gasifier Platform Data Base
Prepared By: R. Bain
Revision Date: 6-Apr-04

Organization	Org. Type	Plant Location City	Plant Location State	Cong District	Gasifier Type	Scale kg/hr	Scale Mg/d	Scale kWt	Scale kWe	Status	Contact Information
Commercial											
Brightstar Environmental **www.brightstarenvironmental.com** **email: gapa@brightenv.com**	I	Baton Rouge	LA		IND-E					UNK	Ron Menville Vice President P.O. Box 539 St. Gabriel, LA 70776 Home Office: **Australia** 848 Boundary Road P.O. Box 535 Richlands Queensland 4077 Tel 61-7-3275-5600 Fax 61-7-3217-0733 **UK** Sheridan House 17 St. Ann's Road Harrow HA1 1JU Tel 44-20-8861-2777 Fax 44-20-8861-2888 **USA** 7700 San Felips, Ste 480 Houston, TX 77063-1613 Tel 713-781-5353 Fax 713-781-5303
Chiptec **www.chiptec.com**	I	Burlington	VT		UD					OP	Robert Bender 48 Helen Ave. South Burlington, VT 05403 Tel 802-658-0956 Fax 802-660-8904 chiptec@together.net
Energy Products of Idaho **www.energyproducts.com** **email:** **epi@energyproducts.com**	I	Coeur D'Alene	ID		FB				6-50 MWe	OP	Joseph Eisele, Director of Business Development 4006 Industrial Ave. Coeur D'Alene, ID 83815-8928 Tel 208-765-1611 Fax 208-765-0503
Emergy Energy Co.	I	Salt Lake City	UT		Mixed UD/DD		10			Const.	Benjamin D. Phillips, President Emery Energy Company 157 West Pierpoint Ave Salt Lake city, Utah 84101

Commercial											
Foster Wheeler	I				CFB						Neil Raskin Director, Global New Products Foster Wheeler Development Corporation Perryville Corporate Park Clinton, NJ 08890-4000 908-713-3190 neil_raskin@fwc.com
GCT International **Global Concepts, Inc.** **email: globalc@earthlink.net**	I	Albuquerque	NM		FB				50kWe - 15MWe	OP	Global Concepts, Inc. 1712 Pedregoso Place SE Albuquerque, NM 87123 Tel 505-294-5068 Fax 505-294-5069
Primenergy, LLC **www.primenergy.com**	I	Tulsa	OK		Mod-UD		27.3			OP	Kevin McQuigg Vice President P.O. Box 581742 Tulsa, OK 74185 Tel 918-835-1011 Fax 918-835-1058
PRME **www.prmenergy.com**	I	Hot Springs	AR		Mod-UD					OP	Ron Bailey Jr, President PRM Energy Systems 504 Windamere Terrace Hot Springs, AK 71913 501-767-2100
Renewable Energy Corporation, LTD **web site under construction**										OP	
Thermogenics **www.thermogenetics.com**	I	Albuquerque	NM		DD-var	455-2730				Pilot	Tom Taylor, President 7100 F St NW Albuquerque, NM 87107 Tel 505-761-5633 Fax 505-341-0424

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Demonstration											
Advanced Alternative Energy Corp	I	Lawrence	KS		various		4				Les Blevins 1207 N 1800 Road Lawrence, KS 66047 Tel 785-842-1943
Carbon Conversion Technogies	I	Denver	CO		Mixed		25		1000	Demo	Robert (Bud) Klepper 6535 N. Washington St, #B Denver, CO 80229 303-287-5318 303-287-5318 (FAX)
Carbona Corp	I	Napa	CA		FB				5000	Design	Jim Patel President P.O. Box 7067 Napa, CA 94558 Tel 707-553-9800 Fax 707-553-9820 carbonacorp@Carbona.us
Community Power Corp	I	Littleton	CO		DD	35			25	OP	Walt, Robb President 8420 S. Continental Divide, Ste 100 Littleton,CO 80127 Bus: 303-933-3135 Bus Fax: 303-933-1497 E-mail: robbcpc@aol.com
Cratech	I	Tahoka	TX							OP	Joe D. Craig P.O. Box 70 Tahoka, TX 79373 Tel 806-327-5220 Fax 806-998-5467
GTS Duratek	I	Oak Ridge	TN							OP	Bob Hensel - V-P International 6 Stoneridge Drive Barrington, IL 60010 Tel 847-304-9646 Fax 847-304-5889 bobhensel@earthlink.net
Emery	I	Salt Lake City	UT				10				
EPA/CLEW	FG								1000		Carol Purvis, EPA - can supply information
FERCO	I	Burlington	VT		IND-CFB		320			OP	
GTI Renugas	I	Birmingham	AL		FB		10				Dr. Suresh Babu 1700 S. Mount Prospect Rd Des Plaines, IL 60018-1804 Tel 847-768-0509 Fax 847-768-0507 email: sureshbabu@gastechnology.org
Hamilton Mauer International/ MIFGA (HMI, Inc.)	I				UD						Rolf Mauer Tel 713-468-6805 Fax 713-468-0761

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Demonstration											
Mississippi Ethanol	I	Winona	MS		IND-E		40				Larry Pearson Missisippi Ethanol P.O. Box 108 Winona, MS 38967 662-283-1461
Thermochem	I	Baltimore	MD		IND	1,800-18,900 dry solids				OP	Lee Rockvam Thermochem (MTCI) 6004 Chemical Road Baltimore, MD 21226 Tel 410-354-9890
Pearson Technologies of Mississippi **No web site.**	I	Aberdeen	MS		IND-E		27.3			OP	Stanley R. Pearson 20088 Norm Cromwell Drive Aberdeen, MS 39730 Tel 662-369-1168
Research and Development											
Biosolutions USA, Inc. **Haven't found a web site.**	I	West Lafayette	IN		DD				40-50	UNK	Robert M. Stwalley 512 Main St. Lafayette, IN 47901-1445 765-409-7483
GAZOGEN **web under development**	I	Marshfield	VT		FB				100	OP	Carl Bielenberg President 1915 East Hill Rd Marshfield VT 05658-8901 Tel 802-456-8993 Fax 802-456-7476 gazogen@yahoo.com
National Laboratory											
NREL **www.nrel.gov**	NL	Golden	CO		Elec-FB	20					R. Bain 303-275-2946 richard_bain@nrel.gov
Education											

Organization	Org. Type	Plant Location City	State	Cong District	Gasifier Type	Scale kg/hr	Mg/d	kWt	kWe	Status	Contact Information
Education											
Iowa State University **www.iastate.edu**	U	Ames	IA		FB		5				Dr. Robert C. Brown Professor Mechanical Engineering Dept Iowa State University 2020 Black Engineering Building Ames, IA 50011-2160 515-294-8733 rcbrown@iastate.edu
Mississippi State University **www.msstate.edu**	U	Starkville	MS								Dr. Mark Zappi Director of Environmental Technology Research and Applications Laboratory Missisippi State University P.O. Box 9595 Mississippi State, MS 39762 Bus Fax: (662) 325-2482 E-mail: zappi@che.msstate.edu
University of Hawaii **www.hawaii.edu**	U	Honolulu	HI		Elec-E						Scott Turn Professor Hawaii Natural Energy Institute University of Hawaii at Manoa 2540 Dole Street, Holmes Hall 246 Honolulu, HI 96822 Bus: (808) 956-2346 Bus: (808) 956-2346 Bus Fax: (808) 956-2335 E-mail: sturn@uhunix.uhcc.hawaii.edu
University of Nebraska **unk.edu**	U	Lincoln	NE		Spouted Bed						Dave Clements 402-472-0177
University of Utah **www.utah.edu**	U	Salt Lake City	UT		IND						Kevin Witte (801) 585-9388

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