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Feasibility studies on selected bioenergy concepts producing electricity, heat, and liquid fuel

IEA Bioenergy

Techno-economic analysis activity

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Cover picture: The RTP^{TM} (Ensyn Technologies Inc.) fast pyrolysis process development unit at VTT, Espoo, Finland.

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Abstract

The IEA Bioenergy Techno-Economic Analysis Activity reported here, had the following objectives:

- To assist companies working with technologies and products related to bioenergy applications in their efforts to demonstrate these,
- To promote bioenergy technologies, processes and applications,
- To built and maintain a network for R&D organisations and industry.

The objectives were pursued 1995 - 1997 through carrying out site-specific pre-feasibility studies in participating countries. Both electricity and liquid fuel applications were studied, utilising gasification, pyrolysis, and combustion technologies. Studies were carried out in collaboration with companies developing new products or services from participating countries (Austria, Canada, Finland, and the United States of America) in the bioenergy field. Cases are:

- Austria: Power production at a district heating station, Stirling-engine driven by unclean boiler flue gases, 50 kW_e
- Canada - Bio-oil production for a boiler power plant, Fast pyrolysis of sawmill wastes & bark, 11 MW_e
- Finland: Co-generation of power and heat at a pulp and paper mill, Pressurised integrated gasification combined-cycle (IGCC) using bark & wood, 34 MW_e
- Sweden: Bio-oil production for heating fuel, Fast pyrolysis of forest residues, 20 000 t/a
- USA - Case 1: Co-firing in a coal boiler, Combustion of plantation willow, 15 MWe
- USA - Case 2: Condensing power production, Pressurised IGCC using alfalfa stems, 75 MW_e

All of the cases studied are at different stages of development. Results from these case studies are reported together with technical uncertainties and future development needs, which are required for all the systems. In general, the results showed that for most of the cases studied economic conditions are possible, through existing subsidies or tax incentives, for feasible industrial operation. Specially designed Stirling engines have a short amortisation time integrated to biomass district heating plants in Austria, provided similar subsidies will be obtained as for district heating plants. The pulp mill IGCC appears slightly more economic than the commercial alternative already without subsidies. Recent press releases from participating industry is included to highlight the industrial applications of the studied technologies.

Preface

IEA Bioenergy is an international collaboration within the International Energy Agency - IEA. IEA is an autonomous body within the framework of the Organisation for Economic Co-operation and Development (OECD) working with the implementation of an international energy programme. There is a general consensus among experts and governments around the world that bioenergy is one of the renewable resources of energy which are expected to play a major role in the future energy market. This is reflected in an effort to increase industrial participation in IEA Bioenergy and shift the emphasis of the collaborative work from Research and Development towards Deployment. At the end of 1996 there were sixteen participants in IEA Bioenergy, fifteen countries and the European Commission.

IEA Bioenergy includes various tasks, under which several activities are dealing with the whole bioenergy utilization chain from biomass production to end product use. One of these activities, the Techno-Economic Analysis Activity is reported here. The countries funding the activity were Austria, Canada, Finland, Norway, and the United States of America. Funding agencies in these countries were Ministry of Science and Traffic, Natural Resources Canada (NRCan) CETC Division, Technology Development Centre Finland (Tekes), The Royal Norwegian Ministry of Energy and Industry, and the United States Department of Energy, respectively. The authors wish to acknowledge these organisations for supporting the work. We would also wish to acknowledge organizations and individuals, who contributed to the work: Carbona Inc. (Finland), Ensyn International Inc. (Canada), professor Björn Kjellström, Luleå University of Technology (Sweden), Resource Transforms International Ltd. (Canada), and Thermal Engineering (Canada). We would especially wish to acknowledge Ed Hogan from the NRCan, who provided additional funds for development of the gas turbine model. In addition, we acknowledge Tuula Mäkinen from VTT Energy, who did the performance calculations for the pyrolysis cases.

The working group members were Erich Podesser (Joanneum Research, Austria), David Beckman (Zeton Inc., Canada), Tiina Koljonen (VTT Energy, Finland), Morten Fossum (SINTEF, Norway), Ralph P. Overend (National Renewable Energy Laboratory, USA), and Yrjö Solantausta (co-ordination, VTT Energy, Finland).

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January 1999

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1. Introduction

1.1 The techno-economic analysis (TEA) activity

The IEA Bioenergy Techno-Economic Analysis Activity reported here, had several objectives:

- To assist companies working with technologies and products related to Bioenergy applications in their efforts to demonstrate these,
- To promote Bioenergy technologies, processes and applications,
- To build and maintain a network for R&D organisations and industries.

The objectives have been pursued 1995 - 1997 through carrying out site specific pre-feasibility studies in participating countries. Both electricity and liquid fuel applications were studied, utilising gasification, pyrolysis, and combustion technologies. Studies were carried out in collaboration with companies developing new products or services from participating countries (Austria, Canada, Finland, Norway, and the United States of America) in the bioenergy field.

The main advantages, which are attributed to the new concepts are high efficiency, low emissions, and projected low costs. However, as none of the concepts presented have been applied in continuous industrial operation, there are technical uncertainties related to all of these applications.

1.2 Sites and applications

Production of both electricity and heat using biomass as fuel is included in the studies. The site cases are listed in Table 1, and shown in Figure 1.

Table 1. Summary of IEA Bioenergy Techno-Economic Analysis Activity Sites.

Country	Application	Technology and fuel	Capacity
Finland	Co-generation of power and heat at a pulp and paper mill	Pressurised IGCC, bark & wood	34 MWe
Canada	Bio-oil production for a SBPP	Fast pyrolysis, sawmill wastes & bark	11 MWe
Sweden	Bio-oil production for heating fuel	Fast pyrolysis, forest residues	20 000 t/a
USA	Case 1: Co-firing in a coal boiler	Combustion of plantation willow	15 MWe*
USA	Case 2: Condensing power production	Pressurised IGCC, alfalfa stems	75 MWe
Austria	Power production at a district heating station	Stirling-engine driven by boiler flue gases	50 kWe

IGCC = Integrated Gasification Combined-Cycle, SBPP = steam boiler power plant
* Power produced from biomass

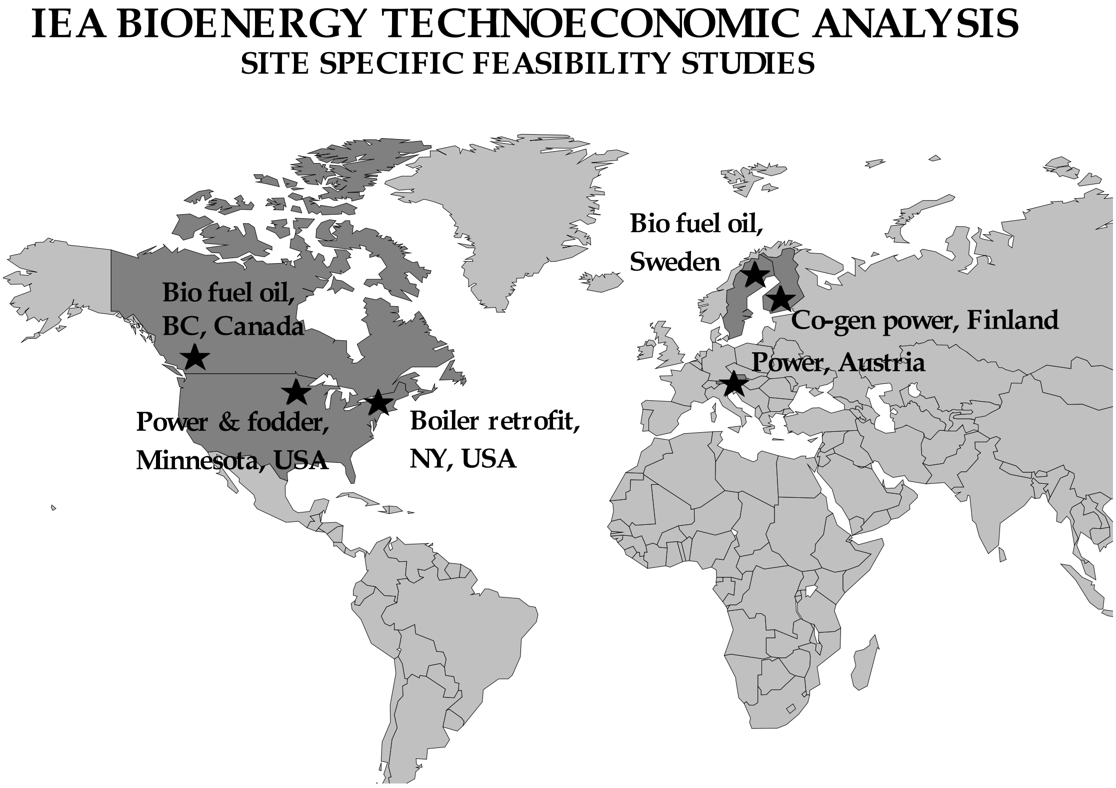

Figure 1. IEA Bioenergy Techno-Economic Analysis Activity Sites.

1.3 Methods

The procedure employed in assessing the feasibility of the site cases is summarised in this chapter. The work included several stages. Some of the technical data was initially worked out with participating industry.

As always with new technology, estimating the cost for these system is very challenging. In this work **emphasis** is on **performance analysis** and in assessing the **technical uncertainties** related to these systems. Economic feasibility is also estimated, but it is recognised that more uncertainty is related to the cost estimation than to the performance estimation.

The tasks included were following:

1. Concept design. This task was determined together with Ensyn Technologies Inc. (The Canadian and the Swedish cases), and with Carbona Inc. (the Finnish case). The US case studies have been designed by engineering contractors.
2. Estimates have to be made by the working group concerning the performance of units not yet demonstrated in industrial scale, and for the units, which are applied outside their normal operating conditions. Estimates were done using AspenPlus^{TM} simulation software.
3. Flowsheets are designed based on analysing proposed concepts by developers. The working group prepared the final flowsheets for all cases.
4. Performance analysis is carried out using AspenPlus. This program is employed by many leading chemical, petrochemical and related companies. The software is employed in deriving mass and energy balances for the processes, except for the Stirling case in Austria, which was assessed in Joanneum Research. The US case studies were estimated separately by engineering contractors.
5. Sizing of the units was done based on normal engineering practises using estimated performances as basis.
6. Costing of the units were done based on data available from developers (Ensyn Inc., Carbona Inc.), from literature, and from the earlier IEA projects [1, 2, 3, 4]. It is not believed that the accuracy of cost estimates is better than ± 30%, and in some cases it may even be larger than this.
7. Economic analysis was carried out. Operating costs were estimated based on normal practises in process and power production industries. Internal rate of return (IRR) was calculated (both production of electricity and bio fuel oil). In addition, product cost were calculated for bio fuel oil production by taking average annual costs for capital costs.
8. Technical uncertainties. This is a critical part of the work. Technical uncertainties are evaluated and reported. Future work is suggested.

2. State-of-the-art of conversion technologies

Technologies studied in this work cover a wide range of capacities and applications. The markets for these systems are therefore rather distinct. Both electricity and heat are included in end products.

Advanced power production concepts based on gasification and pyrolysis are characterised by a high power-to-heat ratio, which is an important parameter in co-generation of electricity and heat (chp, combined heat and power). An IGCC has a power-to-heat ratio of about 1, compared to about 0.5 for a conventional biomass chp plant. Co-generation facilities are sized according to the heat load required. Therefore an IGCC would produce about double the electricity as an existing steam boiler power plant.

2.1 The biomass IGCC

The wood fired IGCC (Integrated Gasification Combined-Cycle) is closest being commercial of the systems studied. An industrial demonstration, the Sydkraft Värnamo plant (6 MW_e and 9 MW_{th}) in Sweden (Figure 2), is perhaps one fourth size of a commercial demonstration capacity. This is a capacity, above which no major risks in scaling up a technology is expected. IGCC has a high power production efficiency, around 47 % at about 50 MW_e [4]. An IGCC is estimated to be economicly feasible only at a relatively large scale (approximately above 40 - 50 MW_e) [5].

The IGCC concepts, which are assessed in this work, employ a pressurised air-blown gasifier. Hot fuel gas produced in the gasifier is combusted in a gas turbine, and remaining sensible heat is used to generate steam, which drives a steam turbine. Electricity is produced in the generators of both these engines.

Carbona Inc. has a gasifier with approximately the same capacity as the Värnamo plant (i.e. about 15 MW_{th}) at their pilot plant in Tampere, Finland (Figure 3). Between 1993 and 1997, 1630 tonnes of wood chips, 1750 tonnes of forest residue, 1180 tonnes of paper mill waste (including bark, paper, and sludge), 400 tonnes of willow, 20 tonnes of straw (together with 120 tonnes of coal), and 120 tonnes of alfalfa stem pellets have been gasified in the pilot plant.

The PICHTR project in the USA (Hawaii) aims in demonstrating pressurised gasification and hot gas clean-up. Bagasse is the dedicated fuel for the plant. Developers in the project include Westinghouse, Pacific International Centre for High Technology Research, and the Institute of Gas Technology [6].

Figure 2. Värnamo biomass IGCC (Sydkraft AB and Foster Wheeler Energia Oy).

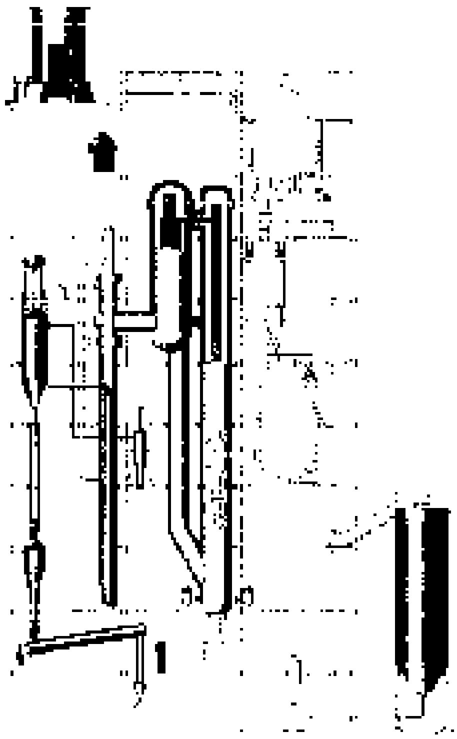

Figure 3. Pilot-gasifier of Carbona in Tampere.

Another recent biomass gasification demonstration is the Battelle/FERCO project at Burlington (Vermont, USA) [7]. A Battelle Columbus twin fluidized-bed gasifier is employed.

There are also three biomass IGCC projects supported by the European Commission in Europe [9]. However, so far (March 1998) none of these are yet at construction stage.

2.2 Bio fuel oil (BFO)

Bio fuel oil (pyrolysis oil) is produced by fast (flash) pyrolysis. The oil may be employed as a heating fuel in boilers, or in combustion engines in power production. All of the application are in different stages of development.

Fast pyrolysis makes it possible to de-couple solid handling stage and product utilisation. Intermittent operation in power production is also possible with liquid fuels for example in diesel engines. In some cases this may be a distinct advantage.

Fast pyrolysis is only proven in pilot-plant operation. The ENEL Bastardo pilot plant (built and designed by Ensyn Inc., Canada) in Italy (Figure 4) is about one tenth of a commercial demonstration capacity. However, as fast pyrolysis is still some years away from commercial operation, estimation of a potential commercial capacity includes large uncertainties.

Fast Pyrolysis technology has been under development since the early 1980's. Several variations of reactor type and process configuration have been tested at laboratory, process development unit (PDU), and even pilot plant scale. The important process parameters common to fast pyrolysis processes are high heat transfer rates to biomass and short vapour residence times. The following organisations are currently conducting research and development of fast pyrolysis technologies: Aston University, UK; BTG, the Netherlands; CRES, Greece; ENEL, Italy; Ensyn Technologies, Canada; Universite Laval, Canada; Resource Transforms International, Canada; Union Fenosa, Spain, and VTT Energy, Finland.

Only a few industrially relevant fast pyrolysis plants have been built so far. Ensyn has built three larger scale pyrolysis reactors at capacities between 0.5 and 1 tonne/h, including two plants at 1 t/h in Wisconsin, USA. However, only one integrated plant, where the char is used for internal energy production, operates at a larger scale of 0.66 t/h, the ENEL plant in Italy [9].Union Fenosa operates 150 kg/h Waterloo Fast Pyrolysis Process (WFPP) pilot plant is Galicia, Spain [10]. All the other fast pyrolysis systems are considerably smaller than these.

Figure 4. ENEL-RTP Bastardo fast pyrolysis plant (Ensyn Technologies Inc.).

Ensyn's development activities include the testing and demonstration of energy related applications for the bio-oil product in collaboration with research organisations and energy industry. The applications studied include bio-oil combustion tests in boilers, diesel engines and gas turbines.

2.3 Stirling engine

The Stirling engine (Figure 5) is a promising alternative in small scale electricity production. A number of different configurations have been developed over the years [11]. Potential advantages related to Stirling engines are their high efficiency also in small scale, and their relative insensitivity towards impurities in the flue gas, if special designed Stirling engines are used.

A market has been defined in Austria for these engines. Heating stations (more then 2500 in Austria) using biomass could cover their own internal power consumption in co-generation with a Stirling engine. Experimental work has been carried out at Joanneum Research, and the IEA study complements this development.

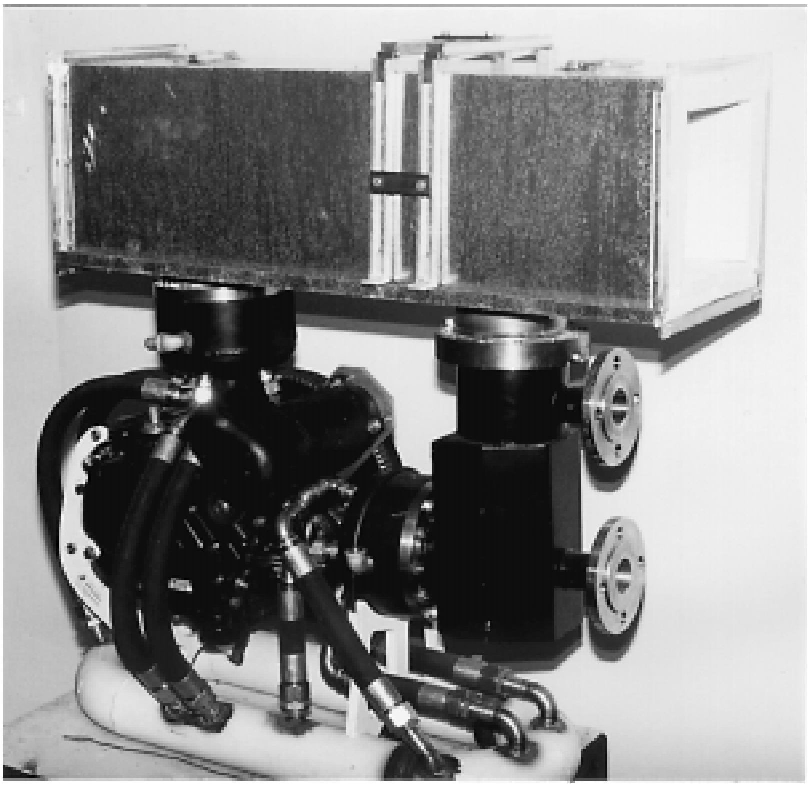

Figure 5. A Stirling engine (Joanneum Research).

3. Sub-contracts for the IEA TEA

Two consultant tasks were carried out as part of the activity, at RTI Ltd., Waterloo, Ontario, Canada, and at Thermal Engineering, Halifax, Nova Scotia, Canada. Both sub-contracts produced critical new data to improve the accuracy of the performance analysis carried out in the activity.

3.1 Fast pyrolysis tests of Swedish birch forest residue, RTI Ltd

Mass and energy balances (performance) for fast pyrolysis have to be estimated because no industrial scale plant producing liquid fuels is in operation. The largest unit operated to March 1998 is the ENEL plant in Bastardo (see above). The pyrolysis section of the conversion plant has been designed and built by Ensyn Tech. Inc. However, no performance data is available from that plant. It should be noted that the pyrolysis reactor capacity assessed in the Swedish case as part of this work is about 13 times higher than the capacity of the ENEL plant, and the Canadian case is about 42 times higher.

The Swedish case study performance estimate for wood fast pyrolysis is based on experiments carried out at RTI in their 150 g/h bubbling fluidized-bed unit. Yields for liquid product, char and gases were determined and analysed. It is assumed that once the residence time for pyrolysis vapours and the reaction temperature is the same, data derived with a bubbling fluidized-bed may be used in estimating the reactor performance of a fast fluidized-bed like the Ensyn RTP. The RTI data is used in the reactor model of AspenPlus, which is employed in deriving mass and energy balances for the whole plant. The report from RTI is attached as an Appendix to the Swedish case study, which is included in volume III of this report.

Heat balance around the reactor in ther Aspen model is based on first principles. No valid measured data for fast pyrolysis to our knowledge has been presented for the reactor heat balance in open literature. A summary from RTI from this topic is attached as Appendix to the Canadian case report, which is included in volume III of this report.

3.2 A simulation model for gas turbines, Thermal Engineering

Only one IGCC plant is being operated at present time (Värnamo). No performance data from that plant is available for estimating the performance of similar cases studied in this work. Therefore the performance of the IGCC concept studied is estimated with a simulation tool, AspenPlus. To improve the accuracy of the AspenPlus gas turbine model used earlier [4], a model was designed and constructed by Thermal Engineering, NS (Canada). The model is integrated as part of the Aspen IGCC model being used.

The design of an IGCC is largely based on the gas turbine characteristics, and therefore a good representation of the gas turbine is critical. The report from Thermal Engineering is volume VI of this final report.

4. Introduction of case studies

4.1 Austria

4.1.1 The market for Stirling engines in Austria

At present, Austrian companies with an annual electric energy consumption of about 30.000 to 100.000 kWh/a are paying 2,00 to 2,60 ATS/kWh. This group includes biomass district heat operators. Thus, a significant potential for the application of combined heat and power (CHP) production from biomass lies in district heat plants and also in the small wood working companies who have to pay a relatively high price for their electric energy. A survey on possible markets in Austria gave the results shown in Table 2, as of 1997.

Table 2. Biomass furnaces in Austria, December 1997.

Application	Number of installations	Average thermal power(kWth)
Biomass district heat plant	321	2 000
Wood-working industry	2 433	1 000
Small private installations	19 823	40

Besides of these Austrian installations about 70 biomass district heat plants exists in Bavaria. The new markets in the Czech Republic, Slovakia and Slovenia should be observed too.

It was found that the CHP production with a biomass Stirling engine directly fired by the unpurified flue gas of the biomass boiler plant is the best technical option.

The objectives of this study are the simulation of a Stirling engine in CHP production with the data of an existing biomass boiler plant, to find out the optimum size of the engine in relationship to the boiler capacity and the thermal part load.

4.1.2 Site information

The district heat plant "Pfarrwerfen" as an example for a typical biomass district heat site in Austria was chosen.

Address: Hackgut- und Heizgenossenschaft Pfarrwerfen, 5452 Pfarrwerfen 120, Austria.

Location: 20 km south of the State capital Salzburg

Plant operation data:

Wood chip fired district heat (existing); a 60 kW Stirling engine/generator set is simulated.

Feedstock	Decorticated wood chips, wood chips (shredded), cut off wood chips, bark
Wood feed	4.452 m^3/a (w = 0.32 av.)
Land area required	800 m^2 for the wood chip storage and district heat plant
Therm. capacity	1 000 kW_{th} furnace, implemented (3 000 kW furnace planned)
Prop. power plant	Stirling engine/Generator Unit, 60 kW_{el}, (120 kW_{el})
Output	Heat and electric energy
Electricity produced	appr. 228 000 kWh/a; 3.800 h/a at full load
Plant cost	23.7 Mio.+ 1.68 Mio. ATS (1 000 kW_{th} district heat and 60 kW_{el} Stirling engine)

4.1.3 Plant scheme

Figure 6 shows the configuration of the process in principle. The primary goal oft the plant is the heat production to fulfil the existing contracts. Secondary goal is electricity production to support the plant demand. The unpurified hot flue gas (1 000 °C) is used to operate the engine. The Stirling engine is designed with a self cleaning heat exchanger for the heater. The CHP principle is realised by transferring the heat from the engine cooler rejected to the return of the district heating system. The flue gas is cooled by the Stirling engine from 1 000 °C to typically 750 °C by the Stirling engine.

Figure 7 shows the energy graph of the "Pfarrwerfen district heating plant" for CHP with a Stirling engine integrated. At this site a flue gas condensation system (FGC) was implemented too. The electric energy produced (ELP) in the proposed Stirling engine drives the pumps of the DH plant and other electric equipments of the plant. The coefficient of performance of the Stirling engine will reach approximately at 28%. For this

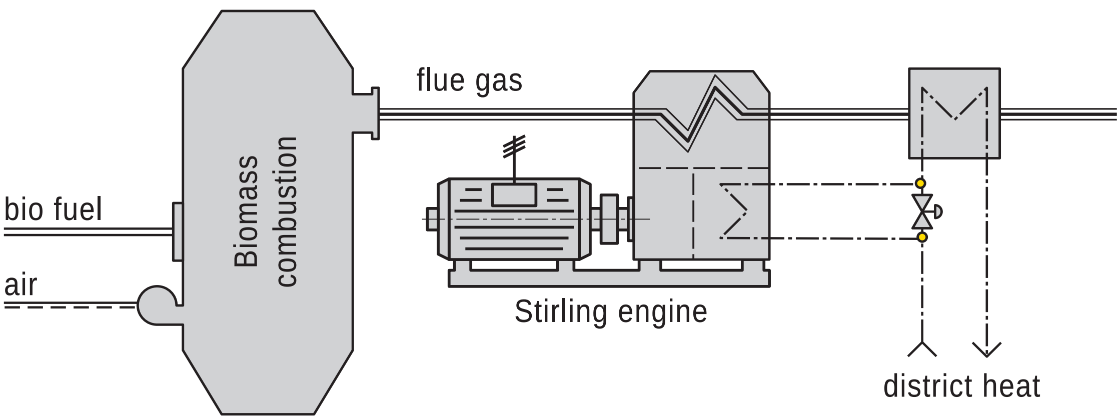

Figure 6. Biomass Stirling CHP production plant; plant scheme.

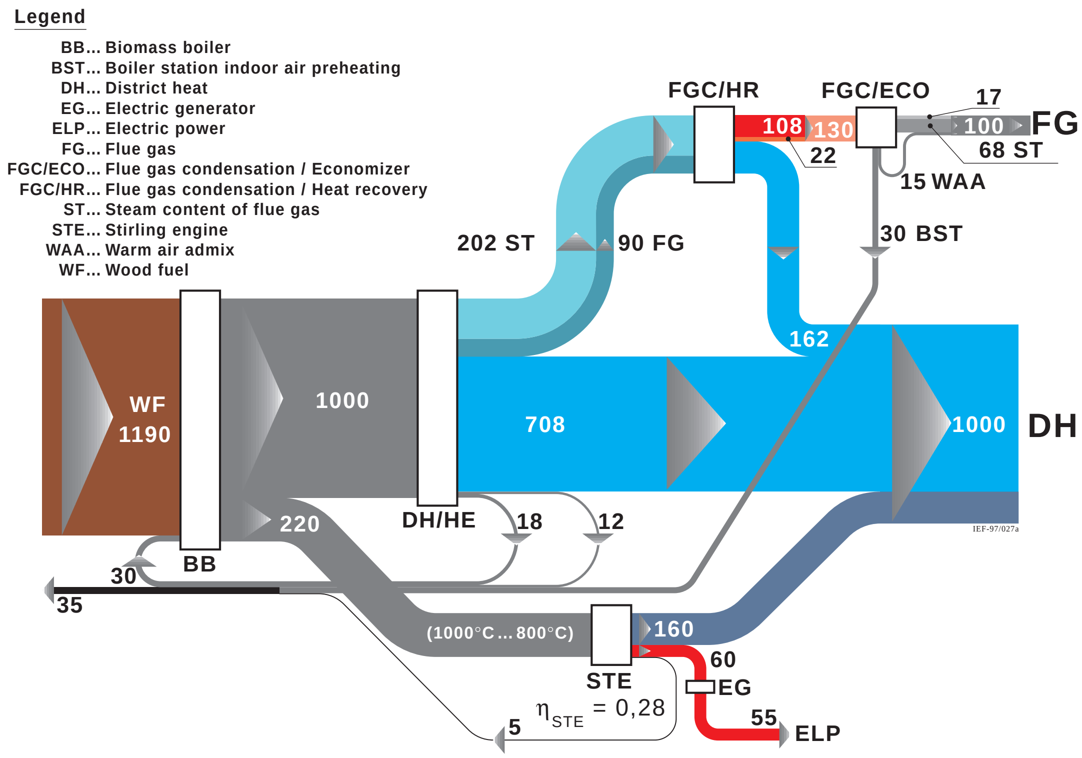

Figure 7. Biomass Stirling CHP production at the Pfarrwerfen district heat plant: Sankey diagram.

application only the Joanneum Research Stirling engine can be used, because of the special construction of the flue gas heat exchanger with the self cleaning effect. This heat exchanger design protects the surface from fouling.

4.2 Canada

4.2.1 Introduction

A techno-economic assessment has been completed for a potential biomass fuelled power plant located in Squamish, British Columbia. The plant will use fast pyrolysis technology, Rapid Thermal Processing, RTP, developed by Ensyn Technologies of Greely, Canada. The RTP process will convert waste wood to a liquid fuel. The fuel will be burned in a boiler to produce steam for power production in a steam turbine.

The feed to the plant will be approximately 330 t/d (wet, 50% moisture basis) waste pine and spruce from local sawmills in the Squamish region. The objective of this study was to determine the performance and economic feasibility of the proposed plant.

Mass and energy balances for the complete power plant were determined using a steady-state simulation model developed using AspenPlus simulation software. Plant capital costs were determined using data provided by Ensyn. Operating costs were based on local site specific conditions. Sensitivity analysis were studied for key process performance and cost parameters such as feedstock costs, plant capital costs, and cost of capital.

4.2.2 Plant overview

The plant will be located in Squamish, British Columbia, Canada. Squamish is located at the north end of Howe Sound on the Pacific coast, 80 km north of Vancouver. The proposal for the Squamish site is a new plant producing approximately 10 MW electricity from waste wood generated in the Squamish region. The plant will process approximately 330 dry t/d of waste wood. The plant will consist of waste wood handling and storage, wood drying and grinding, wood conversion to a liquid fuel (bio-oil) by fast pyrolysis. The fast pyrolysis technology to be used is Rapid Thermal Processing, RTP™, developed by Ensyn Technologies of Greely, Canada. Power will be generated by burning the bio-oil in a boiler to produce steam, which is fed to a steam turbine. Table 3 gives a summary of the bioenergy system proposed for the Squamish site. The schematic flowsheet of the fast pyrolysis plant is shown in Figure 8.

This plant provides a solution to wood waste disposal problems that exist in the Squamish region in addition to the production of electricity.

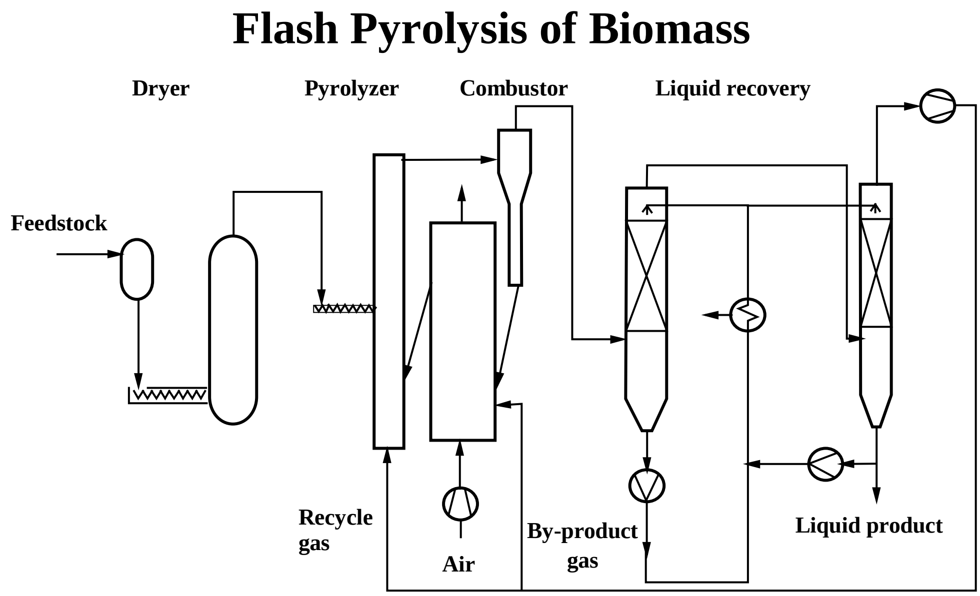

Figure 8. Fast pyrolysis of biomass, simplified flowsheet .

Table 3. Squamish site summary.

Operations	Units	
Conversion technology		Fast pyrolysis
Feedstock		Waste wood
Dryer		Rotary
Conversion reactor		Rapid thermal processing, RTP™
Fuel clean-up		None
Fuel application		Boiler fuel
Power cycle		Steam turbine
Output		Power
Capacities		
Wood feed, dry	t/d	330
Ave. moisture content to site	% daf	50
Ave. moisture content to RTP™	% daf	8
Nominal power	MW_e	11

In addition to the above power cycle a sensitivity case that consisted of substituting the boiler and steam turbine with a diesel engine was also analysed. A higher efficiency can be achieved by burning the bio-oil directly in a diesel engine to produce electricity compared to a boiler, steam turbine cycle. In the diesel engine case the plant nominal power production is 16 MW_e based on the same wood feed rate.

4.3 Finland

4.3.1 Introduction

The site-specific study describes the technical and economic feasibility of a biomass gasification combined cycle producing heat and power for a typical modern pulp and paper mill situated in the central Finland. The idea is to replace an old bark boiler by an IGCC enhancing the economy and environmental performance of the power plant. The IGCC feasibility study is conducted to an pulp and paper integrate also because of its suitable infrastructure for IGCC and large amount of wood waste available at the site.

The pulp and paper mill integrate produces SC (super calantered) paper mill 500 000 ADt/a (air dry tonne per year). The paper mill employs sulphate pulp and GW (ground wood) pulp. The capacity of the pulp mill is 400 000 ADt/a of which 120 000 ADt/a is used at the site. Block flow diagram of the integrate is shown in Figure 9.

At the moment, heat demand of the integrate is covered by a recovery boiler and a bark boiler. A condensing steam turbine with two extraction's generates electricity for the mill. By replacing the old bark boiler by an IGCC the overall process efficiency as well

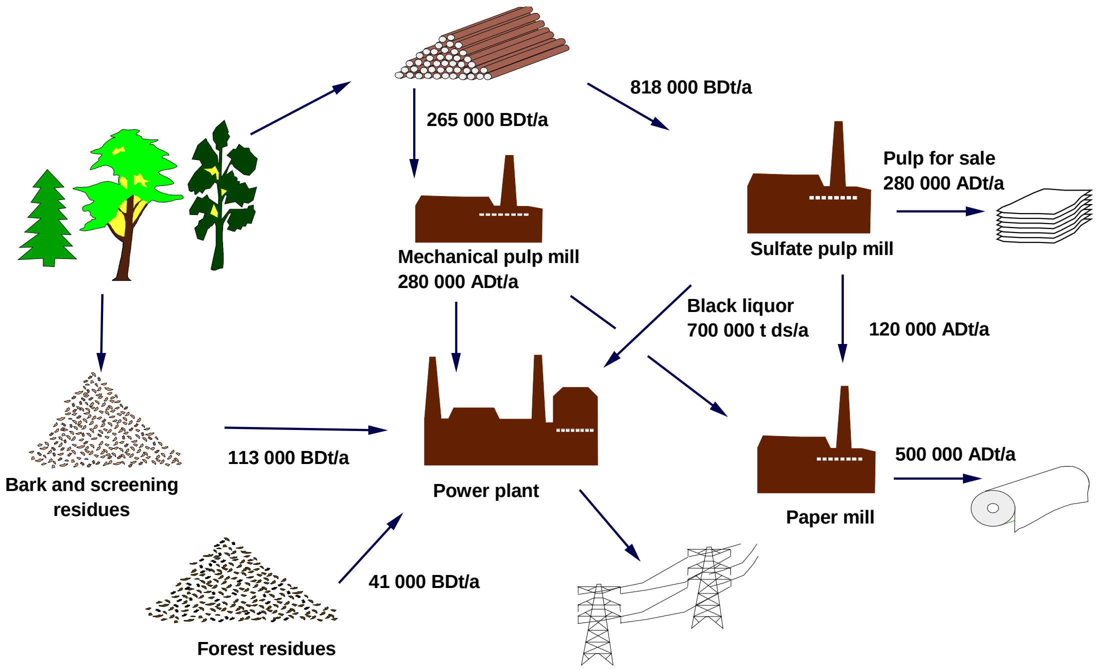

Figure 9. Block flow diagram of the pulp and paper integrate.

as power to heat ratio will improve leading to enhanced economy. Also, the environmental performance would be improved with IGCC concept.

The IGCC concept is based on the research and development work by Carbona inc. (former Enviropower Inc.). The operation and design of IGCC concept is based on Mitsubishi 20 MW_e gas turbine (MW151). The heat of gas turbine exhaust gas is utilised in a HRSG (Heat Recovery Steam Generator) of two pressure levels to generate steam for the pulp and paper mill and steam turbine.

In the Carbona's IGCC system, hot gas cleaning of gasification product gas is employed. Tar production is minimised and tar cracking maximised by keeping the temperature of the fluidized bed high enough with intense internal circulation, by adding secondary air from two or more ports, using calcined dolomite as bed material, and by long enough residence time of gases in the bed/freeboard (about 5/15 seconds). The filter unit selected for particulate removal is Dia-Schumalith type of developed by German filter manufacturer Schumacher. These filter elements are capable of achieving 2 - 3 mg/m^3 (0.00001 g/m^3n) solids in the filtered gas.

4.3.2 Process performance

The performance of the IGCC plant has been calculated with Aspen Plus™ simulation software. In Table 4 the main operating data of the biomass IGCC power plant and existing power plant with a bark fired boiler are given. The assumed ambient temperature for base case is +15 °C. Flowsheet for the power plant section of the IGCC plant is shown in Figure 10.

Table 4. The main process streams of the IGCC and existing power plant.

	IGCC	Existing plant
IN		
Biomass		
BDkg/s	5.1	3.7
MW	82.6	59.9
Black liquor		
t d.s./s	23.1	23.1
MW	280.9	280.9
Natural gas		
kg/s	0.1	
MW	3.8	
OUT		
12 bar steam		
kg/s	13.7	13.7
MW	39.0	390
4.5 bar steam		
kg/s	64.4	64.4
MW	178.6	178.6
Power		
steam turbine, MW_e	55.6	55.2
gas turbine, MW_e	23.9	
total, MW_e	79.5	55.2
PURCHASED POWER, MW_e	30.6	54.9

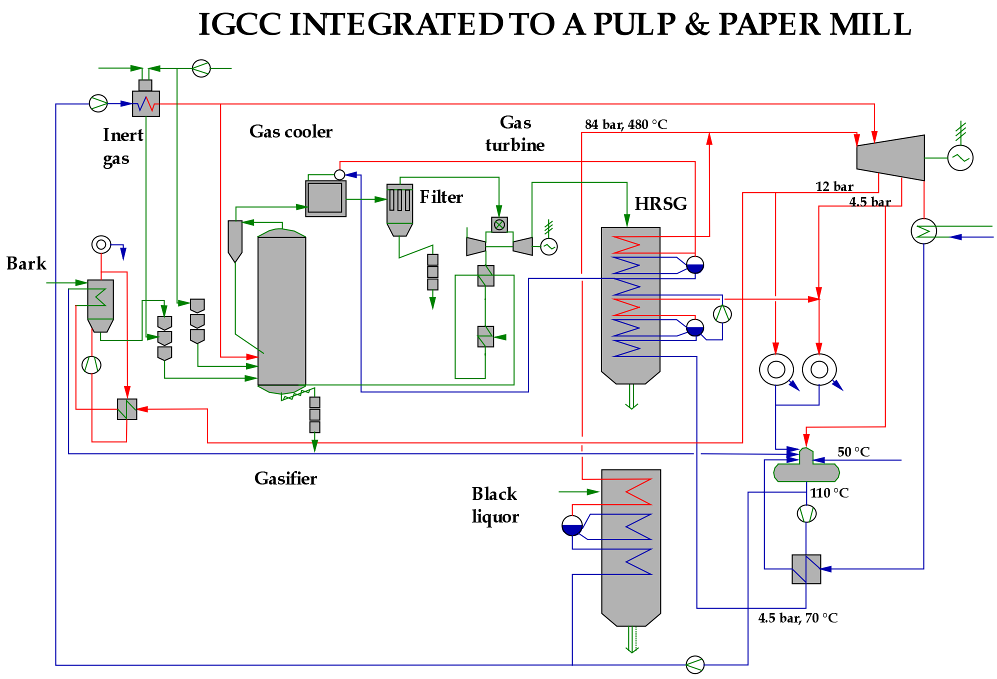

Figure 10. Flowsheet for the power plant section of the IGCC plant.

4.4 Sweden

4.4.1 Introduction

A techno-economic assessment has been completed for a bio-oil production plant located in Överkalix, Norrbotten in Northern Sweden. The plant will use fast pyrolysis technology, Rapid Thermal Processing, RTP, developed by Ensyn Technologies of Greely, Canada. The RTP process will convert waste wood to a liquid fuel, bio-oil. The bio-oil produced will be used as a petroleum heavy fuel oil substitute.

The feed to the plant will be approximately 200 t/d (wet, 50% moisture basis) waste birch chips from local region. The objective of this study was to determine the performance and economic feasibility of the proposed bio-oil production plant.

Mass and energy balances for the complete plant were determined using a steady-state simulation model developed using AspenPlus simulation software. Plant capital costs were determined using data provided by Ensyn. Operating costs were based on local site specific conditions. Sensitivity analysis were studied for key process performance and cost parameters such as feedstock costs, plant operating hours, and cost of capital.

4.4.2 Plant overview

The proposed site location is Överkalix, Norrbotten in Northern Sweden, 50 km south of Arctic circle. The proposal for the Överkalix site is a new grass roots plant producing approximately 23,000 t/y of bio-oil from waste wood generated in the Överkalix region. The plant will process approximately 100 dry t/d of waste wood.

The bio-oil production plant will consist of waste wood handling and storage, wood drying and grinding, and a fast pyrolysis process plant to convert the wood to a liquid fuel (bio-oil). The fast pyrolysis technology to be used is Rapid Thermal Processing, RTP^{TM}, developed by Ensyn Technologies of Greely, Canada. Approximately half of the bio-oil produced will be used as a boiler fuel substitute in the local Överkalix area, within 100 km of the plant. The remaining bio-oil will shipped to central Sweden for use as a petroleum fuel oil substitute in district heating plants. Table 5 gives a summary of the bioenergy system proposed for the Överkalix site. The flowsheet of the pyrolyser is essentially similar to that of the Squamish site (Figure 8).

In addition to producing the bio-oil the plant represents a means of disposal of the wood waste produced in the Överkalix region.

Table 5. Överkalix site summary.

Operations	Units	
Conversion technology		Fast pyrolysis
Feedstock		Waste wood
Dryer		Rotary
Conversion reactor		Rapid thermal processing, RTP^{TM}
Fuel clean-up		None
Fuel application		Boiler fuel
Output		Bio - oil
Capacities		
Wood feed, dry	t/d	100
Ave. moisture content to site	% daf	50
Ave. moisture content to RTP^{TM}	% daf	8
Bio-oil production	t/yr	23 840

4.5 USA case 1

4.5.1 Project overview

The Institute of Gas Technology, Carbona, Kvaerner and Westinghouse Electric Corp. have performed a feasibility study of alfalfa crop production coupled to a gasifier/gas cleanup/gas turbine/steam turbine power generation system (Figure 11). The study investigated economic development through biomass systems integration, emphasising: 1) sustainable biomass energy crop production, 2) efficient feedstock use with gasifier/gas-turbine power generation, and 3) farmer owned value adding co-product production of Minnesota, was chosen for the feasibility study. The area within a 50 mile radius of this

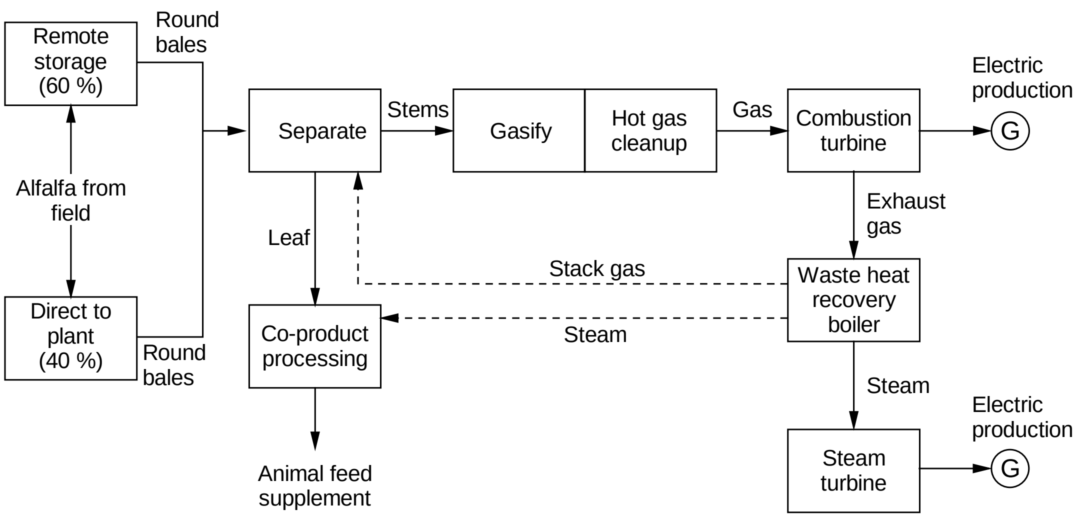

Figure 11. Alfalfa crop production and an IGCC power generation system.

alfalfa-leaf meal. The feasibility study concerned for an integrated biomass power system, where an energy crop (alfalfa) is the feedstock for a processing plant and a power plant (integrated gasification combined cycle) in a way that benefits the facility owners. The sale of an animal feed co-product and electricity both help cover the production cost of alfalfa and the feedstock processing cost, thereby requiring neither the electricity or leaf meal to carry the total cost. The power plant provides an important continuous demand for the feedstock and results in continuous supply of leaf product to provide a reliable supply needed for the leaf meal product.

The study analyses the technical and economic feasibility of producing 75 MW of baseload electricity from a dedicated biomass energy crop (alfalfa) by an integrated gasification combined cycle (IGCC) electric power generation conversion process. A site in south-western Minnesota at an existing NSP power plant, near Granite Falls, site has been defined as the dedicated feedstock production region or biomass shed. Dedicated biomass crops, namely those planted specifically for energy production, are needed to assure long-term reliable feedstock supplies for baseload power generation.

The study team analysed alfalfa production and marketing, including higher-value market obtainable from an upgraded product. Integrated processing included separation of the high-nitrogen bearing leaves from the low-nitrogen bearing, stems, use of the stems as power plant fuel, upgrading the leaves to an even higher-value feed using waste heat from the power plant and a joint venture business arrangement between a farmers' co-operative and the power plant owner/operator. The study team analysed design options, performance and economics of mechanical and power systems for feedstock handling, gasification, gas cleanup, and combined cycle power generation. The team prepared a report covering all aspects of the integrate agricultural and power generation systems, including an assessment of the resource base in counties surrounding the power plant site near the City of Granite Falls.

4.5.2 The process performance

The gasifier is sized to process 1 096 tons per day of alfalfa stems meet the design load requirements of the combustion turbine. In the gasifier, the alfalfa stems are rapidly heated to gasification temperatures approaching 1 650 °F while in contact with air, bed material and steam at a pressure of 300 psig. Leaving gasifier the gases are cooled to 1 020 °F and cleaned so that the fuel gas entering the gas meets the manufacturer's requirements The combustion turbine is one of Westinghouse's standard industrial designs, which has been modified to accommodate low-Btu biogas fuel. The turbine is equipped with Westinghouse's state-of-the-art gas combustion system, which represents the Best Achievable Control Technology (BACT) for the mitigation of NO_x, in combustion turbines. An output of 50.1 MW of electrical power is produced in the turbine generator. The overall performance for the ALFAGAS IGCC plant is summarised in Table 6.

Table 6. Overall plant performance.

Parameter	Biomass gas	Natural gas
Dried biomass feed rate, lb/h (9.4 % moisture)	91 300	0
Gasifier heat input (HHV), MMBtu/h	669	0
Comb. turbine firing rate (HHV), MMBtu/h (note a)	614	574
Heat export to leaf processing plant		
- Steam @ 4,100 lb/h, MMBtu/h	5	5
- Flue gas @ 310,000 lb/h, MMBtu/h	20	20
Combustion turbine gross power, kW	50 100	53 500
Steam turbine gross power, kW	29 300	19 800
Gross plant output, kW	79 400	73 100
Auxiliary power, kW	4 310	2 710
Net plant output, kW	75 090	70 390
Net plant heat rate (HHV), Btu/kWh	8 910	8 155
Net plant efficiency (HHV), %	38.3	41.9

[a] Biomass gas inlet temperature 1 ,020 ^{o}F, HHV = 155 Btu/SCF, LHV = 143 Btu/SCF

4.6 USA case 2

4.6.1 Project overview

Willow hybrids grown as a Dedicated Feedstock Supply System (DFSS) have been analysed and found to be a feasible means of augmenting current coal and natural gas resources for power generation. This study focused on the technology and infrastructure required to grow willow DFSS and integrate it with four existing pulverised coal electric generation facilities in central and western New York.

In the feasibility study, Willow DFSS planted at 7 200 trees per acre on a 3-year coppice harvest cycle is expected to yield 7.5 dry tons per acre per year. Yield improvement to 9 dry tons per acre per year is projected for the post-2005 period. Adapting established European technology will permit agriculturally-based mechanical planting and harvesting. Open land with soils suitable for willow DFSS is available surrounding the four study sites to provide near-term co-firing capability of up to 400 MW. The first co-firing project to be developed, Greenidge Station, will generate 5 to 15 MW from biomass fuels.

The most promising near-term biopower business scenario involves independent growers, a DFSS planting/harvesting/processing co-operative, and a co-firing utility market. Post 2005 business expansion includes markets for new generation capacity based on biomass fired integrated gasification power systems as well as production of liquid and gaseous fuels. Grower revenues for the second generation enterprise include land rents and a 6 % internal rate of return. After a five-year demonstration phase is completed and operations are scaled up to the 3 000-acre level of production, the co-operative is projected to earn a 10 % internal rate of return on investments in farm and processing machinery. Purchasing power producers are expected to be able to buy blended biomass fuels at prices competitive with coal while earning pollution abatement credits (SO_x, NO_x, and CO_2 reductions). It is believed that willow DFSS crop establishment and scale-up could reach 40 000 to 60 000 acres in central and western New York by 2010. Also, natural forest harvests and wood processing industry residues in the study areas could provide large quantities of wood for an integrated biomass resource.

Predicted emissions for a co-fired PC unit show a reduction of SO_x, by 9% at 10% co-firing. Displacement of coal with biomass, a CO_2 neutral fuel, equates to a 9.8% reduction in greenhouse gas emissions. Depending on firing conditions, a reduction in NO_x, is also predicted. At Greenidge Station, 10% co-firing equates to emission reductions of 1 059 tons per year for SO_x, and 70,704 tons per year for CO_2. Because of its higher potential compliance and market value, the NO_x, savings may be the most important to the project. In tests at Greenidge at 5% co-firing measured, NO_x, reductions were equivalent to 146 tons per year. These results are preliminary and will be validated in the next phases of the project.

Environmental issues of biomass energy crops are similar but of lesser magnitude than traditional agriculture. DFSS crops are expected to diversify farm landscapes and reduce fertilizer and other chemical inputs in farm production. Also, NYSEG and NMPC serve the rural areas of New York. Rural economic development benefits include the creation of 287 jobs and over USD 9.1 million annually in income by 2006.

5. Discussion of case results and technologies employed

5.1 Stirling engine

Several calculations of the investment costs, the annual operation costs and the optimal size of the Stirling engine in relationship to the plant size were made. It was found that the investment costs should be between 22 000 and 28 000 ATS/kW$_e$. With the aid of measured plant performance data (6-minute data collection interval during heating period 1995/96) of the Pfarrwerfen plant a simulation model was worked out. Figure 12 shows the amortisation of a biomass-Stirling engine/generator unit as a function of the engine size (20 to 120 kW$_e$), the investment costs, and the cost of electric energy. It was assumed that for Biomass-Stirling engine the same subsidies are available as for the district heat plant. The amortisation of the investment of a Stirling engine plant in 30 to 50% of the engine´s life time can be expected. This optimum power level is in the range of 30 to 60 kW$_e$.

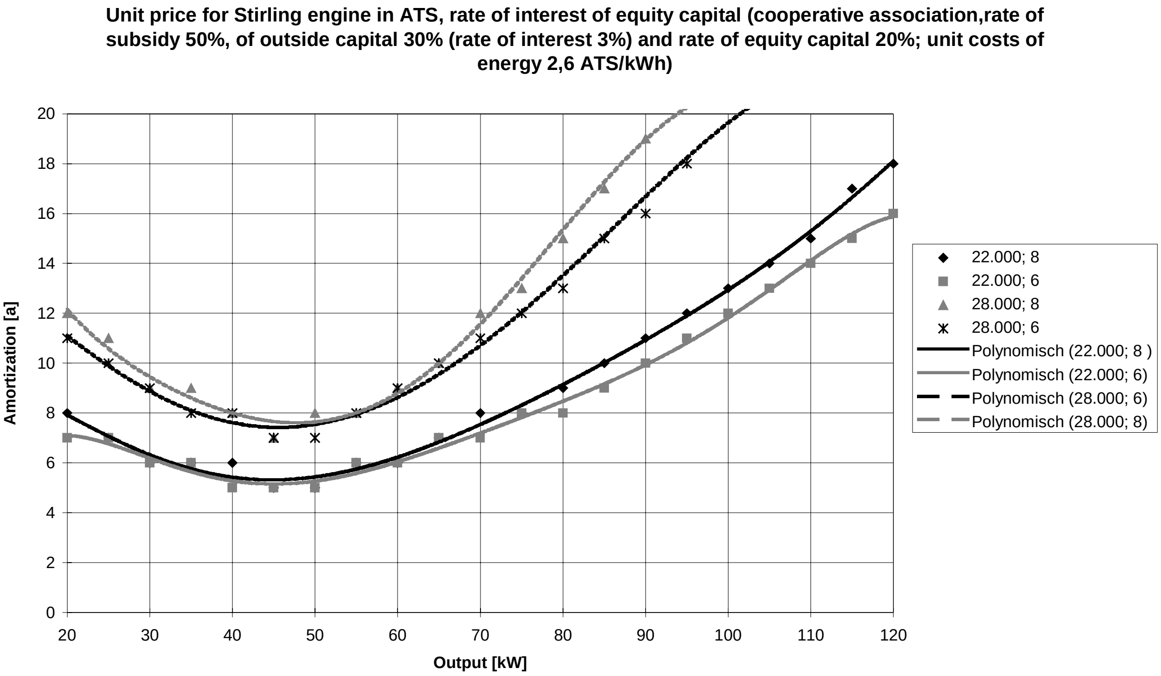

Figure 12. Amortisation of a Stirling engine plant as a function of engine size, investment cost, subsidy and energy price.

Technical and economic results may be summarised as follows:

Technical aspects:

A special Stirling engine designed for the use of the uncleaned hot flue gas of the biomass combuster should be implemented. For that purpose a suitable Stirling engine was developed.

Economic aspects:

Electric energy costs of less than 1 ATS/kWh_e can be expected in the district heat operation mode, if the engine's capacity is between 5 to 7 percent of the thermal capacity of the combustor and the electric energy produced is used to drive the electric equipment of the plant. The investment subsidies provided by government are very important for amortisation time less than the half of the life time of the Stirling engine/generator unit.

5.2 Fast pyrolysis

Two issues should be emphasised when fast pyrolysis of biomass is considered. The first is the possibility to de-couple fuel production and utilisation, as it is possible to store a liquid fuel. Bio fuel oil (BFO) may be produced in a larger facility, and the oil may be distributed to users (boilers, engines) much like fuel oils today. Oil utilisation is thus independent of the schedule and operation of oil production.

The second advantage with pyrolysis is related to handling of solids. It is generally accepted that use of solids in small scale is capital intensive and prone to malfunction. Both of these aspects increase cost of using solid fuels. The advantage in pyrolysis is the possibility to operate the primary conversion plant in a large scale, and thus reduce high cost related to solids handling.

Two pyrolysis cases were assessed. The Canadian case proved uneconomical in comparison to the current electricity prices in British Columbia in spite of the availability of low cost wood residue.

Prices for light heating oil are shown in Figure 13 for some European countries. The Swedish case (bio fuel oil replacing heating oil) is special due to the high taxation of fossil heating fuels in Sweden. Sulphur, CO_2, and fuel taxes are not applied to biofuels, and thus bio fuel oil has a considerable advantage compared to heating oils.

The internal rate of return (IRR) for the Swedish case is shown in Figure 14. IRR is shown on y-axis, wood cost on x-axis, and the selling price of bio fuel oil is shown as

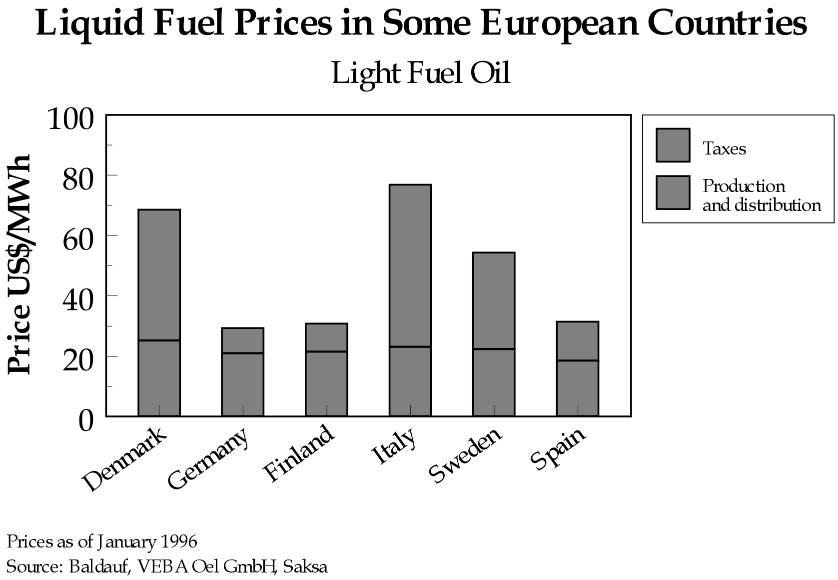

Figure 13. Fuel oil prices in Europe.

parameter. It can be seen that with a high oil value (400 SEK/MWh) a good IRR is reached. As there are technical uncertainties related to the fuel quality of the oil, an accurate estimate of the real value of the oil cannot be determined based on the data available. However, it appears that Sweden is the country where BFO has the potential to be competitive.

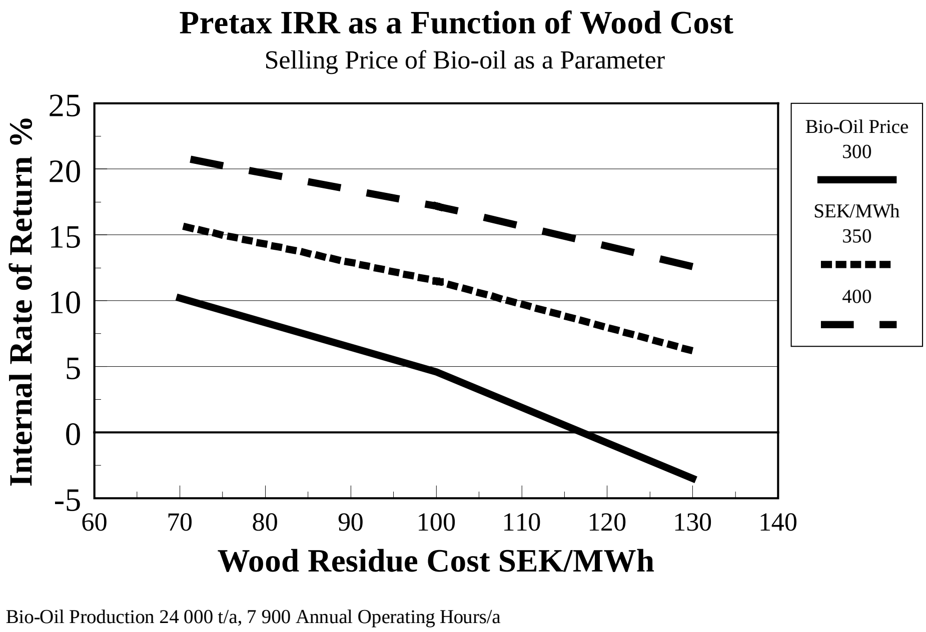

Figure 14. Internal rate of return of bio fuel oil production in Sweden, selling price of oil as a parameter (80 SEK/MWh = 10 USD/MWh).

5.3 The biomass IGCC

The biomass IGCC has two major advantages compared to the conventional steam cycle boiler plant. It has clearly a higher efficiency than conventional technology (Figure 15). This is especially valid in condensing power production. However, initially there is probably only few sites, where enough biomass is available to make operation economic.

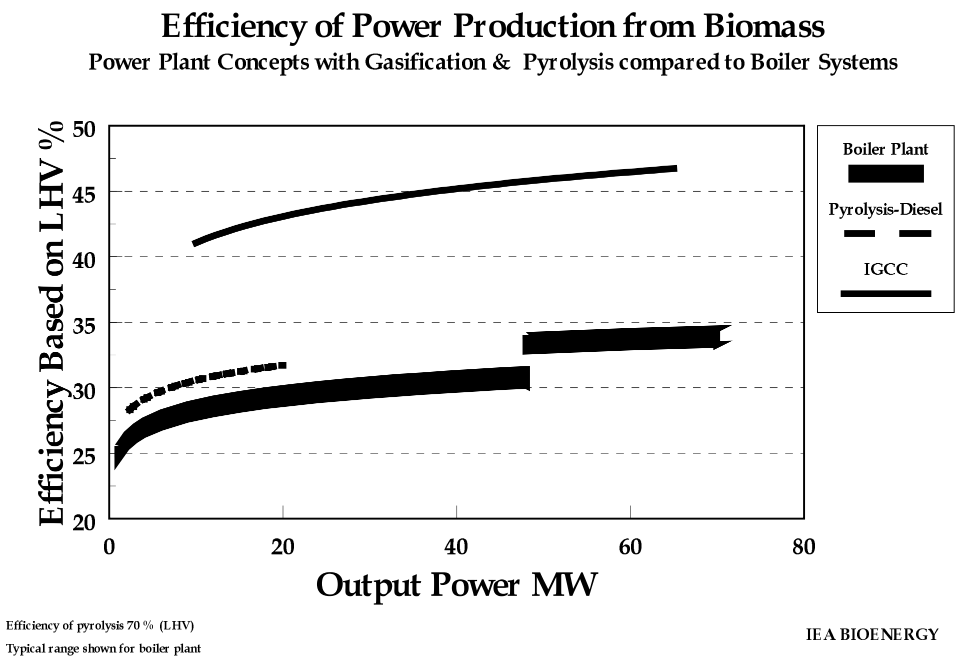

Figure 15. Efficiencies for biomass power process concepts

The other major advantage for IGCC technology is high power-to-heat ratio (α value). This ratio is important in co-generation of heat (process or district heat) and power. A co-generation facility is sized based on the heat load. Because the α value of the IGCC is about twice that of conventional technology (1 versus 0.5), about twice the amount electricity may be produced in co-generation with advanced concepts.

IGCC is estimated competitive especially in large scale. Based on the considerations of developers and also this study, the biomass IGCC may be competitive above 20 to 40 MW_e. The Finnish concept assessed in this study was based on a 24 MW gas turbine.

A result from the pulp and paper integrate assessment carried out in Finland showed that the IGCC is more economic than the conventional bark boiler steam cycle (Figure 16). The internal rate of return (IRR) may appear relatively low even for the IGCC case. However, it should be noted that for the type of investment considered in the study (to replace an existing boiler system), the difference between alternatives in striking.

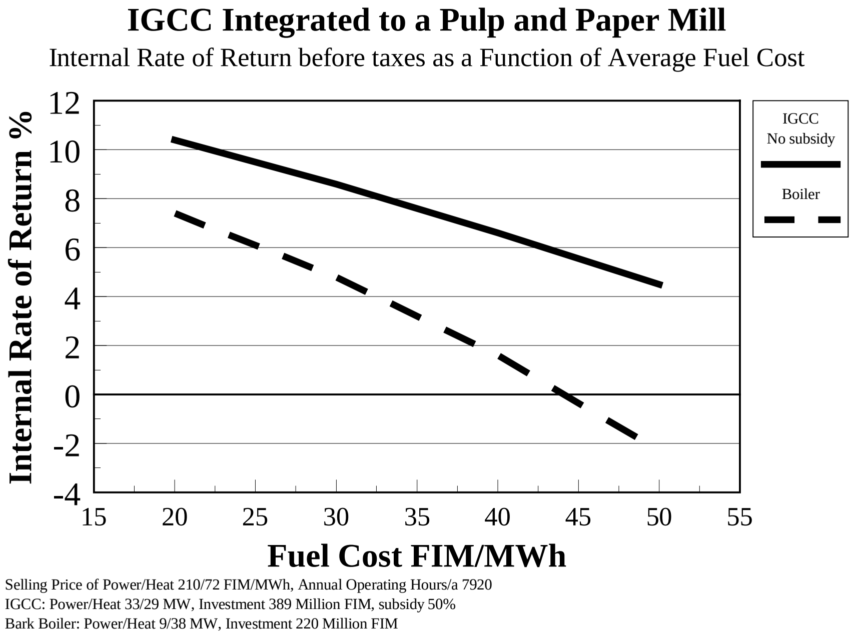

Figure 16. Internal rate of return of IGCC and bark boiler steam cycle at a pulp and paper mil (45 FIM/MWh = 10 USD/MWh).

The other US study dealt with using alfalfa stems as a fuel for electricity production at an IGCC plant. The study included analysis of a co-production scheme, where alfalfa leaves are used a s high-protein animal feed. Minnesota Valley Alfalfa Producers is a farmer-owned co-operative, who has assessed building several alfalfa processing facilities in Minnesota. Highlights of the project include:

- 75 MW of baseload electric power from a new IGCC
- 700 000 tons per year of alfalfa will be produced as feedstock on 180 000 acres (about 72 000 ha)
- potential co-products include livestock feed pellets, liquefied protein supplements, pharmaceuticals, and natural fragrances and dyes.

5.4 Co-firing short rotation forestry (willow) in coal power plants

The Salix Consortium, led by Niagara Mohawk Power Corporation (USA), will grow willow trees as a fuel for co-firing in existing coal power plants. The project has progressed from the feasibility study, which is reported as part of this IEA work, to an execution stage.

The purpose of the project is to successfully demonstrate the use of willow trees as energy crops for power generation. The partners in the project are aiming at scaling-up energy crop site trials and co-firing experiments to a commercial business enterprise. The project is a multiphased, multipartner endeavour to establish one of the first commercial energy crops for power production in the United States by the year 2000. Highlights of the project include:

- 30 - 40 MW of capacity through co-fired applications
- 1 000 acres (about 400 hectares) of willow trees on land in various locations.

6. Future developments

6.1 Small scale CHP production

The proposed application of a **Stirling engine/generator** unit at the district heat site is not yet industrially proven. Only limited amount of reliable data is available about the behaviour of an Stirling engine directly powered by a dirty flue gas of a wood chip boiler. The proposed concept is suggested also for existing heat boilers. The system should be able to work with several types of wood chip boilers, which operate in a wide range of flue gas rates and different flue gas pressure profiles. Further work have to be focused on the main control system of the process, in which the control of the Stirling engine CHP unit have to be embedded.

Common wood chip furnaces are equipped with cyclones to reduce the dust content in the flue gas to the range of 50 - 70 mg/Nm^3. When changing thermal load, or when starting operation, flue gas dust content is much higher, around 300 - 700 mg/ Nm^3. Using a dirty flue gas from the boiler is one of the most important aspects of the engine development for the CHP production. Smooth tubes for heat transfer were used. This aspect had an important influence on the Stirling engine design. Tests with a 3 kW_e test engine showed that a self cleaning effect caused by the temperature variations on the outside of the Stirling engine heater surface may also be employed for large engines.

An important presupposition for a combustion of biomass with low emissions is a certain pressure profile of the flue gas. Using a Stirling engine at a biomass boiler needs integration of the engine heater into the flue gas channel. This heat exchanger - the heater of the Stirling engine - will affect the boiler primary and the secondary combustion air flows, which have to be adjusted to assure low emissions.

The Stirling engine is controlled by a sub-control unit, which is embedded in the main control of the plant. The main goal in combusting biomass is production of district heat. Electricity is produced only for internal consumption. Sub-control has to be able to determine duration of operation as a function of boiler part load capacity. Furthermore the sub-control is responsible for the whole engine management, i.e. working gas pressure variations in dependence of the heat transferred to the engine.

6.2 Electricity and CHP production in large scale

Both of the US cases produced a potentially feasible scheme, and projects are underway to study and plan further work. Gasification tests have been carried out at a pilot plant scale using alfalfa stems. The data will be employed in designing the full scale plant.

There are nevertheless some technical uncertainties in the **IGCC** concepts proposed. Gas cleaning is continuously the biggest technical uncertainty. Continuous operation of the hot gas cleaning unit is critical for gas turbine operation. Only one industrial scale gas turbine (EGT 5 MW engine at Värnamo) has been operated extended hours with biomass fuel gas, and no data is available in public domain about the experiences.

Very little data is available concerning the operation of the complete integrated IGCC for the above reasons. More experiences of the continuous operation of the integrated IGCC is needed.

Although a number of biomasses have been successfully gasified in laboratory scale facilities, only relatively few have been converted in pilot or larger scale units. It will be necessary to test more bio-fuels to pursue the large potential for bio-electricity, which has been proposed. The tests are needed both to verify the operation of the gasifier with fuels of different fluidisation and ash melting properties, and also to study removal of harmful compounds from the fuel gas.

There are also emissions from the renewable energy systems, and an environmental assessment of the whole utilisation chain should be carried out.

6.3 Renewable heating oil

Fast pyrolysis is less developed than the IGCC technology, and there are more technical uncertainties to be solved before industrial applications. An exception may be the use of bio fuel oil (fast pyrolysis oil) to replace heavy fuel oil, which has been carried out in industrial scale tests without major difficulties. However, even with this application, the complete utilisation chain has not been proven.

The biggest problem a user faces with bio fuel oil is that the product is not yet well defined. Different biomasses yield oils with different characteristics. To be able to compete in an open market, a fixed quality for the fuel product has to be specified, and it must be produced continuously.

However, improvements in product quality are also needed. Viscosity, stability, and solids content are properties, which need modifications before a successful introduction of bio fuel oil into the markets may take place.

Quite little is known about fast pyrolysis of different biomasses. The effects of feedstock on conversion performance and product quality are known only for a few biomasses. Most biomasses pyrolysed have only been converted in laboratory scale equipment. Usually no utilisation tests have been carried out for these. More tests are needed to study the applicability of biomasses proposed for pyrolysis.

As only few biomass pyrolysers have been operated in pilot scale or larger, there are not much experiences of continuous operation of a fully integrated plant. The same is true for bio fuel oil utilisation: only limited tests have been carried out with all applications proposed.

As there are also emissions from the system, and an environmental assessment of the whole utilisation chain should be carried out.

7. Updated information of applications

7.1 Joanneum Research demonstrates a micro power plant

Graz, Austria, 28 May 1998

Joanneum Research announces the start of a development project, where together with Styrian electric utility "STEWEAG" (Steirische Wasserkraft und Elektrizitäts-Aktiengesellschaft), and LMF (Leobersdorfer Maschinenfabrik), a small scale combined heat and power plant concept will be demonstrated. Location for demonstration is the city of Deutschlandsberg in the state Styria, Austria, where an existing biomass fired district heat plant with a capacity of 3 MWth will be equipped with a 30 kWe Stirling engine supplying electric power for the demand of the district heat plant. The biomass-Stirling engine will be designed and constructed at JOANNEUM RESEARCH.

The current step in development work of the biomass Stirling engine was made possible after the Styrian Government together with EU Regional Support decided to finance 50% of the 12 Mio ATS (1 Mio US$) demonstration project.

More information about the development project is available from Dr. Erich Podesser at Joanneum Research:

Joanneum Research, Institute of Energy Research, Elisabethstrasse 5, A-8010 Graz, Austria
Tel. +43 316 876 1327, fax +43 316 876 1320, e-mail: erich.podesser@joanneum.ac.at

7.2 Ensyn Inc.

7.2.1 RTP to replace beehive burner

Prince George, B.C., Canada, 5 May 1998

The search for solutions to replace the Rustad beehive burner got a boast today with Northwood Inc's announcement of intent to proceed with a plant which will utilise leading edge technology to dramatically reduce wood waste by adding value to it.

"It's remarkable technology." Said Des Gelz, Northwood's Vice President, Wood Products. "We've spent the last three years trying to find ways of eliminating our Rustad sawmill beehive burner by finding other ways of handling the waste. Now we think we have the solution."

The new technology - Rapid Thermal Processing - was developed, and is owned by Ensyn Technologies Inc. of Ottawa, Ontario. The plant in prince George, which will utilise the technology, will be built and operated by Ensyn Technologies, B. C. Inc. Mr Frank Oberle is president of this B. C. company. The proposed process could convert nearly 100 per cent of the current wood waste into commercially viable products. It uses broken chips, sawdust and bark created in the manufacturing of lumber.

It's the ultimate in added value - in waste reduction - and in maximum limber utilisation." Said Gelz. "We'll be replacing our burner with an enclosed process. Basically, we'll be taking that is now considered waste fibre and turning it into three products - a fuel oil, pure carbon and a natural resin product that could be used as a bonding agent in plywood manufacturing."

Current engineering timelines estimate that the first phase of the Rapid Thermal processing Plant could be on stream as early as June 30, 1999. "Our current burner permit runs out December of this year, so we'll be asking the government and the public to allow us to extend our burner permit for six months to June 30. 1999," said Getz. "While our burner has been operating within compliance for many years, the government has an initiative to close down the burners."

Ensyn Technologies spokesman, Frank Oberle, that this plant will be the first of kind in Canada, and one of the first in the world utilising sawmill wood waste. There are three RTP plant in Wisconsin and three other under construction in Europe.

7.2.2 Ensyn invests 200 million SEK i Söderhamn

Gothenburg, Sweden, 18 May 1998

The Canadian Ensyn will invest about SEK 200 million (about USD 25 million) to a plant at Långrör, which is the port of Söderhamn. Bio-oil will be produced at the plant from wood. A sawmill is negotiating with Ensyn of the delivery of 200 000 m^3 of sawdust and wood chips. Ensyn has today two plants in operation, which are similar to the one planned in Söderhamn. The plants are in North-America and Europe.

More information on these projects are available from Ensyn:

Ensyn International Inc., Robert Graham, President, 6847 Hiram Drive, Greely, Ontario K4P 1A2 Canada
Tel. +1-613-821 2148, fax +1-613-821 2754, e-mail: ensyn@fox.nstn.ca

7.3 Carbona Inc.

7.3.1 Gasification technology of Carbona Inc.

Helsinki, Finland, April 1998

Carbona Inc. was founded in beginning of 1996 to continue Enviropower Inc.'s activities. Enviropower, a subsidiary of former Tampella Power Inc. - now Kvaerner Pulping Inc. - and Swedish Vattenfall AB, was established to develop gasification technology. Enviropower's operations were ceased due to ownership changes in Tampella Power. The rights for Enviropower's know-how and on-going projects were acquired by some of its management, who formed Carbona Inc. Carbona, with offices in Helsinki, and Tampere, has the key Enviropower employees on its payroll. The company also has a subsidiary in Atlanta, Georgia, USA.

Tampella Power/Enviropower was developing new power plant technology licensed in 1989 from the Institute of Gas Technology of USA. Based on this license, a pilot plant was built in Tampere, Finland, where it is still operational.

The new power plant technology (IGCC - Integrated Gasification Combined Cycle) is based on solid fuels - coal, wood, peat and various kinds of biomass to be used in a gas turbine process. With Carbona's technology the solid fuel is changed into gas, purified and fed to gas turbine. The heat in the exhaust gas from the gas turbine is used to make steam for a steam turbine. This method produces about double the amount of electricity from the same fuel amount than in a regular power plant. It also significantly reduces carbon dioxide and other emission and lowers production cost of the electricity.

7.3.2 Major projects of Carbona

The power plant project in Minnesota, USA is based on Carbona's IGCC technology. The 75 MW IGCC power plant will use biomass fuel produced from alfalfa farms. The plant will be largest of its kind in the world, with project costs of around USD 200 million. Carbona will deliver design and engineering for the gasification island for the project and during the second phase deliver equipment together with Kvaerner Pulping Oy. Westinghouse will deliver gas and steam turbine plant. This project is partially financed by united States Government's Department of Energy.

Alfalfa gasification tests were successfully conducted in the spring of 1997 at the Tampere 15 MW_{th} pilot plant.

The project in India is based on co-operation with Madras based boiler manufacturer, IBIL Tech Ltd. The power plant for Sanghi Industries Ltd. is based on IGCC technology using local brown coal (lignite) as fuel. The plant, which will supply power to India's largest cement plant, is located in Western Indian state of Gujarat. The power plant will produce 55 MW electricity and its investment costs are around USD 70 million. Carbona Inc. will supply know-how, design, project management, plant commissioning and some critical equipment for the Sanghi project. Equipment for the gasification island is being manufactured by IBIL Tech. General Electric will provide gas and steam turbine equipment.

Plant realisation has already started and first phase should provide electricity in the spring of 1999. Gas turbine island is being installed first and will be followed by the gasification island. Initially the fuel for the plant will be naphtha. After the gasification island is completed the fuel source will be switched to lignite, which is significantly cheaper than naphtha.

7.3.3 Example of co-operation between countries

The big investment of industry and public funds in development of gasification technology has started to reap results. The determined development work in USA and the Nordic countries has continued for over fifteen years. In Finland, Ministry of Trade and Industry / Tekes have systematically supported development work in industry, graduate school and Technical Research Centre of Finland (VTT), which has become world known pioneer in development of biomass gasification technology.

Carbona offers an example, how a small company from a small country can be part of big projects world wide. Alone this of course is not possible, but by connecting with the right partners, this type of new technology based commercial breakthrough has been possible.

More information on these projects are available from Carbona:

Carbona Inc., Kari Salo, President, Kaupintie 11, FIN-00440 Helsinki, Finland
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7.4 NREL

7.4.1 Recent accomplishments, MnVAP project

Granite Falls, MN, USA, 1997

MnVAP was selected to negotiate a 75 MW power purchase agreement by Northern States power Company for long term, guaranteed energy sales. The city of Granite Falls donated 100 acres of land for the power project and provided a loan guarantee. The state of Minnesota appropriated USD 200 000 to support development of the alfalfa production and processing capabilities, and personal property and sales tax exemptions (worth more than USD 3 million per year) to support the MnVAP project. In 1996, MnVAP purchased an existing alfalfa processing plant and designed, installed and successfully operated the fractionation system to separate the stems from leaf material.

7.4.2 Recent accomplishments, co-firing of biomass

New York, USA,1997

Retrofit of pulverized coal boilers for co-firing with wood biomass can be readily accomplished with modest capital investments. NYSEG recently completed the design optimization and the fuel supply plant for the Greenidge Power Station. Initial modifications of the plant have already been made for test firing and test firing results have supported the study's findings. The South Central New York Resource Conservation and Development Project, Inc., is working worth growers to develop trial contracts for willow crop production. In combination with land dedicated by consortium power partners, 1000 acres are targeted for willow production. Burlington Electric Department has planted willow at a field pilot in Vermont to evaluate productivity and pest resistance.

The Salix Consortium's Phase II application was due in July 1997. Of the estimated USD 13 million total project cost for Phases I and II, DOE plans to contribute nearly USD 5 million.

More information on these projects are available from NREL.

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8. List of all volumes of the final report

The final report consists of the following volumes:

Volume I Solantausta, Y., Koljonen, T., Podesser, E., Beckman, D. & Overend, R. Feasibility studies on selected bioenergy concepts producing electricity, heat, and liquid fuel. IEA Bioenergy, techno-economic analysis activity. (This report). Espoo: VTT, 1999.

Volume II Podesser, E., Beyer, H. & Fankhauser, G. Small scale combined heat and power production with Stirling engines in biomass furnaces. Graz: Joanneum Research, 1998.

Volume III Beckman, D. Squamish, Canada site study. Pyrolysis power plant using Rapid Thermal Processing and a steam cycle. Burlington: Zeton Inc., 1998.

Beckman, D. Överkalix, Norbotten, Sweden site study. Bio-oil production plant using Rapid Thermal Processing. Burlington: Zeton Inc., 1998.

Volume IV Koljonen, T., Solantausta, Y., Salo, K. & Horvath, A. IGCC power plant integrated to a Finnish pulp and paper mill. IEA Bioenergy, techno-economic analysis activity. Espoo: VTT, 1999. 77 p. + app. 44 p. (VTT Research Notes 1954).

Volume V Generation of electricity and co-product processing from alfalfa produced in South-West Minnesota. Northern States Power Company, 1995.

Co-firing of willow with pulverized coal in existing coal power plants in New York. New York: Empire State Biopower Consortium, 1995.

Volume VI Ong'iro, A., Ugursal, V. & Taweel, A. Development of a gas turbine subroutine for the International Energy Agency Bioenergy Techno-Economic Analysis Activity. Halifax: Thermal Engineering, 1997.

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