THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
345 E. 47th St., New York, N.Y. 10017

98-GT-349

PRESSURIZED GASIFICATION OF BIOMASS

K. Salo, A. Horvath

Carbona Inc.

Kaupintie 11, FIN 00440 Helsinki, Finland

J. Patel

Carbona Corporation

4015 Circle 75 Parkway, Atlanta GA 30339, USA

ABSTRACT

Biomass is a fuel of increasing interest in power generation since it is clean and renewable. Besides conventional power generating systems biomass fuel will be utilized in Integrated Gasification Combined Cycle (IGCC) power plants in the near future.

Carbona Inc. (the successor to Enviropower Inc.) is commercializing a biomass fueled 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) and further developed by Enviropower before licensing the technology to Carbona and an advanced hot gas clean-up system.

An extensive pilot test program has been carried out by Enviropower/Carbona covering all aspects of a biomass based gasification process. More than 5000 tons of different biomass feedstocks have been gasified at the pilot plant in Tampere, Finland. The pilot plant converts 15 MW (51 MMBtu/h) thermal input of fuel to product gas. Several biomass qualities/mixtures have been used during the test runs including hard wood, soft wood with and without branches, needles and bark. Short rotation biomass like willow and alfalfa have also been tested.

This paper concentrates on the results and differences in gasification of different biomass materials with special emphasis on the suitability of product gas for gas turbines, the fate of ammonia, vapor phase alkali metals and air toxics. The development of demonstration projects is also discussed in this paper.

Presented at the International Gas Turbine & Aeroengine Congress & Exhibition
Stockholm, Sweden — June 2–June 5, 1998

INTRODUCTION

The Integrated Gasification Combined Cycle technology is potentially the most significant novel solid fuel utilizing power generating technology of high efficiency and environmentally acceptable performance. It benefits from the high efficiency of the combined cycle technology combining it with a solid fuel to combustible gas converting process. The IGCC-technology was originally developed for coal utilization but the increasing interest in the renewable biomass fuels promoted the development of its biomass application.

Carbona Inc. (the successor to Enviropower Inc.) is commercializing a biomass fueled IGCC system. This system applies the gasification technology originally developed by the Institute of Gas Technology (IGT) and further developed by Enviropower before licensing the technology to Carbona and an advanced hot gas clean-up system.

The biomass IGCC concept considered by Carbona will be demonstrated as complete full-scale power plant as a next step. Besides the discussion of the biomass test results, demonstration project development will also be described in this paper.

BIOMASS BASED IGCC PROCESS

Process Description

The biomass based IGCC concept considered by Carbona is shown in Figure 1.

Gasification Plant includes fuel handling, drying, feeding, gasification and gas clean-up. The fuel handling process is a conventional process including storage, conveying, chipping and sieving equipment specifically designed for the different biomass fuel types.

The dryer system applied in the IGCC concept is commercial technology. Low pressure steam dryer is considered which is integrated into the combined cycle process on steam side. The biomass fuel is dried generally from 50-60 to 15-20 % moisture. The steam generated by the dryer (steam from the fuel) is utilized to generate low pressure steam for the steam turbine or for district heat/process steam generation.

The fuel feeding system includes feeding lines based on lock-hoppers which pressurize the fuel up to gasifier pressure. The biomass feeding line has a special design suitable for biomass type fuels to enable the uninterrupted fuel feed. The biomass fuel is fed by screw feeder into the gasifier reactor. The gasifier system is a pressurized fluidized bed gasifier developed by Enviropower for biomass gasification utilizing IGT's U-Gas and Renugas experiences. The gasification medium is air and a small amount of steam depending on feedstock moisture content. The gasification air is extracted from the gas turbine and after passing through the booster compressor/heat exchanger system it is fed into the gasifier. The product gas is a typical low-calorific gas of 4 to 6 MJ/m^3 LHV (100-150 Btu/scf). It contains combustible gas components like carbon monoxide (9-18%v), hydrogen (9-15%v) and methane (4-8%v) and inert gas components (nitrogen, carbon dioxide and water vapor). The product gas impurities are ammonia and a small amount of sulfur gases, light tars and vapor-phase alkalines as well as dust particles.

The product gas treatment of the simplified IGCC-process includes two steps: gas cooling and filtering. The product gas exiting the gasifier cyclone is cooled from freeboard temperature to 450-550 °C (840-1020 °F) in a fire tube type gas cooler. The gas cooler generates saturated steam. The dust content of the cooled product gas is removed in a filter unit, which operates at gasifier pressure and at 450-550 °C (840-1020 °F) temperature. The clean product gas is directed to the control valve of the gas turbine.

Gas Turbine Plant includes the gas turbine package of usual components. Heavy duty, single shaft industrial gas turbines of high efficiency, specific power and exhaust temperature are preferred for IGCC-application. The gas turbine is a commercial equipment which is modified for low calorific value gas combustion and IGCC-application. The product gas of 450-550 °C (840-1020 °F) temperature is fed to the gas turbine through the control valve system. The combustion chamber of the gas turbine is modified for low calorific value gas combustion (4-6 MJ/m^3 i.e. 100-150 Btu/scf) and low ammonia to NO_x conversion. About 10% of the total air flow is extracted after the last stage of the compressor and used as gasification agent. The extracted air is returned to the combustion chamber as a part of product gas.

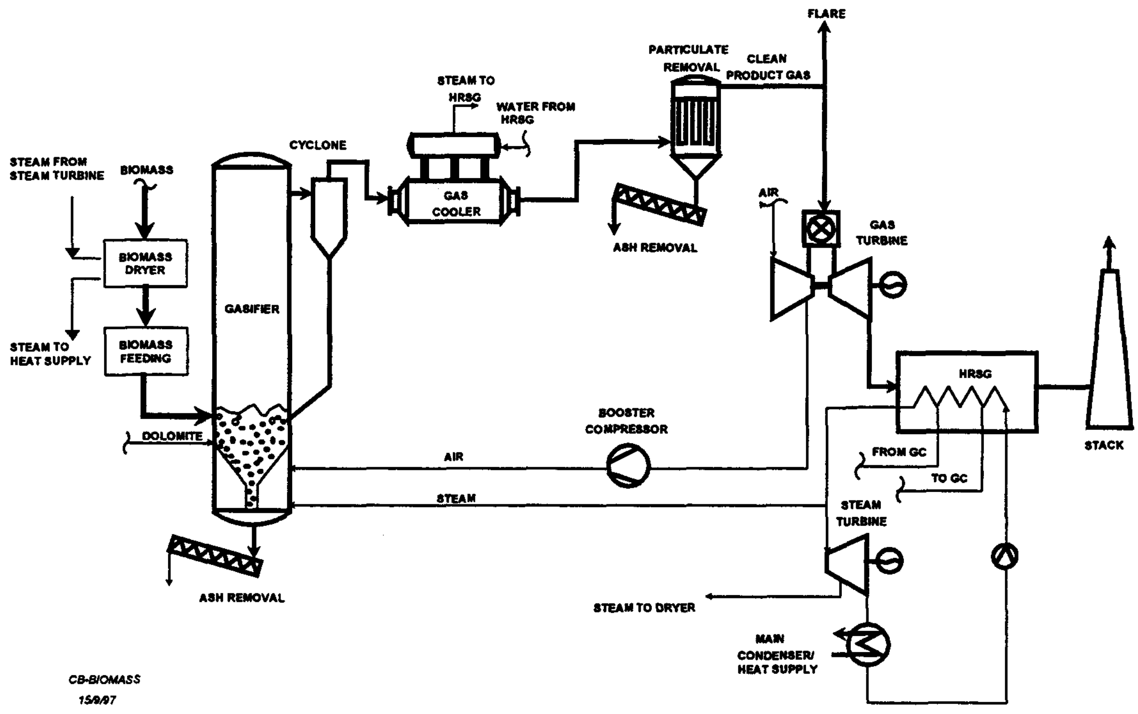

Figure 1 - Simplified IGCC Process Flow Sheet

Steam Cycle of the IGCC-plant is similar to the steam cycle of conventional combined cycle plants including heat recovery steam generator (HRSG) steam turbine and condensate and feed water system. Both in condensing and cogeneration applications the integration of gasification plant (drying, gas cooler, etc.) into the steam cycle provides numerous possibilities to establish different, efficient process configurations.

Process Development

From 1991 to 1997 an extensive development and test program was executed to minimize the technical and economical risks related to the design and operation of a biomass IGCC plant of demonstration size. Biomass drying was tested in three different commercial full-size steam dryers /1/. Improved lock-hopper system was developed and tested at the gasification pilot plant and alternate feeding systems were developed and tested /1/. Altogether 5000 tons of biomass of different type was gasified at Enviropower's pilot plant. Combustion tests of low calorific value gas were executed by General Electric /1/ and presently by Westinghouse. The above development provides basis for the design of the demonstration and commercial plants.

Process Performance

When selecting technology for power generation, the IGCC technology is compared with well developed conventional power generating systems (fossil fuel fired, super critical power plants) where the plant efficiencies have already reached or exceeded 40% (LHV), the environmental performance meets with the regulations (deSOx and deNOx systems) and the investment costs are determining the base line. The main strength of the IGCC-process in this competition is the high efficiency which increases with the increasing efficiency of the combined cycle process. The key component of the process is the gas turbine. The size of the IGCC plant is determined by the gas turbine size and the efficiency of the overall process depends mainly on the efficiency of the gas turbine. Some of the potentially significant gas turbines and the related condensing biomass IGCC plant performances based on Carbona's estimations are listed in Table 1.

Table 1
Gas Turbines for Biomass IGCC

Gas Turbine	IGCC power, MW	Net efficiency, LHV, %	Biomass consumption metric t/a	m^3/a
EGT, Typhoon	6.6	43.5	55000	171000
GE, F6B	60	47.1	472000	1.46 million
Westinghouse, CW251B	72	46.1	556000	1.72 million
GE, F6FA	110	50.5	827000	2.56 million

Assumptions: ISO conditions, 8000 h/a, wood waste of 50% moisture AR, condensing plant, fuel LHV (dry base) 18.5 MJ/kg

The above process performances are affected not only by the high efficiency of the combined cycle but also by process optimization where the integration of the biomass fuel drying process has an important role. The upper size of the biomass IGCC power plant is mainly determined by the availability of biomass /2/. Application surveys show that the biomass fueled IGCC process fits best with combined heat and power-applications (industrial processes or district heating) due to plant size and fuel availability. In the combined heat and power applications the biomass IGCC has the significant advantage of high power to heat ratio (typical power to heat ratio is about 1) /2/. This can be an advantage for example in Finland where the district heat demand is not increasing while the electrical power consumption increases.

The environmental performance of the biomass IGCC process is also competitive and meets environmental regulations. The low ash, low sulfur biomass fuel and the high efficiency of the overall process will result in emissions as shown in Table 2.

Table 2
Estimated Air Emissions of a Wood Fuel Based Biomass IGCC

sulfur dioxides	<50 mg/MJ	<0.1 lb/MMBtu
nitrogen oxides	<50 mg/MJ	<0.12 lb/MMBtu
particulate	<5 mg/MJ	<5 ppmw
carbon dioxide	<780 gCO_2/kWh	<1.73 lbCO2/kWh

BIOMASS PILOT TEST PROGRAM

Extensive test program has been carried out at the Gasification Pilot Plant since 1993 covering all aspects of a biomass gasification process for IGCC application. The test program consisted of ten test runs totaling 2000 operation hours. The main objectives of the test runs were to demonstrate the ability of the gasifier process and hot gas cleanup system for gasification of different, project specific fuels and to provide firm technical basis for the engineering of the demonstration project.

Pilot Plant Description

Enviropower's pressurized fluidized bed gasification pilot plant (recently used by Carbona Inc.) is located in Tampere, Finland. The pilot plant includes all essential modules for research, component testing and the completion of the development of the gasification process for IGCC applications. The pilot plant converts 15 MJ/s (51 MMBtu/h) thermal input of fuel to a product gas which is suitable for combustion in gas turbine. The gasifier operates at pressures up to 30 bar (435 psi) and at temperatures up to 1100 °C (2020 °F). The process flow diagram of the pilot is shown in Figure 2.

The plant is equipped with separate coal and biomass preparation and feeding systems which allow the testing of a variety of feedstocks like wood waste, straw, other biomass types, coal and lignite. The gasifier is an air-blown, single stage pressurized fluidized bed gasifier. The gasification agents (air and steam) are fed through the bottom of the fluidized bed to maintain the proper conditions for simultaneous fluidization and bed material/ash removal. Freeboard temperature can be controlled by air injection. Due to the low ash content of biomass fuels dolomite or sand is used as bed material in the fluidized bed. Gasification steam is produced in the gas coolers and it is superheated in the heat recovery boiler. The bed material containing some biomass ash is removed from the bottom of the gasifier through cooling screw and lock hopper system.

The bulk of the entrained fines from the gasifier is separated from the product gas in an external cyclone. The fines are returned from the cyclone to the fluidized bed. The product gas leaving the cyclone is cooled in two steps: first to 400-650 °C (750-1200 °F), and after hot gas clean up to 200-350 °C (390-660 °F). After the first gas cooling stage, the remaining dust particles are removed from the gas stream by the ceramic candle filters cleaned by nitrogen pulsing. In the case of high sulfur fuels like coal, the sulfur compounds can be removed in a post gasification desulfurization system also shown in Figure 2. The pressure of the cooled product gas is reduced before the burner of the waste heat recovery boiler which is connected to the district heating system of the city of Tampere. The flue gas of the boiler is directed to the stack.

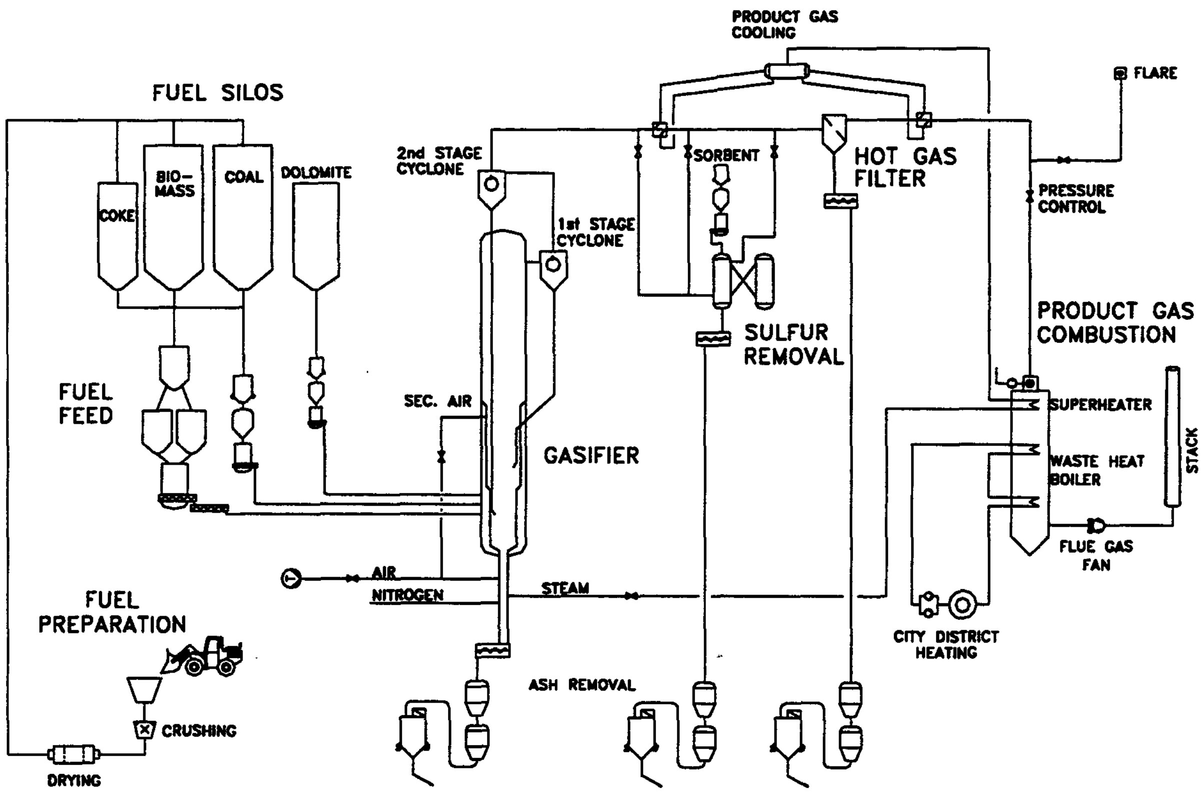

Figure 2
Enviropower's Gasification Pilot Plant

The pilot plant is equipped with a state-of-the-art data acquisition and control system. Over 1000 parameters (gas flow rates, temperatures, pressures, etc.) are measured continuously, product gas and flue gas quality is analyzed on-line and all solid flows are sampled.

Biomass Fuels

The Pilot Plant was operated more than 2000 hours with different type of biomass in the 1993-1997 period as listed in Table 3.

Table 3
Biomass Fuels Gasified at The Gasification Pilot Plant

fuel type	**total gasified amount**
- wood chips	1630 metric tons
- forest residues (wood waste)	1750 metric tons
- paper mill waste (bark, sludge, paper)	1180 metric tons
- willow	400 metric tons
- straw (in a mixture with coal)	20 metric tons (+120 tons coal)
- alfalfa	117 metric tons

The wood chips were prepared from soft and hard wood and the mixture of these. Forestry wood residue was a mixture of soft- and hardwood consisting of trunk wood, branches, bark and needles and it represents a wide variety of woods including for example spruce, pine, birch, alder and aspen. The wood waste of the paper mill consisted mainly of bark and wood fiber sludge, but it contained also some amount of other wastes like paper, wood/saw residue and plastics. Willow (salix) is a typical plant for short rotation energy forestry. Wheat straw gasified in loose form, while alfalfa stems in pelletized form. The wood type feedstocks were crushed to a coarse size and dried to 18-42 % moisture content. The typical as fed fuel contained about 30 % moisture. Straw was received in bales and it was chopped at the pilot plant, while the pelletized alfalfa required no preparation. Straw and alfalfa required no drying since their moisture content was about 10%. The range of feedstock properties is shown in Table 4.

Table 4
The Range of Feedstock Properties

Fuel type	wood chips	forest residue	paper mill waste	willow	wheat straw	alfalfa
Proximate analysis:						
total moisture, %	14-18.5	18-30	20-42	15.5-25.7	10.8-11.2	11.4-11.9
volatile, db., %	79.6-80.4	77.3-77.7	70.7-76.3	78.4-80.4	73.1-73.8	74.3-74.5
ash, db., %	1.6-2.0	3.4-3.7	2.7-5.4	1.6-3.4	4.8-6.4	9.0-9.3
Cfix, db., %	17.6-18.8	12.6-12.9	21.0-24.0	17.5-18.7	20.5-21.4	16.4-16.5
Ultimate analysis:						
carbon, db., %	49.4-50.2	50-50.2	49.7-51.0	48.3-48.9	47.4-48.3	44.9-45.6
hydrogen, db., %	6.0-6.4	5.9	5.5-5.9	5.9-6.0	5.6	5.5-5.6
nitrogen, db., %	0.4-0.6	0.5-0.6	0.5-0.7	0.4-0.6	0.48-0.54	2.7-2.9
oxygen, db., %	41.5-44.9	39.5-40.1	36.5-40.1	41.5-43.1	39.6-40.5	36.9-37.1
sulfur, db., %	<0.1	<0.1	<0.1	<0.1	0.09-0.13	0.22
chlorine, db.,%	n/a	n/a	n/a	n/a	0.18-0.3	0.39
ash, db., %	1.6-2.0	3.4-3.7	2.7-5.4	1.6-3.4	4.8-6.4	9.0-9.3
Heating values:						
HHV db., MJ/kg	20.7-22.0	20.2-20.4	19.8-20.4	18.4-19.6	19.2-19.4	18.1-18.3
LHV db., MJ/kg	19.4-20.6	18.9-19.1	18.5-19.3	17.1-18.3	18.0-18.2	16.9-17.1

Gasifier Operation

The range of the main operating parameters of the Gasification Pilot Plant is shown in Table 5. The gasifier was operated at the pressure level which is required for the operation of an industrial gas turbine. The gasification medium was mainly air. In the case of wet fuels (wood type biomass) no steam was required for the gasification process. For low moisture fuels like straw or alfalfa or for the gasification of coal/biomass mixtures also steam was used as gasification medium. A wide range of fluidization velocities was tested as well. The bed material was typically dolomite.

The ash properties (sintering temperature) of the biomass was the main determining factor when selecting the operating conditions of the gasifier. The sintering temperature of the ash of wood type biomass is sufficiently high to allow gasifier operation above 800 °C (1470 °F). The ash of willow however showed inclination for sinter formation at this temperature. The ash sintering temperature of straw and alfalfa is very low (600-700 °C / 1100-1300 °F) therefore straw was gasified mixed with coal and alfalfa was gasified at a low temperature (700 °C / 1290 °F).

Table 5
The Range of Main Operating Parameters

Gasifier pressure	7 - 19 bar(g)	100 - 276 psig
bed temperature	700 - 880 °C	1290 - 1620 °F
fuel feed rate (as fed)	0.38 - 0.98 kg/s	3016 - 7778 lb/h
thermal input (LHV)	5.0 - 13.3 MJ/s	17.1 - 45.5 MMBtu/h
air feed rate	0.60 - 1.43 kg/s	4762 - 11350 lb/h
steam feed rate	0.04 - 0.23 kg/s	320 - 1830 lb/h
fluidization velocity	0.5 - 1.2 m/s	1.6 - 3.9 ft/s
filter temperature	450 - 570 °C	840 - 1060 °F

Main Test Results

Carbon Conversion: The fuel conversion at wood type biomass gasification was in the range of 97-99 % depending on fuel quality and pilot plant operating conditions. In the case of straw/coal mixture gasification the carbon conversion was determined by the coal. Due to the low temperature for coal gasification (850 °C / 1560 °F) the fuel conversion varied between 81-90 %. During alfalfa gasification the gasification temperature was low (700 °C / 1290 °F) resulting in low fuel conversion of 93-97 %.

LHV of Product Gas: Lower heating value (LHV) higher than 4.2 MJ/m^{3}n (110 Btu/scf) was obtained at about 30 % fuel moisture content of the wood type biomass. The contribution of tars to the heating value of the product gas was small. In the case of alfalfa gasification the LHV of the product gas was higher, in the range of 6.4-6.7 MJ/m^{3}n (160-170 Btu/scf) with a significant contribution of C_2- and C_3-hydrocarbons and ammonia.

Tars: The term **light tars** generally refer to organic compounds (from benzene to pyrene) with molecular weights of less than 200. The light tar concentrations, measured in biomass gasification were in the 5-15 g/m^{3}n (4500-14000 ppmw) range with benzene and naphthalene comprising about 95% of the total tars / 3/. The light tars do not condense in the temperature of the hot gas cleanup train (450-550 °C /840-1020 °F) and enter the gas turbine in the gas phase, adding as much as 10% to the heating value of the low calorific value gas.

Heavy tars are polyaromatic compounds with molecular weights between 200-300 and which range between fluoranthene and coronene. The heavy tar fraction measured in the biomass gasification tests was below 150 mg /m^{3}n (140 ppmw) /3/ for all biomass fuels. In the test runs with a variety of biomass fuels, no sign of blockage on the ceramic filter (550 °C/1020 °F) has ever been observed or other problems encountered due to condensation of tars, not even in the low temperature gas cooler (200-350 °C/390-660 °F) of the gasification plant. In conclusion, as long as the hot gas cleanup train is operated at 450-550 °C (840-1020 °F), no "tar problem" is foreseen, i.e. they burn in the gas turbine and are converted to carbon dioxide and water vapor.

Ammonia and HCN: The source of ammonia in the gasification process is the fuel-bound nitrogen. A substantial proportion of the nitrogen in the biomass will be converted to ammonia and to lesser extent HCN. The conversion of the fuel bound nitrogen to ammonia was in the range of 50-95 % depending on fuel type and gasification conditions. 400-20000 ppmv ammonia have been measured during the biomass gasification tests. High ammonia concentration was measured at alfalfa gasification due to the high nitrogen content of alfalfa and low gasification temperature. The HCN concentration was below 100 ppmv with all biomass types. Depending on the type of gas turbine combustion system a part of the ammonia will be converted to nitrogen oxides in the gas turbine when the gas is combusted to produce power. Gas turbine manufacturers are developing combustion systems where a NO_x reduction i.e. low ammonia to NO_x conversion conversion can be achieved.

Sulfur Compounds: The sulfur compounds in the gasifier gas are H_2S and COS, which were measured as TRS (Total Reduced Sulfur). The measured TRS concentration was below 100 ppmv for wood type biomass, due to the low sulfur content. Alfalfa has exceptionally high sulfur content which resulted in TRS between 400-600 ppmv during gasification which would result of about 55 ppmvd (O_2=15%) sulfur dioxide emission. However, generally the gasification of biomass would result in sulfur emissions of below environmental regulatory limits.

Alkalines: The alkali metals (Na and K) which are found in various biomass-based feedstocks in varying quantities (from a few hundred ppm to more than 24000 ppm in alfalfa) are not regulated because of environmental considerations but have to be removed to protect the gas turbine hardware. Alkali metals are also partitioned in the gasifier and a very small fraction exit the gasifier in the vapor-phase in the fuel gas. Experimental data with various fuels such as wood chips, straw, forest residue, alfalfa, show that when the product gas is cooled to below 600 °C (1100 °F), both Na and K are removed from the fuel gas and the measured values after the ceramic filter are typically in the 0.05-0.1 ppmw range which is acceptable for the gas turbine even at the higher sulfur content of alfalfa.

Chlorine: The fate of fuel-bound chlorine in the gasification process is directly related to those of alkali metals (Na, K) and the calcium compounds. There is experimental evidence that both K and Na will react either with the chlorine released from the fuel or HCl, when formed in the gasifier, to form alkali chlorides (NaCl and KCl). As a result of these reactions, the measured concentration of HCl in the gasifier gas has been found to be much less than what it would be when all of the chlorine would exit the system in the form of hydrogen chloride. These reactions help to remove gaseous halogens from the gasifier gas which are then bound with filter ash and bottom ash in solid phase. The reactions of calcium compounds with both chlorine and hydrogen chloride are also investigated, primarily in conjunction with the addition of dolomite or limestone to the fluidized-bed gasifier. Experimental data show that when calcined, a significant portion of the HCl is removed from the gasifier gas in the filtration stage in the form of calcium chloride with the filter ash. In conclusion, most of the fuel-bound chlorine is removed either with the bottom ash or bound in the filter ash in the solid-phase as alkali chlorides and calcium chloride. HCl concentrations of 10-460 ppm have been measured in the fuel gas with various biomass-based feedstocks, the latter from alfalfa gasification tests.

Trace elements / air toxics: Trace elements exist in biomass-based feedstock in much smaller amounts (ppm level) than in coal except in some biomass-based wastes such as in demolition wood. As an example, Table 6 shows the trace element content of pelletized alfalfa. Fuel-bound trace elements are partitioned in the gasifier and a very small fraction leaves the gasifier in the vapor-phase in the fuel gas, except for highly volatile metals such as mercury (Hg), selenium (Se), Be (beryllium), cadmium (Cd) and arsenic (As). Most of the volatilized fraction condenses on or is adsorbed by the filter cake when the product gas is cooled to 450-550 °C (840-1020 °F) and filtered using ceramic candle filters. However, there is evidence that trace elements such as mercury may penetrate through these filters and will be in the vapor-phase or in the form of sub-micron particles and will be eventually emitted to the atmosphere.

Table 6
Trace element content of alfalfa feedstock (mg/kg fuel)

Mercury (Hg)	<0.07	Manganese (Mn)	<26
Cadmium (Cd)	<0.2	Beryllium (Be)	<2
Lead (Pb)	<5	Arsenic (As)	<5
Selenium (Se)	<5	Chromium (Cr)	<2
Antimony (Sb)	<5	Nickel (Ni)	<10
Cobalt (Co)	<2		

During alfalfa testing the trace element concentrations in the gas-phase after the ceramic hot gas filter unit were measured by two different techniques, wet chemistry and using active carbon filter beds as described in reference /4/. The filters were delivered by Imatran Voima Oy and which were recommended by Radian Corp. in the United States. The wet chemistry technique is also described in detail in reference /4/.

The results show extremely low (mostly below detection limit) concentrations of all the trace elements analyzed and good agreement between the two sampling/ measurement techniques employed. As an example, concentrations of cadmium and lead were 2.0 $\mu g/nm^3$ and 2.4 $\mu g/nm^3$, respectively, measured with the impinger train. With the active carbon system, the corresponding figures were 0.7 $\mu g/nm^3$ and 2.3 $\mu g/nm^3$, respectively. Mercury (Hg) and beryllium (Be) concentrations were below detection limit. None of the trace elements shown in Table 6 would be emitted to the atmosphere in amounts of concern in Europe or in the United States, i.e. their concentrations are below the environmental standards imposed in Europe or to be regulated in the United States.

Particulates in Product Gas: Combined dust and tar loading in the product gas were below 5 ppmw (particle size below 3μm) after filtration in the case of all biomass feedstocks. This level of dust loading is lower than the dust concentration typically specified by gas turbine manufacturers and well below the limit required by environmental regulations.

The main test results of the biomass pilot plant test program are summarized in Table 7.

Table 7
Biomass Pilot Test Results

fuels	wood, forest residue, paper mill residue, straw, alfalfa
product gas LHV	4-7 MJ/m^3 (100-170 Btu/scf)
carbon conversion	83 - 99 %
gas composition	
carbon monoxide	9-18 %-vol
hydrogen	9-15 %-vol
methane	4-8 %-vol
carbon dioxide	15-19 %-vol
nitrogen	46-57 %-vol
water vapor	9-20 %-vol
heavy tars in product gas	< 140 ppmw
light tars in product gas	4500-14000 ppmw
ammonia in product gas	400-20000 ppmv
total reduced sulfur in product gas	100-600 ppmv
HCl in product gas	10-460 ppmw
dust in product gas (after filter)	< 5 ppmw
alkalines in product gas (after filter)	0.05-0.1 ppmw

Product Gas for Gas Turbine

The IGCC process concept considered by Carbona Inc. applies integrated air blown gasification and hot gas clean-up. The gas turbines applied in the IGCC process are heavy duty industrial machines originally designed for natural gas or distillate firing. The application of a commercial industrial gas turbines in the above IGCC process requires some modification of the machine. These are

- - modification of the fuel gas feeding and control system for a large mass flow of hot (450- 550 °C/ 840-1022 °F) fuel gas,
- - modification of the combustion system for the combustion of the low calorific value gas with low emissions,
- - dual fuel capability and fuel switch between product gas and back-up fuel,
- - air extraction (about 10% of the total air flow) after the last stage of gas turbine compressor.

Gas turbine manufacturers specify the properties of different fuel types acceptable for the gas turbine. These specifications can not be directly applied for solid fuel derived low calorific value gases therefore case by case evaluation required. This evaluation concentrates mainly on the combustion properties of the gas, the contaminants in the gas (gas turbine protection) and gaseous emissions caused by the combustion properties of the gas and the contaminants in the gas. The combustion system of the gas turbine has to be modified to accommodate the larger fuel gas flow and to provide sufficient combustion conditions for reduced emissions. The modifications are usually tested in an actual gas turbine combustion system at actual pressure using simulated biomass derived fuel gas.

The main differences between natural gas and the biomass derived gas are the following:

- the LHV of biomass derived gas is 8-10 times lower than that of the natural gas,
- the main combustible components of biomass derived gas are 9-15 % hydrogen, 9-18 % carbon monoxide and 4-8% methane,
- the biomass derived gas contains a variety of hydrocarbons (tars),
- the biomass derived gas contains sulfur and nitrogen compounds,
- the biomass derived gas contains contaminants like alkalines and dust.

For heavy duty industrial gas turbines the LHV of the gas can be as low as 80-100 Btu/scf. The limiting factor is the increasing carbon monoxide (CO) and unburnt hydrocarbon (UHC) emission with decreasing LHV. The variation of gas composition has to be kept also within specified limits. It is mainly defined as the ratio of hydrogen to carbon monoxide. The tars in the product gas burn in the gas turbine combustor contributing to the LHV of the fuel gas. The gas temperature has to be kept high enough between the gasifier and gas turbine to avoid heavy tar condensation in the fuel gas supply system.

The sulfur and nitrogen compounds in the fuel gas mainly burn to SO_2 and NO_x. Typically the thermal NO_x generated in the combustion system is much lower than the NO_x evolving by the ammonia combustion. Gas turbine manufacturers are developing special combustion systems for the reduction of fuel bound nitrogen to NO_x conversion to between 10 and 50 %. If such gas turbine is not available or the ammonia content of product gas is extremely high, selective catalytic reduction (SCR) will have to be employed in the heat recovery steam generator (HRSG) to meet NO_x emission standards.

The alkalines can react with the sulfur compounds in the gas forming sulfates which may cause deposition on the turbine blades. Therefore the vapor phase alkaline content in the fuel gas is required to be the under the limit specified by the gas turbine manufacturers. This limit is typically bound to the concentration of the sulfur compounds in the fuel gas.

Particulates in the fuel gas cause erosion of the turbine blades, therefore the concentration and maximum particle size is required to be below the limit specified by the gas turbine manufacturers.

The biomass derived gas generated by the Carbona gasification system with wood type biomass was evaluated by numerous gas turbine manufacturers and the heating value, composition and the level of contaminants were approved and performance guarantees were provided. The alfalfa derived gas is under investigation at present. Carbona has co-operated mostly with General Electric and Westinghouse on the evaluation of the low calorific value gas. In 1995 General Electric tested the Enviropower/ Carbona's biomass gas in a modified F6B combustion chamber /1/ with good results:

- Temperature and dynamic pressure levels were well within design limits and the combustion characteristics of the fuel gas were good through the operating load range. Thermal NOx, CO and unburnt hydrocarbon (UHC) emissions were very low.
- The fuel gas composition was acceptable and the gas heating value was within the required range.
- Conversion rate of fuel bound nitrogen to NOx was much lower than expected.

At present Westinghouse is testing the alfalfa derived gas determined by Carbona based on alfalfa pilot plant testing in a W251B12 gas turbine combustion system.

IGCC DEMONSTRATION PROJECT

Carbona along with Kvaerner Pulping Inc. is participating in the *Minnesota Agri-Power Project* (MAP) in the USA as the gasification technology supplier. The project will demonstrate a 75 MW biomass IGCC plant based on alfalfa fuel. The IGCC plant will operate in conjunction with an agricultural preparation plant. The gasification plant will utilize alfalfa stems to produce product gas for the gas turbine plant. The exhaust heat of the gas turbine will be used to generate steam to power a steam turbine. The feedstock supply system will provide alfalfa produced in the area within a 50-mile radius around the Granite Falls. Carbona in cooperation with Kvaerner Pulping Inc. will supply the biomass fuel gasification technology, Westinghouse Electric Corporation will supply power generation equipment and Stone & Webster Engineering Corporation will provide balance of plant engineering and construction services. The project is partially financed by the U.S. Department of Energy under its Biomass Power for Rural Development.

REFERENCES

/1/ Liinanki, L., Horvath A., Lehtovaara, A., Lindgren, G. "The Development of a Biomass Based Simplified IGCC Process". Thirteen's EPRI Conference on Gasification Power Plants. San Francisco, CA. October 19-21, 1994.

/2/ Horvath, A., Lehtovaara, A., Salo, K. "Demonstration of a Biomass Gasification for IGCC Application". Conference on New Power Generation Technology. San Francisco, CA. October 25-27, 1995

/3/ Mojtahedi, W., Ylitalo, M., Maunula, T., and Abbasian, J. 1995. Catalytic decomposition of ammonia in fuel gas produced in pilot-scale pressurized fluidized-bed gasifier. Fuel Processing Technology, 45, pp. 221-236.

/4/ Mojtahedi, W. and Salo. K. 1996. Fate of a few selected trace elements in pressurized fluidized bed gasification and hot gas cleanup. Proceeding of 13th. Annual Int. Pittsburgh Coal Conference, Pittsburgh, PA, USA. 1996. pp. 61-67