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A SMALL SCALE BIOMASS FUELED GAS TURBINE POWER PLANT

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ABSTRACT

A new generation of small scale (less than 20 MWe) biomass fueled, power plants are being developed based on a gas turbine (Brayton cycle) prime mover. These power plants are expected to increase the efficiency and lower the cost of generating power from fuels such as wood. The new power plants are also expected to economically utilize annual plant growth materials (such as rice hulls, cotton gin trash, nut shells, and various straws, grasses, and animal manures) that are not normally considered as fuel for power plants. This paper summarizes the new power generation concept with emphasis on the engineering challenges presented by the gas turbine component.

Keywords: gas turbine, gasification, hot gas cleanup, low calorific value (LCV) gas

BIOMASS POWER PLANT RATIONALE

Many entities worldwide greatly desire improved and more economic methods for using and/or disposing of biomass in the course of generating electricity. At present, the amount of useable power being produced from biomass is very small relative to the biomass resources available for this use. If there is such a desire to employ biomass power and there are vast biomass resources for fueling biomass power plants, why do we not see rapid development of this industry? First, any proposed biomass power plant has to compete with other power supply options. In the majority of cases the only other option is power supplied by a fossil fueled power plant. Power supplied by a fossil fueled power plant can be very economical. It is economical because it is reliable; uses the latest in power plant technology (e.g., an efficient gas turbine engine combined with the steam cycle); can be installed relatively quickly; can be built on both a small and large scale; and is well known by the finance community. Fossil fuels are currently abundant and available at a reasonable price in many parts of the world. Second, biomass power plants rely on less efficient boiler/steam turbine technology; have a higher installed price per kWe; and

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draw on fuel supplies that are bulkier, less homogeneous, and more difficult to fire and handle than fossil fuels (especially relative to oil and natural gas which are not solids).

The major reasons for consideration of the biomass power option are: (1) disposal of biomass residues combined with the production of electricity and heat, (2) power production from abundant indigenous biomass resources, (3) power for remote locations rich in biomass resources, and (4) it is a renewable energy option. This option has been chosen for many applications. In the U.S. there is an estimated 6000 MWe of wood-based generating capacity that is dispatchable (Neos Corporation, 1992). The amount of power that could be generated from biomass resources is much greater, especially considering the worldwide market. But to effectively capture this underutilized renewable resource requires a new generation of biomass power plants.

TECHNICAL PATH FOR PRODUCING ELECTRICITY FROM BIOMASS

There are numerous decisions to be made when choosing a path for producing electricity from biomass. The path Cratech has chosen is shown in the simplified block diagram of Figure 1. The block diagram of Figure 1 shows a pressurized air-blown fluid bed reactor with fuel injection from a biomass pressurization and metering unit. The air is supplied to the reactor from a booster compressor which in turn is fed from the turbine compressor final stage. The product gas is passed through a hot gas cleanup system followed by injection into the turbine combustor. Electricity is produced from the generator which is powered by the output shaft of the gas turbine. Also, shown is a heat recovery steam generator (HRSG) that can be added if desired. A gasification system similar to the system shown in Figure 1 has been tested with the results reported (Craig, 1996). Cratech is projecting to have an operating power plant as shown in Figure 1 (excluding the HRSG) by the fourth quarter of 1998. Many hours of further testing will be required before the unit can be offered for sale. This path is a promising option for cost effective production of electricity from the largest variety of biomass materials. This system takes advantage of the higher practical thermodynamic efficiency of the Brayton cycle over the Rankin cycle.

Gumz (1950) is the earliest reference found describing the concept of combining a pressurized gasifier with a gas turbine engine, although Gumz himself references an earlier work proposing this concept. He also states that the combination could certainly benefit from future development of pressurized hot gas cleaning to avoid excessive turbine blade wear. Gumz was speaking of coal-fueled plants but the concept is similar when using biomass as fuel. Currently, similar concepts are being developed for using biomass as fuel in Hawaii (Wiant et al, 1997), Sweden (Skog, 1993), Finland (McKeough and Kurkela, 1993), Minnesota (DeLong et al, 1995), Europe (Maniatis and Ferrero, 1995), and other locations.

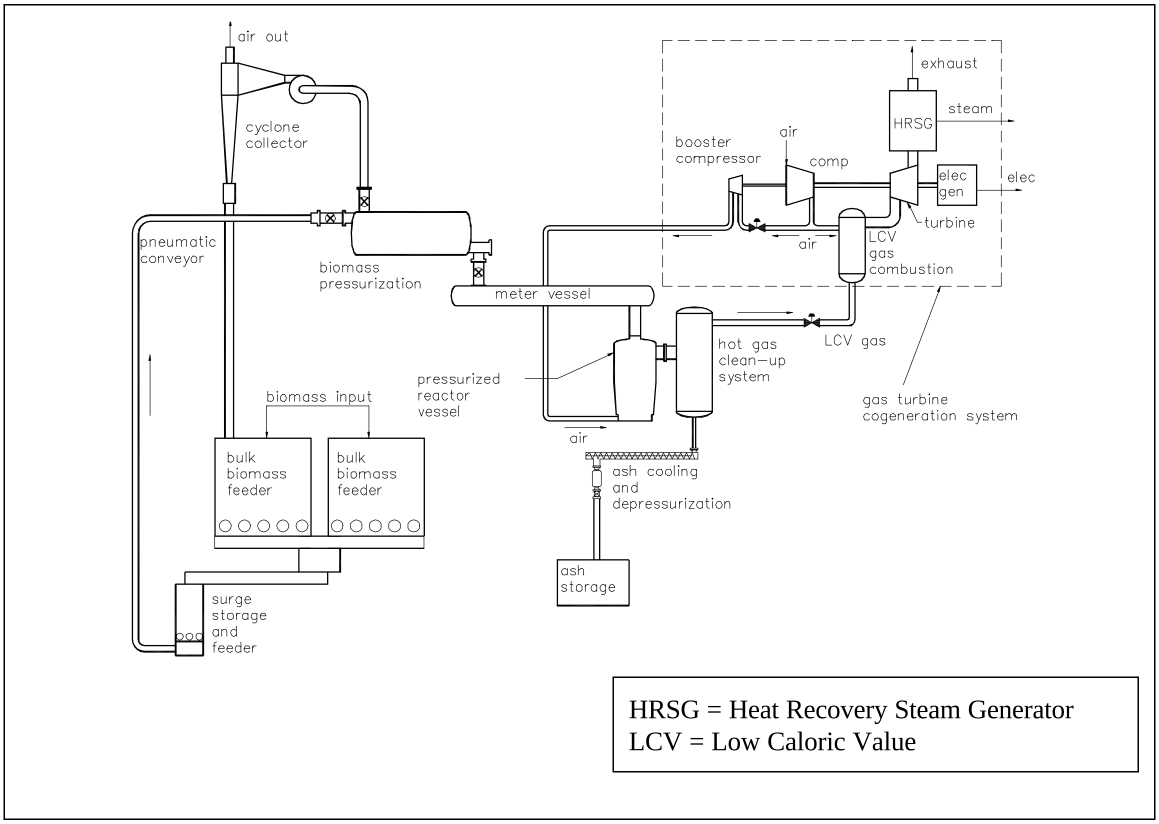

Figure 1: Cratech's Chosen Path for Producing Electricity for Biomass.

The Cratech system can operate at a maximum design pressure of 13.8 atm (1353 kPa), at a feed rate of 2 tonnes (2.2 tons) per hour of wood, and at a gasification temperature just below 730°C (1346°F). The gas is maintained at, or just below, this temperature to retain valuable sensible energy and prevent condensation of the tars. In this state, the solid particles are removed from the gas by a hot, dry gas cleaning system. The gas is then directed into the combustion chamber of a gas turbine engine. This path has several notable benefits. It avoids ash softening temperatures before the ash is removed, thus avoiding ash slagging problems. It retains the sensible energy in the gas, which helps maintain overall system efficiency. Wet scrubbers are not used; therefore, no wastewater will have to be treated. The tars will remain in a vapor state, avoiding tar sticking and corrosion problems. The chemical energy contained in the tar will be recovered as the hot vaporized tar is burned. No catalyst or higher temperatures are needed for tar destruction before combustion.

Pressurized operation allows for higher heat rates per square area of the reactor; reduces the size of the hot gas clean-up system; and eliminates the need for compression of the gas prior to injection into the gas turbine. Direct, or air, gasification was chosen over indirect gasification to reduce the overall complexity of the system. Steam is not required for fluidization, and minimizing steam use cuts down on latent heat losses.

There are barriers to overcome with this path. Most prominent are feeding biomass into a pressure vessel, developing hot gas cleanup, low carbon conversion efficiency at low gasification temperatures, alkali vapors in the fuel gas, and fueling a gas turbine engine with a hot low energy gas. These barriers are worth exploring to obtain the significant advantages cited above.

GAS TURBINE ENGINE MODIFICATIONS

Low calorific value (LCV) gas will fuel the gas turbine. Table I contains the LCV gas composition and Table II contains the LCV gas characteristics as produced from cotton gin trash fuel. Figure 2 is a block schematic of the gas turbine and its fuel control scheme.

Table 1. LCV Gas Composition

Component	% mole fraction
H_2	10.4
CH_4	3
C_2H_4	1
C_2H_6	0.3
CO	17
CO_2	15.3
N_2	41
H_2O	12

Table 2. LCV Gas Characteristics

Molecular weight: 26.2
Gas temperature: 700°C (1292°F)
Chemical energy of gas: 5.18 MJ/scm (139 Btu/scf)
Sensible energy of gas: 1.05 MJ/scm (28 Btu/scf)
Solid particle concentration < 6 ppmw with max particle size of 3 µm
Tar content was not measured.

The Cratech gasification system is capable of fueling a turbine of 1500 kWe output with a maximum pressure ratio of about 11.0; however, the initial gas turbine combustion test will be performed with a Solar Spartan turbine rated at 225 kWe with a pressure ratio of 4.0. This small gas turbine generator package will provide for economical fuel system and combustor modification, and subsequent testing.

An Engineering Challenge

One major challenge to overcome in making this type of power plant possible is designing a gas turbine fuel and combustion system that will accept and burn hot LCV gas. An EGT Typhoon gas turbine has been designed to operate on gas of 5 MJ/scm (134 Btu/scf) at a fuel injection temperature of 400°C (752°F) (Mina et al, 1994). Westinghouse is planning to fuel a 251B12 gas turbine with 5 MJ/scm (134 Btu/scf) LCV gas at an injection temperature of 550°C (1022°F) (Stambler, 1997). Cratech plans to fuel a modified Solar Spartan gas turbine with 5 MJ/scm (134 Btu/scf) LCV gas at a fuel injection temperature of 700°C (1292°F). This challenge consists of designing a suitable fuel delivery system and an LCV gas combustor.

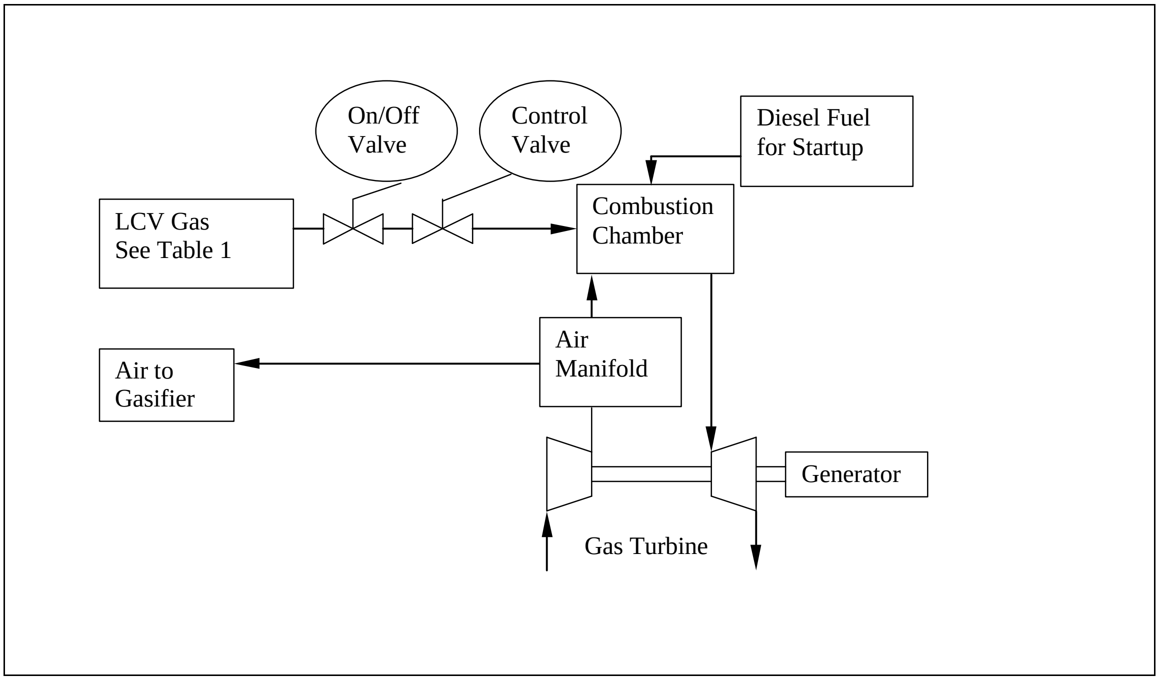

Figure 2. Gas Turbine Fuel Control Scheme.

LCV Gas Delivery and Injection System

Designing a fuel gas delivery and injection system that can handle the high temperature LCV gas is a major engineering challenge. Careful attention must be paid to selection of valves and materials that can handle the high temperatures and pressures. The on/off or blocking valve closes in the event of overspeed of the turbine shaft, over temperature of the turbine inlet gas, or emergency shutdown (see Figure 2). The fuel gas control valve operates in relation to the turbine shaft speed. This valve will be required to operate at high temperatures while controlling the fuel flow required to maintain a constant shaft speed over the entire power range of the generator. Cratech will collect data on technical performance and cost effectiveness of the valves.

LCV Gas Combustion

The Spartan is a much smaller turbine than any that has been fueled with biomass derived LCV gas to date; however, it will be possible to fuel this small turbine with an extensively modified combustion chamber. Cratech considered several parameters when designing the combustion chamber for burning LCV gas. One of the most important parameters is the pressure drop across the combustor. The objective is to maintain and promote stable combustion with a combustor pressure drop of approximately 4%.

Diesel fuel will be used for startup in the conventional manner. The initial test runs will be conducted under no load conditions. LCV fuel gas will gradually be fed to the combustor, and the flow of diesel fuel will be gradually cut back. It is expected that the diesel fuel can be completely shut off and the turbine will operate totally on LCV gas. When stable combustion is occurring with 100% LCV gas under no load conditions, the process will be repeated under gradually increasing load conditions until the goal of 100% load with 100% LCV gas is reached. With a fuel delivery and combustion system properly operating, the next step would be a 100-hour test run to check for any seriously detrimental effects from solid particles or possible alkali attack on the gas turbine blades. The gasification system has been designed so that alkalis remain in solid form and exit with the filter ash. The hot gas filtration system is expected to remove more than enough particulate matter to protect the turbine blades. Once the power plant demonstrates satisfactory operation for short periods of time, Cratech plans to relocate the plant to a commercial site for long term endurance and reliability testing.

The successful completion of such an ambitious development program will bring the new generation of small scale biomass power plants much closer to technical, economic, and commercial reality.

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