THE BIOMASS GASIFICATION PROCESS BY BATTELLE/FERCO: 
DESIGN, ENGINEERING, CONSTRUCTION, AND STARTUP

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Abstract

Modernization of the use of biomass for energy, which in primary energy terms represents about 15% of the world’s energy supply, is needed in order to address environmental and economic development concerns. In particular, the production of high performance secondary energy forms, such as electricity and liquid fuel, that are both compatible and competitive with fossil fuels, will enable the efficient use of biomass in rural and international development. In the United States there is considerable interest in modernizing the power islands of the wood-processing industries especially in the pulp and paper sector that last made major investments in power production technology in the 1950s and 1960s. Since that time, the ratio of electricity demand to thermal needs in the processing plant have risen considerably; and replacement of current boiler and steam turbine technology by gasifier and gas turbine combined cycles in combined heat and power applications have offset these trends while improving environmental performance. The U.S. Department of Energy, in partnership with industry, is addressing these development needs, and one technology that is showing promise is the medium heating value gasification system developed by Battelle and licenced to Future Energy Resources Corporation (FERCO). The first large-scale plant, rated at 40 MWth, is now in startup at the McNeil power station of Burlington Electric Department in Burlington, Vermont. The development path and current status of this technology is discussed.

Keywords: biomass gasification, power generation, gas cleanup, commercialization, medium Btu gas, McNeil Generating Station, FERCO, Battelle
Introduction

Current biomass to electricity systems are almost all based on boilers fired with wood or agricultural residues with a Rankine cycle operating in either a condensing or extraction mode on the steam turbine. While the overall thermal efficiency in combined heat and power generation can be greater than 70%, the average efficiency in stand alone (condensing) power generation is about 20%-22% at small scale. In modern large-scale wood-fired plants, such as the McNeil Station with 50 MW net output, steam temperatures up to 480°C (900°F) have been used and electrical efficiencies around 25% (HHV) can be reached, though there are increasing concerns about the formation of ash deposits and superheater corrosion from the biomass ash. Recent experience in Denmark at the Enstedværket with a sequentially fired straw and wood boiler has achieved superheater temperatures as high as 542°C. In this case the steam from the 88 Mwth biomass fired boiler is passed to a large coal boiler (630 MW) where generation efficiencies are 40% (LHV basis).¹

Much higher efficiencies are being achieved in natural-gas-fired combined-cycle units where 58% has been attained² in large-scale utility systems. This combination of the Brayton and Rankine cycles has become the system of choice in recent new power plants and retrofits the benefits include high efficiency on relatively low-cost natural gas, and very good emissions performance at low-capital investment. With support from the Department of Energy's (DOE)'s Advanced Turbine Systems Program, thermal efficiencies of 60% are being targeted, while in small sizes (5 to 20 MW), combined-cycle efficiencies are over 40%.

Transforming solid fuels such as coal or biomass to gas to take advantage of such advances in combined cycles is a goal of many national programs in both the United States and the European Union.

There are basically two gasification approaches being followed: low-heating value gas production through air gasification, and medium-heating value gas production either through allothermal indirect cycles or oxygen/steam (nitrogen free) autothermal gasification. In coal gasification, both routes are being followed. Pressurized air gasification with high temperature gas filtration for particle and other contaminant removal, using specially adapted gas turbines, avoids the loss of the product gas enthalpy that low-pressure gasification routes with gas clean-up prior to pressurization to the gas turbine compressor pressure sustain. A medium-heating value gas appears to require few modifications of gas turbines. Its higher chemical energy density of 11-14 MJ/Nm³ (compared with 4-5 MJ/Nm³ for air-blown gasifiers) allows the use of low-pressure gasification followed by cleanup and pressurization without a large energy penalty. For coal, the main option for a medium-heating value gas is to use oxygen gasification with its attendant need for an air separation plant. However, for biomass, these product gas requirements can be met by rapid pyrolysis processes such as that developed by Battelle with support from DOE. This process depends on very rapid heating of the raw biomass, to minimize tar formation, and on the efficient use of the solid residue (or char) as a heat source for the pyrolysis process. This gas has been demonstrated to be interchangeable with natural gas as a gas turbine fuel, firing a small (200 kW) solar gas turbine with only minor modifications to the fuel feed system¹. Gas turbine fuel changeover is achieved simply by operation of a solenoid valve which switches the fuel supply.
from natural gas to medium heating value gas.

**The Battelle/FERCO Biomass Gasification Process**

The Battelle biomass gasification process, licensed in North America by Future Energy Resources Corporation (FERCO) in Atlanta, Georgia, produces a medium-Btu product gas without the need for an oxygen plant. The process schematic in Figure 1, shows the two reactors and their integration into the overall gasification process. This process uses two physically separate reactors: (1) a gasification reactor in which the biomass is converted into a medium-Btu gas and residual char, and (2) a combustion reactor that burns the residual char to provide heat for gasification. Heat transfer between reactors is accomplished by circulating sand between the gasifier and the combustor.

The Battelle/FERCO Process, takes advantage of the inherently high reactivity of biomass feedstocks. The reactivity of biomass is such that throughputs in excess of 14,600 kg/hr-m² can be achieved. In other biomass gasification systems, throughput is generally limited to less than 1,000 kg/hr-m². These high reactivities at relatively low temperatures have allowed the development of gasification processes that are different to those used for coal. The scale-up of the Battelle/FERCO process is taking place in Vermont and is to demonstrate these throughputs at a near commercial scale.
Technology Description and Project Objectives

The objective of the Vermont project is to achieve a significant scale-up of Battelle’s indirect gasification technology from a process development unit of 12 tonne/day throughput to a scale that would be large enough to handle commercial-size components (200 tonne/day or 45 MW). The economic analysis of the system in combined cycle at the 50B70 MW\textsubscript{e} scale showed attractive returns\textsuperscript{4}.

The Vermont gasifier project is outlined in the schematic of Figure 2, which shows Phases II and III of the development. The unit has a design capacity of 182 dry tonnes of wood per day.

The Vermont Gasification Project

![Diagram of Vermont Gasifier First Phase Co-firing, and Future Second Phase Gas Turbine Operation](image)

equivalent to a thermal input of approximately 42 MW. When the gas is fired in the McNeil boiler the net efficiency of conversion to electricity is generally about 23\%-25\%, resulting in a generation rate of 7B8 MW at a cold-gas efficiency of about 70\%. The final design of the second power-generation phase is not complete; however, one possible variant would be to generate about 8 MW in the gas turbine (open cycle) and pass the exhaust gas to the boiler air preheater, and surplus gas to the boiler as in the first power-generation phase.

The gasifier building is 34 m in height and the footprint is 10.5 m x 14.5 m, while the scrubber building is 11.5 m in height with a footprint of 10.5 m x 10.5 m. At the top of the gasifier building, there is a 6 m enclosed flare. See Figures 3a and 3b.
Figure 3a
Vermont Gasifier General Layout View From West
Figure 3b
Vermont Gasifier General Layout View From East

The gasifier is connected to the McNeil boiler via a pipe-bridge that is 90 m in length. This bridge
serves as a bi-directional data highway between the gasifier control room and the McNeil station, brings services such as water and steam to the gasifier, and carries the product gas after scrubbing and the flue gas after quenching to the McNeil boiler.

Though the scale-up in most respects follows the design of the pilot scale unit, there are three significant variations: the PDU has a circulating fluid bed (CFB) pyrolyzer and a bubbling fluidized bed combustor, while both units at McNeil are CFBs. The gas seal between the vessels in the PDU is a single AJ@阀, while at McNeil the isolation and solids circulation flow control is provided by two L-valve and dashpot arrangements. The other significant modification concerns water management and the scrubber arrangement. In the PDU, the scrubber is a once-through liquid design. Because of the site environmental constraints at McNeil, the scrubber is self-contained and consists of an atomizer quench, followed by a venturi scrubber. Water balance is obtained by evaporating the excess water into the product gas stream and then to the McNeil boiler. There are no aqueous effluents from the gasifier. Solids (char fines, elutriated bed materials and other solids, and tars) that accumulate in the scrubber circuit are pumped as a slurry to the combustor for evaporation and incineration.

In the first operational phases, the biogas is co-fired with wood fuel in the McNeil boiler, while in the second operational phase, a gas turbine will be incorporated into the system to evaluate the full performance potential in advanced cycles. The goals of the first phase are to measure the plant performance, and to identify the remaining development issues.

**Financing the Project**

The project embodies a novel approach to financing this type of engineering development. Traditionally, a technology of this type would be developed in one of two ways: either internally in a large engineering company, or in a research institute and then transferred to a large engineering company. This company would then finance the scale-up and demonstration with internal venture funds along with some level of government assistance. This pathway was followed by the Clean Coal Technology demonstrations by DOE during the past decade. However, the licensee of Battelle=s technology is FERCO, of Atlanta, Georgia=a startup technology venture. Though the company is atypical in the power industry, it is a common model in biotechnology startups in that the development is financed in stages using the marketplace to raise the money. Initially the company strategy is to seek investments by individuals and groups of private investors (known as Angels@). These private shareholders effectively start the company, and as the technology pathway develops and matures, they acquire different types of additional capitalization that lead eventually to venture capital. As the first commercial sales are made, there is an initial public offering (IPO), which takes the company public through the sale of public shares (stock).

After FERCO was formed and had acquired the rights to the Battelle license for indirect gasification technology, it approached DOE for support under the financial assistance provision of Energy Policy Act of 1992 (EPAct). This assistance is available for renewables and energy efficiency projects that will benefit the United States and its industries. FERCO proposed a project that would retain an engineering procurement and construction company to construct a
A turnkey plant that would be colocated with an operating biomass power plant situated in Burlington, Vermont, as described earlier. The startup company strategy depends on the company obtaining ever-increasing private funds for the project and its operating costs as it moves from concept to demonstration in a milieu where the final EPAct government share is 50%.

Completion of the demonstration in Vermont is the first stage of commercialization. The next step is the construction of the first commercial plant, which will take place after the IPO in FERCO=s development strategy. At that stage, there will need to be equipment performance guarantees and warranties for the technology to be commercial and bankable.

Project History and Developmental Milestones to Date

The State of Vermont initiated its long-standing interest in electricity from renewable energy and sustainable use of biomass resources when it broke ground for the construction of the McNeil Station in 1982. By the early 1990s, Vermont was a participant along with DOE and the U.S. Environmental Protection Agency (EPA) in work with the General Electric Company in Schenectady, New York, evaluating the performance of the potential for biomass gasification to realize significant performance improvements over normal combustion technology. At around the same time, Battelle and the National Renewable Energy Laboratory were evaluating the performance of the Battelle system at the pilot scale of about 12 tpd. This led to a licence agreement with FERCO for the scale-up and commercialization of the system. FERCO approached the joint owners of the McNeil plant to be the host for the scale-up demonstration project. The joint owners agreed to the project with the provisos that (1) the project was to be at no cost to the joint owners, (2) there had to be no significant impact on the operation of the McNeil Station, and (3) the joint owners have a right of first refusal to purchase the gasifier at the completion of the demonstration phase. If they choose not to execute this, they required a bond to be in place before the start of construction that would enable FERCO to remove the unit from the site.

These requirements had several consequences, two of which required technical solutions. The first consequence was the emissions. The station permits for air, water, and solids emissions could not be compromised by the gasifier operation, and because the environmental and operating permits are for the site rather than the power station island only, a very close integration of the gasifier with the boiler was dictated. The product gas in the first stage is burned in a modified burner in the McNeil boiler; the flue gas from the gasifier combustor section is directed into the economizer stage of the boiler. The boiler emissions controls of multi-clones and an electrostatic precipitator are used for the joint wood-fired stream and the gasifier/combustor streams. There is no net increase in the output of the McNeil boiler, so there is no net change in the boiler emissions (the gasifier input offsets the wood used on the grate to maintain a turbine output of 55 MW<sub>e</sub> gross). The use of a flare for the product gas under Aupset conditions is limited to less than 180 hours per year of operation.

The second consequence was sound and other nuisance values had to be considered. The plant
is very close to the center of Burlington, Vermont, and is adjacent to a large area of residential housing; thus, noise emissions are severely constrained, and the designers had to take this into account. Fortunately, climate considerations require the building to be enclosed, which minimizes the sound problem and creates three other challenges:

$ \text{Aesthetics: the building enclosure was required to meet exactly the same appearance standards as the power island including the siding.}$

$ \text{Enclosed spaces: because of the enclosed spaces, the entire building was designated as Class I, Division 2 for fire and explosion protection. This increased the cost and complexity of fittings and appliances in the building.}$

$ \text{Traffic: a community issue was that of increased traffic to and from the site (the junction at the main access is a narrow access), so as a condition of the municipality giving the building permit, traffic signals had to be installed at the main access. This traffic issue had surfaced in 1982 during the original plant development.}$

$ \text{The McNeil station must receive 75\% of its wood feedstock by rail as a consequence.}$

The overall project development schedule is shown in Figure 4. At present (August 1998), the project is completing the startup and initial stages of parametric testing to establish the mass and energy balances. Calibration of the subsystems was completed during the late Spring of 1998.

Figure 4

Project Development Schedule
Progress to Date

As with most large-scale construction projects, there are a number of equipment reliability and warranty issues that continue to need attention. However, to describe the current status of the project, it is useful to describe the operational startup procedures, and where the project is in relation to them.

Startup Procedures

The unit starts up on compressed air blowers with in-line natural gas fired heaters (the combustor has an over-bed burner in addition). Once the refractory has reached a safe temperature of about 550°C, sand circulation is initiated to bring about 16 tonnes of sand inventory to the same temperature. At this point, wood is added to the gasifier and is combusted to raise the temperature to around 830°C. This combustion phase is usually at about 12%-16% oxygen in the gasifier flue gas which is being passed to the McNeil burner. With all of the upstream wood feeders and downstream scrubber systems lined up, the wood flow is then increased to create a condition of partial oxidation operation. The gas produced is burnt in the McNeil boiler and the char that is not consumed in the gasifier is transferred to the combustor where it burns to increase the sand temperature. Full-steam gasification is initiated by turning off the gasifier=s natural gas heater and air supply, followed by turning off the natural gas firing to the combustor.

So far, very extensive experience has been obtained up to and including the partial oxidation stage with only a limited time in full-steam gasification operation. A number of equipment issues have prevented steady-state operation in the steam gasification mode. The systems that have presented the most challenges have been the fuel feed and the scrubber-evaporator.

Fuel Feeding Issues

The fuel feed problems had their origin in problems that were encountered in putting a drier on site. The initial concept was to have a natural gas fired drier to use the regular wood chips that are normally fed to the McNeil boiler. Unfortunately the permitting requirements for this drier would be very stringent and the decision was taken initially to use dry industrial wood available in the region. This material is not prepared by chipping, but consists of urban wood waste and pallets that are size reduced in a tub grinder. The resulting feedstock has an entirely different granulometry especially with respect to astringiness which resulted in wood fuel-flow difficulties in the lock-hopper and feed system. This has been resolved by taking McNeil wood chips (the design fuel) offsite to a commercial fuel-drying operation, and bringing them back to the site at the correct moisture content of 25% (+/- 5%).

Scrubber-Evaporator

The design basis for this circuit was for it to handle a mainly tar and light-ash burden. The
venturi scrubber is taking out a much larger amount of attrited bed material than was expected. This material does not behave at all like a sludge in the circuit, rather it is a silt that forms a dense phase occupying a smaller volume of the scrubber tank than expected. The pumping system has been revised by replacing the diaphragm pumps with traveling cavity pumps that can handle the much denser silt phase. The management of this circuit under gasification conditions with tar production also represents a different mode than originally anticipated, as there is significant foam production in the early runs that have been made.

**Results to Date**

So far mainly qualitative data has been obtained on the system performance. For example, under steam assisted partial oxidation conditions, the gas composition was pretty much as expected with values of CO-30%, H₂-4.1%, CH₄-4.4%, C₂H₄-1.18%, and C₂H₆-0.34%. The heating value was 6.71 MJ/Nm³. Temperature increases in the combustor confirmed that char was being transferred to that vessel. Figure 5 shows the burner in the McNeil boiler before and during combustion of the product gas. The gas supply rate was between 15 and 20 MW, and typically the gasifier is producing around 8 MWh of electricity in the McNeil station during the short trials so far undertaken.

![Figure 5](image)

Photographs of the flame at the McNeil product burner. The left hand picture is in the early stages of partial oxidation and shows the natural gas pilot. The right hand picture shows the flame at about 20 MW, gasifier product gas input.

**Parametric Testing and the Third Phase of the Vermont Gasifier Program**
During the parametric testing that will take place from September through mid-October of 1998, the goals are to measure the performance baseline with the specification fuel with respect to particle size and moisture content. This will establish throughput data and verify the mass and energy balance design data. This will be followed by measurements of the operational limits with respect to moisture content and particle size, mapping of the turn-up and turn-down ratios, and determination of the dynamic response to transient events. During the third phase, the goals will include long duration testing to establish the critical systems requirements for reliability, as well as testing fuels other than the dry McNeil feedstock. The feedstocks will include willow from the New York Salix project and switchgrass from one of the Mid-West integrated projects. Other fuels of interest include the clean fraction of urban wood wastes, mixed residues from the pulp and paper sector, and chicken litter from intensive poultry operations.

While the long duration testing is underway at Burlington, design and engineering for the addition of a catalytic cracker to minimize tar cleanup issues in the scrubber will be undertaken. The addition of a gas turbine is anticipated in late 1999 and early 2000 for long term trials.  

End Notes

[A] The McNeil generating station is owned by the Burlington Electric Department (BED), Central Vermont Public Service Corporation (FVPS), Green Mountain Power Corporation (GMP), and the Vermont Public Power Supply Authority (VPPSA), collectively known as the joint owners.

[B] Of course, the permit for the McNeil station did have to be modified to recognize the addition of the gasifier to the site. The Air Pollution Control Permit to Construct and Operate and Phase II Acid Rain Permit amendment, which does not increase the allowed levels of emissions and was finally issued in October 1997.


References


