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STATUS OF EXISTING BIOMASS GASIFICATION AND PYROLYSIS FACILITIES IN NORTH AMERICA

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ABSTRACT

A search of websites for firms in the United States and Canada identifying themselves as gasification or pyrolysis system suppliers indicates that there are a number of existing facilities where their technologies are installed. According to the websites, the companies' existing installations focus on processing biomass and industrial residuals, rather than mixed refuse. The biomass processed, according to the websites includes yard waste, wood, and wastewater treatment sludge. The existence of these facilities provides a potential opportunity for communities in areas with a high density of development, who experience difficulties in siting "traditional" facilities for processing these biomass wastes. Such traditional facilities include yard waste and sludge composting, wood mulching, sludge drying, chemical treatment or pelletization, and combustion-based waste-to-energy. As a result of these facility siting difficulties, these communities often resort to long-haul trucking of the biomass wastes to processing facilities or landfills. Certain potential advantages associated with gasification and pyrolysis technologies could ease the siting difficulties associated with the traditional technologies, due to smaller facility footprints, reduced odors, and the potential for energy production through combustion of syngas/synfuel to power internal combustion engines or produce steam using boilers. Lower stack emissions may result as compared to direct combustion of biomass wastes. Locally sited biomass gasification facilities could reduce the environmental impacts associated with long-haul trucking and generate an energy product to meet nearby demand.

Research has been conducted by the Author on behalf of client communities to identify gasification and pyrolysis facilities in the United States and Canada that are in actual operation in order to assess their potential for processing biomass wastes and for providing the advantages listed above. Website reviews, interviews with company representatives, and facility visits were conducted in order to assess their potential for development to meet the biomass management objectives of the communities. The information sought regarding design and operating parameters included the following:

- Year of start-up.
- Availability.
- Process description.
- Design throughput.
- Actual throughput.
- Energy product.
- Energy generation capability and technology.
- Residuals production and characteristics.
- Emissions.
- Construction and operating costs.

In addition, the system suppliers' business status was addressed in terms of their readiness and capabilities to participate in the development of new facilities.

Confidentiality requirements imposed by the system suppliers may prevent the identification of the company name or facility location and certain details regarding the system designs.

INTRODUCTION

Much of the recent years' attention regarding the potential development of gasification or pyrolysis facilities for municipal solid waste ("MSW") has focused on utilizing technologies which have been commercialized in Europe and Japan. However, several firms in the United States and Canada have developed and commercialized systems that are operating at numerous locations. Some have extensive operating histories. These existing facilities are generally relatively small scale and typically process biomass (forestry, lumber mill, or crop wastes). The operators report experience processing a wide variety of biomass, including yard wastes and sludge. One relatively new facility processes sewage sludge [1]. Research was conducted by the author in order to determine if these systems could be developed to process yard wastes, wood, or sewage sludge generated in communities where the scarcity of sites, regulatory hurdles, and local opposition have prevented or made it politically perilous to develop facilities employing other processing technologies, such as yard waste/wood composting or mulching; sludge drying, chemical treatment, pelletization, or combustion. Such difficulties sometimes force local governments to resort to long haul of these biomass wastes to processing or disposal facilities, with the attendant considerable expense and emissions from trucking.

The preferred development scenario for a biomass gasification or pyrolysis facility to serve these communities is as follows:

1. Flexibility to process each of the biomass wastes generated on a seasonal and non-seasonal basis over the course of the year, with their varying fuel characteristics. Leaves, grass clippings, brush, and wood waste are generated seasonally, while sewage sludge is generated on a relatively stable basis throughout the year. These biomass wastes exhibit a range of fuel characteristics that a processing system must be capable of handling.

2. A facility footprint that would enable development at existing biomass waste transfer stations. Existing sites where the biomass wastes are currently delivered and loaded into trailers for transport have gained a certain level of acceptance. Their use for a thermal conversion facility would avoid the need to select new sites with sufficient acreage to support a composting or treatment process facility.

3. Low profile building envelope. Avoidance of a significant visual impact would mitigate local opposition.

4. Convert syngas to mechanical or electrical energy via direct firing in internal combustion engines or combustion turbines. Direct firing would avoid the need for intermediate steam generation as required for steam driven turbine-generators. There is also familiarity and acceptance of direct firing of landfill gas at local landfill sites.

5. Favorable reception by regulatory agencies. Regulatory agencies have been reluctant to support combustion. Their attitude toward gasification or pyrolysis is uncertain. Gaining regulatory support for gasification or pyrolysis would be partially dependent upon the ability to demonstrate the ability to meet existing emissions standards and to attain the very low dioxin and furan emissions claimed for these systems. Although, such demonstration would not guarantee regulatory support.

6. Cost competitive with current management strategies. Absent a legal mandate, cash-strapped municipalities must realize a savings from the project in order to support it.

GASIFICATION SYSTEM DESIGNS

This section provides a brief review of gasification system design alternatives and issues. It does not extensively address pyrolysis systems, since they are in a minority with regard to commercially available systems. Refer to Figure 1 for an illustration of the gasification system components.

Biomass Preprocessing, Storage, Drying, and Feeding

Preprocessing and Storage

The requirements for systems handling segregated biomass will be influenced by the characteristics of the particular waste material. The systems reviewed often employ size reduction to attain consistent material and fuel characteristics, and the use of familiar solid waste management equipment for storage and feeding. Since these are processing segregated biomass, the elaborate systems associated with refuse derived fuel systems are not used.

Drying

Gasification and pyrolysis systems are differentiated from combustion systems by the need for some systems to conduct biomass drying *prior* to feeding it into the gasifier, and the need to control the introduction of air during the feeding process in order to maintain substoichiometric conditions. Specific requirements vary among commercially available pyrolysis and gasification systems. In combustion systems, the first section of the stoker is utilized for drying and the heated water vapor combines with flue gas, allowing some of the heat from the vapor to be recaptured in the boiler. As further addressed below, certain gasifiers utilize stokers, and thus have the capability for fuel drying during the gasification process. However, others which do not employ a stoker, may not provide adequate residence time in the gasification reactor for drying to occur. Excessive moisture in the biomass may also prevent or inhibit the desired thermal reactions. The presence of moisture in the biomass would reduce the reactor operating temperature, creating the potential for increasing the methane and reducing the hydrogen content of the syngas. The methane, in combination with the water vapor that would be present in the syngas could also interfere with the downstream operations. The gasification and pyrolysis systems reviewed by the author utilize a variety of drying methods, including fluidized bed and rotary mechanisms, direct exposure to flue gas, or a thermal fluid [2]. In order to avoid losing the energy used to drive off the water vapor, heat recapture would be necessary. It is not apparent from the review of these systems that this is commonly practiced, which is probably due to the added expense.

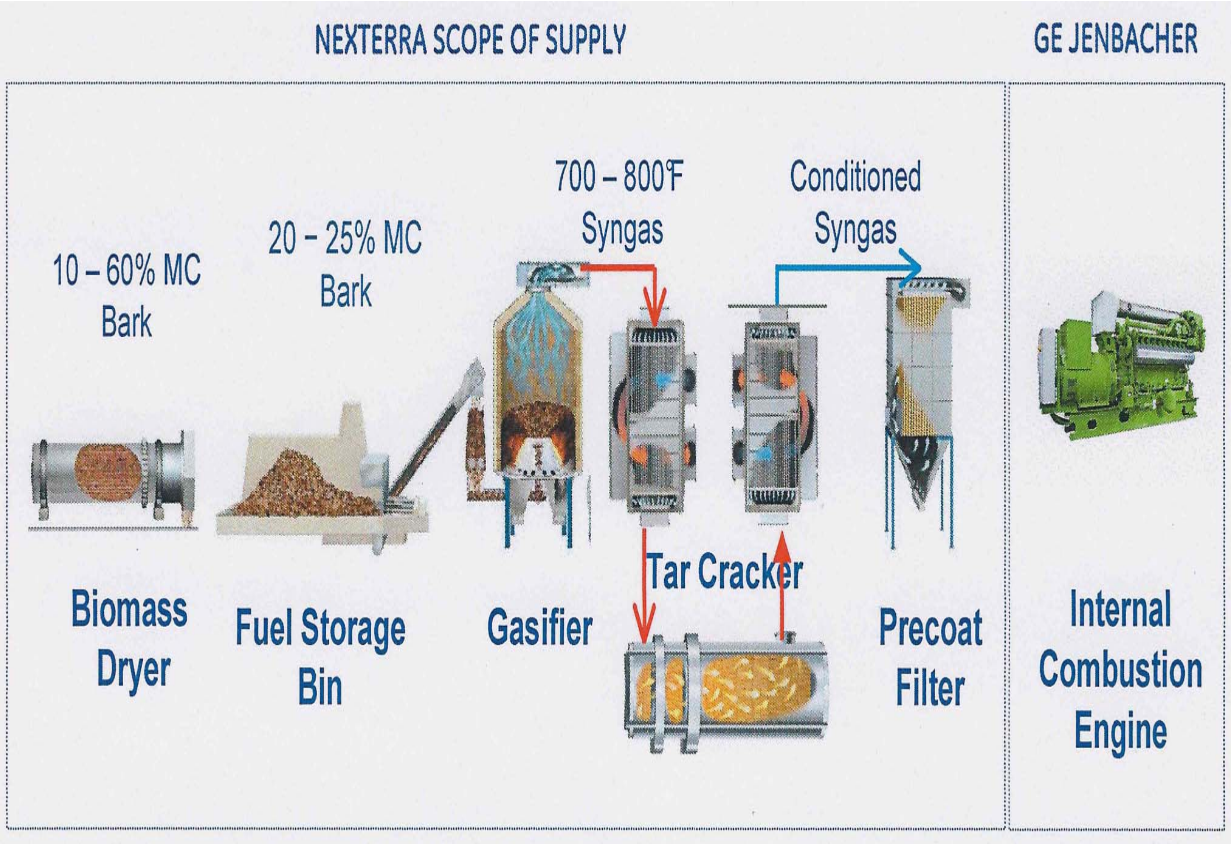


Figure 1 – Illustration of Gasification System Components (Nexterra website)

Feeding

In order to maintain the oxygen free or substoichiometric conditions necessary for pyrolysis or gasification, respectively, the air introduced during the biomass feeding process must be controlled. The companies do not generally describe how they accomplish this. A fluidized bed wood chip gasifier that operated until 2001 used nitrogen to purge the feed hopper each time wood was fed to the unit, and to purge the system prior to restart following outages. This necessitated the installation of a storage tank in order to maintain the continual supply to the gasifier during operations [3].

Gasification

Fixed bed – updraft, fixed bed – downdraft, and fluidized bed gasifiers are the three (3) primary varieties of gasification technologies. Advantages and disadvantages vary among the different designs. A description of each will help to understand the differences of these types and the inherent uses of each design [4].

Updraft Gasifier

Also referred to as a counter-current, fixed bed gasifier, an updraft gasifier's flow of gas is upward, as the name suggests. Starting from the bottom and working upward, a fixed bed of carbonaceous material reacts with the gasification agent (air, oxygen, steam, or hydrogen), which flows through the grate at the bottom of the gasifier. As it ascends, the resulting gas will pyrolyze the fed biomass. Fuel must be "non-caking" so that the bed stays permeable. Tar and methane build up is significant, in comparison with downdraft and fluidized bed designs, considering the relatively low operation temperature of this design. Due to this fact, extensive cleaning of gas is required before it is useable in other than close-coupled operation.

Downdraft Gasifier

Also referred to as a co-current fixed bed gasifier, in a downdraft system, the gasification agent (air, steam, or oxygen) is fed downward in the same direction as the fuel. Relatively high temperatures in this design help reduce tars as the evolving syngas passes through the hot bed. Differences between updraft and downdraft designs result from the direction in which the process takes place, and the effects the operational flow has on the reactions taking place during gasification.

Fluidized Bed Gasifier

In a fluidized bed gasifier, the gasification agent rises through the grate with substantial velocity where it fluidizes a heat transfer medium (sand or limestone) that meets and gasifies small particles of the fuel, and, in result, a type of "fluidized bed" is formed. This type of gasifier is most useful for fuels, such as biomass, that normally would form corrosive ash, which would damage the walls of a slagging gasifier. Since the forceful air pushes around the particles of fuel, corrosive ash may not be a problem for this design. Bubbling fluidized bed and circulating fluidized bed are variations of this design. Issues to be addressed in the design include the quality and replenishment of the heat transfer medium and erosion of the reactors due to the abrasive nature of the heat transfer medium. The circulating fluidized bed wood chip gasifier previously mentioned required sand with non-agglomeration additives. Due to the loss of the sand at the rate of approximately one (1) pound per hour, a constant supply of the treated sand was necessary [6].

Updraft and downdraft designs are less complex than fluidized bed; but generate lower energy value syngas. Fluidized bed systems are more complex and produce greater particulate. However, fluidized beds produce higher fuel value syngas and accept a wider range of biomass feedstocks [7]. In selecting a gasifer design, the advantages and disadvantages of each must be weighed with regard to the objectives of the project in terms of feedstock, energy product, cost constraints, and emissions.

A number of the commercially available updraft and downdraft units operate in a manner highly similar to the "controlled air, modular combustion units" that are familiar to the waste-to-energy industry. However, the gasification industry calls them "close-coupled gasification" [5]. These systems appear to have been developed in the lumber and food processing industries for recovery of energy from their residuals. The similarities include the use of moving stokers, gasification of the waste under substoichiometric conditions in a primary chamber, and immediate oxidation of the syngas in a secondary chamber via the introduction of air. The resulting flue gas is used to produce steam in either fire-tube or water-tube heat recovery steam generators. In discussions, gasification system representatives have indicated that this approach is dictated in part by the difficulties encountered thus far in attempting to remove impurities from the syngas as necessary for direct firing. Efforts by the vendors to market these gasifiers for managing biomass wastes from municipal sources and the desire to adapt them to direct firing of their syngas in IC engines, is hampered by their high tar production rates, as well as other contaminants in the syngas.

Syngas Conversion to Energy

In close-coupled gasifiers, syngas undergoes immediate oxidation in response to the introduction of air into the secondary chamber. The resultant flue gas is used to produce steam in either fire tube or water tube boilers. Fire tube boilers are used for lower capacity gasification units marketed to institutions (schools and hospitals) where minimizing purchase costs and unit size are key. The waste-to-energy industry has experience with fire tube boilers in controlled air modular combustion facilities. These boilers are subject to frequent fouling when exposed to the flue gas associated with waste firing. The steam produced by the existing biomass gasifiers is used to produce power via turbine-generators, or is used for heating or process applications. One (1) vendor offers steam driven piston engines for power production. However, no applications of this system in the United States or Canada are cited [8].

The direct firing of syngas from a biomass gasifier in an IC engine is rare. No examples of commercial facilities in the United States or Canada operating in this mode have been identified. One (1) firm cites a facility in Moissannes, France that fires syngas in a Caterpillar engine [9]. Another firm states that it is developing this capability and predicts near term availability for commercial applications [10]. A biomass pyrolysis system has tested firing syn-oil in a gas turbine [11].

Safety

The direct firing of syngas may pose safety hazards since syngas is hot, combustible, and poisonous gas. Air leaking into the system or syngas leaking out, downstream of the gasifer, could cause unintended oxidation resulting in explosions or fires. In addition, syngas leaking out could cause CO poisoning.

Syngas Cleaning

The syngas produced by biomass gasification can contain one (1) or more of the contaminants listed in Exhibit 1 [12]. The identity and amount of these contaminants depend on the gasification process and the type of biomass feedstock. Syngas cleaning is generally not needed for immediate oxidation or co-firing in boilers. However, cleaning is essential for direct firing in IC engines or gas turbines. Efforts by vendors and research organizations to identify cleaning technologies and reliable system designs for contaminant removal are ongoing [13]. Tars are composed of polynuclear hydrocarbons that can clog engine valves, cause deposition on turbine blades, or fouling of a turbine system. Wet scrubbing systems have been utilized for removal of tar, chlorides, ammonia, and alkaline compounds. However, scrubbing cools the gas and produces a wastewater stream. Removal of tars by catalytically cracking the larger hydrocarbons could reduce or eliminate the wastewater, avoid the loss of thermal energy due to scrubbing, and enhance gas quality and quantity. Incompletely converted biomass and ash particulate removal may be accomplished with cyclones, wet scrubbing, or high temperature filters. A cyclone can provide primary particulate control, but is not adequate to meet gas turbine specifications. A high temperature ceramic filter can avoid thermal energy losses associated with gas cooling and remove particulates [14].

Control of Stack Emissions

The pollutants contained in the stack emissions from gasification and pyrolysis systems are the same as those in combustion systems. The measured levels of emissions are influenced by the thermal conversion technology employed and the nature of the waste being processed. A 2009 report by the University of California at Riverside compiled emissions data from fifteen (15) gasification and pyrolysis facilities [15]. The data was obtained from independent source test reports, compliance reports from regulatory agencies, and peer-reviewed publications. It includes air emissions data for several pollutants from facilities employing a variety of gasification and pyrolysis technologies, and various synfuel utilization approaches. Twelve (12) of the facilities process municipal waste, two (2) process medical waste, one (1) processes circuit boards, and one (1) processes a combination of industrial and municipal waste. Eleven (11) of the sixteen (16) facilities are not in North America. The technologies include fluidized bed, fixed bed, plasma arc, high temperature gasification, and pyrolysis plus gasification. The synfuel utilization approaches include close-coupled combustion, IC engines, and gas turbines. The emissions ranges reported are summarized in Exhibit 2. Also included for comparison are emissions reported from mass burn and controlled air waste-to-energy facilities, all processing municipal waste [16, 17, 18, 19, and 20]. Given the variation in fuel-feedstocks being processed, conclusions regarding comparative emissions would be premature. However, it appears that the emissions from the gasification/pyrolysis, mass burn, and controlled air systems lie within the same ranges, with the exception of low end nitrogen oxides, mercury, and dioxin/furans from gasification/pyrolysis, which are one (1) or more orders of magnitude less than mass burn and controlled air. A closer look at the gasification/pyrolysis emissions seems to indicate that the fluidized bed and plasma arc gasification and pyrolysis systems achieve the very low dioxin/furan emissions, whereas the close-coupled gasification systems emissions lie within the same range as mass burn and controlled air combustion. The lowest dioxin/furan emissions reported are associated with a plasma gasification facility that processed circuit boards.

Due to the variety of gasification technologies, the varying waste types processed, and the relative newness of the technology, there is no industry-standard air pollution control strategy or technology. The air pollution control devices employed by gasification and pyrolysis vendors in existing facilities vary and include electrostatic precipitators and scrubbers alone and in combination, including selective non-catalytic nitrogen oxide control, scrubbers, and baghouses. The control strategy utilized in a proposed project will be dependent upon the wastes to be processed, the thermal processing and energy recovery system, and its projected emissions and requirements imposed by regulators.

Slag and Ash Handling

The slag and ash handling approaches used by various gasification system vendors are dependent upon the reactor design and their objectives regarding the recovery of byproducts. Fixed bed systems generally operate like a combustion facility and capture the slag/ash in solid form. Fluidized bed systems may employ a melting process, wherein liquid slag and ash may be tapped from the bottom of the reactor. Circulating fluidized bed systems must also incorporate a process for separating ash from the heat transfer agent that escapes the reaction chamber. Systems employing plasma arc technology often use the torches to melt the slag and ash. It is expected that these systems, like those in combustion systems, are problematic and require a large amount of ongoing attention from the operator.

Exhibit 1

SYNGAS CONTAMINANTS

Contaminant	Example	Potential Problem
Particles	Ash, char, fluid bed material	Erosion
Alkali Metals	Sodium and Potassium Compounds	Hot corrosion, catalyst poisoning
Nitrogen Compounds	NH_3 and HCN	Emissions
Tars	Refractive aromatics	Clogging of filters
Sulfur, Chlorine	H_2S and HC1	Corrosion, emissions, catalyst poisoning

Exhibit 2

COMPARISON OF EMISSIONS RANGES FROM GASIFICATION/PYROLYSIS, MASS BURN, AND CONTROLLED AIR SYSTEMS

(all units in mg/dscm@7% O_2, except as noted)

Pollutant	Gasification/ Pyrolysis	Mass Burn	Controlled Air
Particulate	<1.0 - 18.2	0.73 - 9.84	4.93 - 20.13
Hydrogen Chloride	<2.8 - 55.8	3.2 - 15.8	30.3 - 38.7
Nitrogen Oxide	10 - 254	172 - 180	200 - 206
Sulfur Dioxide	0.44 – 51.9	1.0 - 16.0	NR
Mercury	0.0001 - <0.007	0.001 - 0.007	0.0052 - 0.014
Dioxin/Furan (ng/dscm)	0.000013-0.098	0.01 - 0.04	0.072 - 0.11

The biomass gasification industry does not focus on the quantity of slag/ash generated by their systems as a percent of biomass input, or the pollutants contained therein. This probably owes to the fact that their focus is in converting harvested biomass to fuel, rather than on destroying harmful waste and minimizing the volume to be disposed. Additionally, the slag from gasification of pure biomass will be high in carbon and low in impurities, making it useful as a soil additive.

SURVEY OF EXISTING BIOMASS GASIFICATION SYSTEMS

A list of companies with operating biomass gasification and pyrolysis systems in the United States or Canada, their existing facilities, and pertinent characteristics, identified as of January 2010, is provided on Exhibit 3. The list is not complete in that there are numerous pilot scale and demonstration facilities in existence. In addition, companies offering these technologies that do not have facilities processing biomass in the United States or Canada are not listed. Facilities processing mixed refuse are also not listed. However, the Exhibit provides a sense of the large number of firms active, as is characteristic of a start-up industry. Information is presented below regarding four (4) firms that have developed biomass gasification and pyrolysis facilities, as gathered from company websites and obtained during the course of the author's project assignments for clients. Exhibit 4 summarizes the primary design characteristics and existing installations for these firms.

Ensyn

Process – Ensyn, is a United States company that has developed a fast pyrolysis technology based upon a transported bed reactor that utilizes biomass to produce a liquid pyrolysis oil [21]. The system (Figure 2) is called the Rapid Thermal Process or RTP. RTP pyrolysis technology is claimed to convert biomass to liquid in under two (2) seconds. Hot sand is used as a heat transfer medium for the feedstock fed into the reactor, wherein it is heated to 500 degrees Celsius. The company describes it as a "tornado of hot sand." After the vessel reaches the desired temperature, it is cooled within seconds. This process results in bio-oil, and the process has a yield of approximately sixty (60) to eighty (80) percent, by weight, depending upon the biomass feedstock. Along with bio-oil, by-product char and non-condensable gas are produced during the process. Both can be used to provide process energy. Biomass must be pre-dried to five (5) – six (6) percent moisture and a particle size of 0.125 – 0.25 inches. This energy can be used in the RTP process or in pre-stages of the process through use in a dryer which prepares bio-mass for the RTP process. The company's pyrolysis oil meets ASTM standards for biofuels used in industrial burners. The company does not provide details on the mode in which its pyrolysis oil is fired. However, the information provided indicates that it has experience in firing in industrial boilers, and development of gas turbine power generation is underway. In 2008, Ensyn teamed with UOP, a subsidiary of Honeywell, Inc. to form Envergent Technologies, LLC. Envergent will further develop and market the technology.

Existing Facilities – Ensyn claims that its RTP technology is the only pyrolysis technology to be proven through long-term commercial operation. Ensyn currently claims eight (8) commercial RTP plants in the United States and Canada; and have achieved over ninety (90) percent availability. The largest of these resides in Renfrew, Ontario. This plant's capacity is 100 tons of dry residual wood per day. The company has plans to scale-up the system's processing capacity in future projects.

Scope of Supply – Envergent offers to undertake a twenty (20) to twenty-seven (27) month project development process, leading to initiation of construction. Details regarding the schedule for construction and testing are not provided. Ensyn states it designed, built, and commissioned all eight (8) commercial RTP plants.

Nexterra

Feedstock – Current systems operate on wood fuel; however, future systems are being developed that will be capable of operating on coal and other low cost fuels [22].

Gasification Process – Nexterra utilizes a fixed-bed, updraft gasifier (Figure 3). Feedstock must be shredded to three (3) square inches or less and then fed into the center of the dome-shaped refractory lined gasifier. The system's fixed bed design allows it to gasify feedstocks at six (6) to sixty (60) percent moisture. Partial oxidation, pyrolysis, and gasification occur after combustion air, steam, and/or oxygen are introduced into the gasifier. The gasifier heats to 1,500 – 1,800 degrees Fahrenheit and the feedstock is converted to syngas, along with some non-combustible ash. An in-floor ash grate removes the ash from the bottom of the gasifier. The syngas is then processed according to the customer's needs in order to produce energy. According to information provided by company representatives, and in a recent submission to a county agency, Nexterra's product development effort is aiming toward progressively higher value applications for its system, including direct firing in IC engines and gas turbines and production of synthesis fuels and chemicals. At the present time, the system is operated in a close-coupled mode.

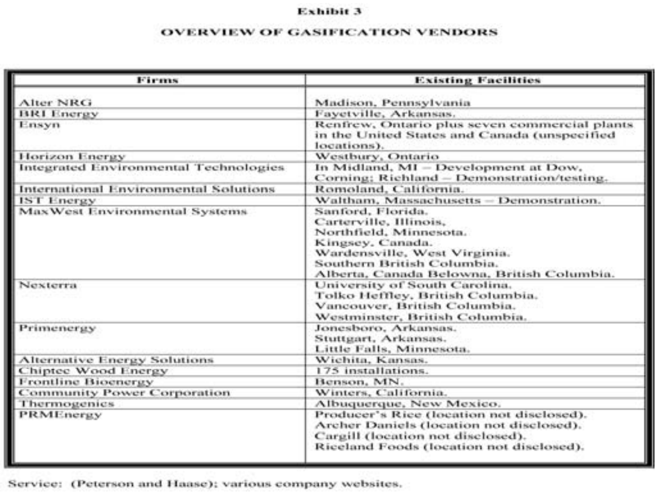


Exhibit 3

OVERVIEW OF GASIFICATION VENDORS

Firms	Existing Facilities
Alter NRG	Madison, Pennsylvania
BRI Energy	Fayetville, Arkansas.
Ensyn	Renfrew, Ontario plus seven commercial plants in the United States and Canada (unspecified locations).
Horizon Energy	Westbury, Ontario
Integrated Environmental Technologies	In Midland, MI – Development at Dow, Corning; Richland – Demonstration/testing.
International Environmental Solutions	Romoland, California.
IST Energy	Waltham, Massachusetts – Demonstration.
MaxWest Environmental Systems	Sanford, Florida. Carterville, Illinois, Northfield, Minnesota. Kingsey, Canada. Wardensville, West Virginia. Southern British Columbia. Alberta, Canada Belowna, British Columbia.
Nexterra	University of South Carolina. Tolko Heffley, British Columbia. Vancouver, British Columbia. Westminster, British Columbia.
Primenergy	Jonesboro, Arkansas. Stuttgart, Arkansas. Little Falls, Minnesota.
Alternative Energy Solutions	Wichita, Kansas.
Chiptec Wood Energy	175 installations.
Frontline Bioenergy	Benson, MN.
Community Power Corporation	Winters, California.
Thermogenics	Albuquerque, New Mexico.
PRMEnergy	Producer's Rice (location not disclosed). Archer Daniels (location not disclosed). Cargill (location not disclosed). Riceland Foods (location not disclosed).

Service: (Peterson and Haase); various company websites.

Exhibit 4

EXISTING GASIFICATION INSTALLATIONS FOR FOUR VENDORS

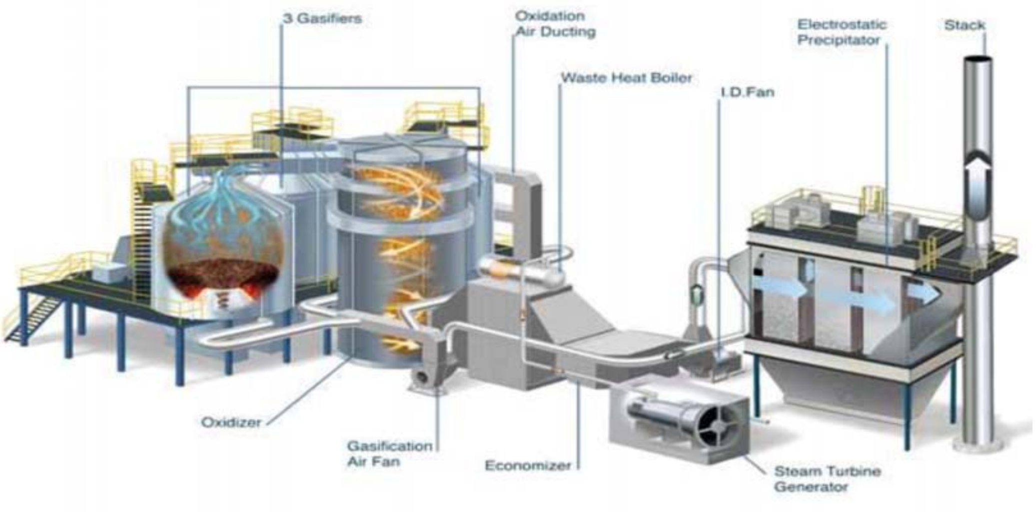
Firms	Technology	Commercial Facility Locations	Biomass Experience	Start-Up Date	Syngas Conversion To Energy
Ensyn	P	Renfrew, Ontario.	Residual wood from Ottawa Valley forestry industries converted to bio-oil.	2007	Fuel oil replacement
Nexterra	FBUD	Columbia, South Carolina – University of South Carolina.	Wood chips/residue.	Q4 2007	CC/B
			Wood residue.	May 2009	CC/B
		Victoria, British Columbia.	Wood residue. Local mills.		CC/B
		New Westminister, British Columbia.	Clean construction debris.		CC/B
		Prince George, British Columbia.	Wood residue.		CC/B
		Heffley Creek near Kamloops, British Columbia.			
MasWest	FBDD	Sanford, Florida.	Dried biosolids (sludge).	7 months	Thermal energy via a hot oil system.
		Kingsey Canada.	Paper biosolids.		
		Wardensville, West Virginia.	Chicken litter.		Chicken coop Heating.
		Southern British Columbia.	Cow manure.		CC/B.
		Kelowna, British Columbia.	Waste wood.		CC/B.
		Carterville, Illinois.	Multiple feedstocks.		CC/B.
PRM Energy	FBUD	Northfield, Minnesota.	Turkey litter.		Hot oil passed through turbine.
		Stuttgart, Arkansas – Four Installations.	Rice hulls.	1982 – 1996	CC/B.
		Tulsa, Oklahoma	All biomass fuel types.	1996.	CC/B and DF.
		Archer Daniels – Midland.	Cotton gin waste.	1985.	CC/B.
		Greenville, Mississippi.	Rice husks.	1995.	CC/B.
		Joneboro, Arkansas.	Rice husks and straw.	1996.	CC/B.
		Little Falls, Minnesota.	Wood.	2006.	CC/B.

Notes:

Technology:

P – Pyrolysis
FBDD – Fixed Bed Downdraft
FBUD – Fixed Bed Updraft
CC – Close-Coupled
FB – Fluidized Bed

Figure 2 – Ensyn Pyrolysis System (Ensyn Website)



Nexterra Biomass Gasification System at Johnson Controls' University of South Carolina Cogeneration Project.

Figure 3 – Nexterra Biomass Gasification System at Johnson Controls' University of South Carolina Cogenation Project (Nexterra Website)

Existing Facilities – The company has five (5) operating facilities, a product development and test plant facility is located in Kamloops, BC; an installation at Tolko Industries in Kamloops, BC; and commercial facilities at the University of South Carolina; Kruger Paper, Westminster, BC; and Dockside Green in Vancouver, BC. The company has contracts or has been selected to construct additional facilities at the Oakridge National Laboratory, Tennessee, the University of Northern British Columbia, and Stamford, Connecticut. Dockside Green is a residential and commercial development in downtown Vancouver.

MaxWest

According to the company, the MaxWest system has been demonstrated to process biosolids and agricultural wastes, including manures and solid wastes [23]. The system is composed of five (5) components (Figure 4).

Waste Handling System – The waste handling system is designed to deliver waste to the gasifier at the correct moisture level. Typically, waste is delivered to the gasifier at fifty (50) percent moisture or lower.

Drying System – If the waste is not below fifty (50) percent moisture level, the drying system will dry it or combine it with other dryer waste to reach the desired moisture level.

Gasifier – The gasifier is a fixed bed, downdraft design (Coaltec website). Gasification units can be purchased in one (1), two (2), or three (3) cell models. These models can handle up to thirty (30) mmBtu/Hour. Feedstocks with particle size up to 1.5 cm (six (6) in) can be processed. Gasification takes place in a refractory lined, primary gasification chamber. Company representatives describe the output as a hot fuel gas and not a syngas. The fuel gas is combusted in a close-coupled, oxidation/ temperature control chamber, called the thermal oxidizer.

Thermal Oxidizer – The thermal oxidizer receives fuel gas from the gasifier and through the introduction of air, converts it into useable energy.

Energy Recovery and Power Generation System – The flue gas is utilized to create steam which can be used for heating or process application or directed through a turbine generator to produce electricity. The company is associated with Coaltec, Inc. Coaltec, Inc. operates the Carterville, Illinois test facility. Both companies have indicated that they do not intend to develop the capability to clean the fuel gas for direct firing applications.

Existing Facilities – The MaxWest technology is based upon a system developed by Westwood Fibre in Kamloops, British Columbia. The company presently has operating facilities in Sanford, Florida; Wardensville, West Virginia; southern British Columbia; and Carterville, Illinois. Facilities under construction include Northfield, Minnesota; Kingsey, Quebec; Alberta; and Kelowna, British Columbia. The Sanford, Florida facility uses the thermal energy in a hot oil system in order to dry Sanford's wastewater treatment plant sludge. Its operating size is seven (7) mmBtu/Hour and its feedstock is dried biosolids.

PRM

The PRM gasifier is a fixed bed, updraft design [24] (Figure 5). It was originally developed to process hulls produced in rice processing. The company has several operating facilities throughout the world gasifying rice hulls. They report to have also processed tree waste, saw dust and wood chip fines, biosolids, and refuse derived fuel. They have nine (9) operating facilities in the United States, with the earliest dating to 1982. The facilities primarily operate in the close-coupled mode. However, the company states that it can offer the following configurations and applications:

1. PRME Waste Gasification Fired IC Engine/Generator Systems – The combustible syngas produced from the waste is conditioned and cooled for firing IC Engines. For this application, the waste feed stock to be gasified must contain a minimum calorific value of 14.3MJ/kg (6,160 btu/lb) at a maximum moisture content of twenty (20) percent and maximum particle size of 8mm (0.3 in), delivered to the PRME Gasifier. This application is incorporated into a test/demo facility in Moissannes, France, owned by ENERIA, the Caterpillar distributor for France, Poland, Romania, Algeria, and Belgium. The application is fully supported by Caterpillar USA.

2. PRME Waste Gasification Steam Cycle Systems – The combustible syngas produced from the waste is fully combusted and fired directly into a Heat Recovery Steam Generator ("HRSG") to raise steam for a steam turbine/generator or for process steam. For this application, the waste feed stock must contain a minimum calorific value of 11.0MJ/kg (4,739 btu/lb) at a maximum moisture content of forty (40) percent and maximum particle size of 8mm, delivered to the PRME Gasifier. This application is incorporated into PRME facilities in the United States and Asia.

Figure 4 – MaxWest System
(MaxWest Website)

Figure 5 – PRM Energy System
(PRM Website)

3. PRME Waste Gasification Direct Firing Systems – The combustible syngas produced from the waste is fully combusted and fired directly into a dryer, kiln, furnace, thermal oxidizer, or into a heat exchanger to reduce the temperature of the products of combustion for drying/thermal applications. Feed stock requirements are the same as item #2 above. This application is incorporated into PRME facilities in the United States, Asia, Latin America, and United Kingdom.

4. PRME Waste Gasification for Co-Firing Utility Boilers – The combustible syngas produced from the waste is co-fired into a large pulverized coal fired utility boiler. See Co-Fire flyer. The PRME Co-Firing Technology is almost the same as firing an industrial boiler.

5. PRME Waste Gasification for conversion to liquid fuels – The combustible syngas produced from the waste is conditioned and cooled for processing into liquid fuels.

System Construction and Operations Costs

The estimation of construction and operation costs for biomass gasification and pyrolysis systems encounters difficulties in several respects, as described below.

- Many of the existing projects are privately owned by processing industries, who are reluctant to publicize their operating costs due to concerns regarding sharing information with their competition.

- Reports containing cost information do not specify the scope of the projects covered.

- Costs may be provided as dollars per million BTU output by the system, rather than daily tons of biomass processed. It is typically not specified whether system output is rated capacity or actual operations.

- Some cost quotations available to the author have been provided on a confidential basis.

Therefore, cost estimates for existing projects as presented below must be viewed as “ballpark” values providing a general idea of the cost of these systems.

Construction costs are presented in Exhibit 5 for three (3) gasification facilities. The three (3) are all-in capital costs, in that they are obtained from facilities that are operating or did operate. They include the wood chip gasification facility at the University of South Carolina, using the Nexterra system; a wood chip gasification facility at Middlebury College, Vermont, using the Chiptec system; and a circulating fluidized bed gasifier in Burlington, Vermont, using the FERCO system, that has ceased operations. The University of South Carolina and Middlebury College [25] applications supply steam and power to the campuses. The Burlington, Vermont system was co-located at a wood fired combustion power plant. The Exhibit provides the capital costs, the date of construction, and the cost per daily ton of biomass (wood) throughput. The throughput estimates assume 365 day per year operations. Since the colleges may operate under reduced load in the summer, this may understate the throughputs during peak operating periods and thus overstate the cost per daily ton of capacity.

Project Development and Operations Capabilities of the Vendors

The project development and operations capabilities of system vendors is determined by their organizational, financial, and management competence, in addition to the soundness of their technology. As indicated in Exhibit 3 above, there are many firms offering biomass gasification and pyrolysis systems at this time. Several of the firms have been active in offering proposals to the public sector. One (1) project, in Sanford, Florida, has been constructed for the public sector. As proposed, public sector projects advance, the heightened scrutiny of their proposals by engineers, attorneys, regulators, financial underwriters, and the public during the proposal review, contract negotiation, permitting, financing phases, construction, and acceptance testing phases will separate firms that have the capability to develop viable projects from those that do not.

CONCLUSIONS

The research thus far has indicated that, at present, the preferred configuration can be attained with regard to some of the criteria and may be attainable with regard to the others, as is discussed below.

Flexibility to process each of the biomass wastes generated on a seasonal and non-seasonal basis over the course of the year, with their varying fuel characteristics – Several of the vendors indicate that they have produced synfuel or pyrolysis oil from yard waste and wood. The fuel characteristics of these wastes are similar to the wood chips that are most typically processed in existing systems. Particle size would have to be controlled by preprocessing.

A facility footprint that would enable development at existing biomass waste transfer stations – The modular design of the existing systems is aimed at matching unit size to the amount of biomass to be processed and achieving a small footprint for industrial and institutional applications.

Low profile building envelope – Certain vendor gasifier designs utilize a vertically oriented reaction chamber. In addition, close-coupled systems that incorporate a boiler and air pollution control equipment, such as electrostatic precipitators, scrubbers, and baghouses will require higher building envelopes. However, certain modular close-couple systems package the feed system, gasifier, and boiler in a low profile design.

Exhibit 5

CAPITAL COSTS FOR BIOMASS GASIFICATION FACILITIES

Facility/Technology Vendor	Gasification Design	Capital Cost	Year Of Construction	Daily Biomass Throughput	Capital Cost Per Daily Ton	Debt Service Per Ton[1]
University of South Carolina/Nexterra	Fixed Bed-Updraft	$20M	2006 – 2007	155	$129,032	$28.37
Middlebury College/Chiptec	Fixed Bed-Updraft	$12M	2007 – 2008	55	$218,182	$47.97
Burlington, Vermont/FERCO	Circulating Fluidized Bed	$52M	1996 – 1998	200	$260,000	$57.16

Convert syngas to power via direct firing in internal combustion engines or gas turbines for sale to the grid – It is questionable whether this can be achieved presently. Apparent concerted efforts by several vendors may attain this goal in the next few years.

Favorable reception by regulatory agencies – The Sanford, Florida, MaxWest biosolids gasifier provides an example of the successful permitting of a municipal gasification system. Efforts underway to develop systems for municipal waste may provide additional success stories.

Cost competitive with current management strategies – Further analysis is necessary. The capital cost information in Exhibit 5 indicates that the debt service burden is not excessive; and that reasonably estimated operating costs and energy revenues could result in net operating costs in the $50 to $75 per ton range.

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