# Biogasification and Other Conversion Technologies

White Paper
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# White Paper on Biogasification and Other Conversion Technologies

Worldwide, biomass is the most used non-fossil fuel. In the United States, more than 10 gigawatts of biomass electrical generation capacity, (about 1.4% of national usage), have been installed since the Public Utilities Regulatory Act (PURPA) was passed. The use of biomass is expanding from traditional forest products and thermal applications to uses including wastewater residuals gasification in the production of liquid fuels, gas fuels, and hydrogen derived fuels. These fuel products can produce electrical power and other energy sources without the adverse environmental concerns commonly associated with fossil and nuclear-fueled energy production.

Gasification processes give biomass tremendous flexibility in the way it can be used to produce energy. These combined power & heat technologies, use a variety of organic residuals, agricultural wastes, and dedicated energy crops to produce a clean fuel gas. A wide range of energy conversion devices can be applied to utilize this fuel gas to produce power, including; gas turbines, reciprocating engines, and hydrogen powered fuel cells.

Technological advancements in pyrolysis and gasification energy conversion systems are taking place rapidly. These advancements, coupled with progress in other related emerging technologies, will increase efficiency and lower capital cost. The economic incentives, reduced cost, and positive environmental impact inherent to these systems could alter public perception of the methods for the handling of many of the organic residual wastes considered appropriate today. Already Sweden, Japan and Canada operate very successful energy recovery systems using what we now consider waste products including; wastewater residuals, sorted urban waste, wood, rubber, agro-food, and select industrial wastes.

## Summarized Fundamentals of Gasification:

Gasification literally means to convert a solid or liquid substance into a gas. In a biomass gasification energy conversion system, larger molecule carbonaceous solids are converted, by oxidization-reduction reactions, to smaller molecule combustible gas products.

Biomass Gasification can be termed a two-step, or combined step (pyrolysis/gasification) process in which solid fuel (biomass) is thermochemically converted to a low to medium grade BTU gas. In the first reaction, (pyrolysis), volatile matter is chemically changed into carbon rich "char" by heat (1,100°F, or less) in an atmosphere devoid of oxygen. Char (fixed carbon) and ash are by-products not volatized by the pyrolysis reactions. In the second reaction, the char is gasified through reaction with air/oxygen, steam and hydrogen. Some of the unburned char is combusted to release the heat needed for the endothermic (heat absorbing) pyrolysis reactions.

Gasification systems can be designed to combine these steps in a single reactor (direct-heated gasifiers) or isolate them in separate reactor vessels. (indirectly-heated gasifiers).

In conventional air/oxygen blown gasification, thermo chemical reactions occur at typical temperature ranges of $600^0$ to $900^0$ C ($1,100^0$ to $1,650^0$F) and about 30% of the stoichiometric oxygen required for combustion. In direct-heat gasifiers some of the char is combusted within the reactor vessel to release the heat needed for the pyrolysis reactions.

Because biomass fuels tend to have more volatile components (70% to 86%, dry basis) than coal (30%), pyrolysis plays a larger role in biomass gasification. Pyrolysis is an irreversible chemical change activated by heat in an atmosphere devoid of oxygen. The production of charcoal from wood is an example of pyrolysis that has been practiced since 2000 BC.

Char, the by-product of the pyrolysis step, contains inert mineral ash and other noncombustible material plus a large fraction of fixed carbon. The fraction of fixed carbon is a function of the carbonaceous fraction of the feedstock.

A comparison of biomass and coal fuels from work by F.M. Lewis is provided in Tables 1 and 2, with an added third column to show comparison with the component characteristics of wastewater residuals.

**TABLE 1**
Comparative Fuel Analysis

| Constituent | Biomass[1] (percent) | Coal[2] (percent) | Wastewater Residuals[3] (percent) |
|---|---|---|---|
| *Proximate Analysis* | | | |
| *Moisture* | *24.5* | *2.5* | *74* |
| *Volatile Matter* | *65.5* | *37.6* | *16* |
| *Fixed Carbon* | *9.5* | *52.9* | *3.0* |
| *Ash* | *1.0* | *7.0* | *7.0* |
| *Ultimate Analysis* | | | |
| *Carbon* | *51.5* | *76.9* | *10.5* |
| *Hydrogen* | *6.9* | *5.1* | *1.6* |
| *Oxygen* | *40.6* | *6.9* | *5.3* |
| *Nitrogen* | *0* | *1.5* | *0.2* |
| *Sulfur* | *0* | *2.4* | *0.2* |
| *Ash* | *1.0* | *7.2* | *7.9* |
| *Heating Value (Btu/lb)* | *7,125* | *13,000* | *1,840* |

**TABLE 1**
Comparative Fuel Analysis

| Constituent | Biomass(1) (percent) | Coal(2) (percent) | Wastewater Residuals(3) (percent) |
|---|---|---|---|

(1) Typical Biomass, exact make-up not reported.
(2) Eastern U.S. Coal.
(3) Average value from three Wastewater Treatment facilities in Pennsylvania.

**TABLE 2**
Comparative Fuel Analysis; Same Fuels on a Dry, Ash-Free Basis

| Constituent | Biomass(1) (percent) | Coal(2) (percent) | Wastewater Residuals(3) (percent) |
|---|---|---|---|
| *Proximate Analysis* | | | |
| *Volatile Matter* | *87.3* | *41.5* | *89.6* |
| *Fixed Carbon* | *12.7* | *58.5* | *10.4* |
| *Ultimate Analysis* | | | |
| *Carbon* | *52* | *82.9* | *51* |
| *Hydrogen* | *7* | *5.5* | *7.0* |
| *Oxygen* | *41* | *7.4* | *27* |
| *Nitrogen* | *0* | *1.7* | *0.8* |
| *Sulfur* | *0* | *2.5* | *1.0* |
| *Heating Value (Btu/lb)* | *9,500* | *14,365* | *11,169* |

(1) Typical Biomass, exact make-up not reported.
(2) Eastern U.S. Coal.
(3) Average value from three Wastewater Treatment facilities in Pennsylvania.

There are important differences between Tables 1 and 2. The percent volatile matter of the biomass fuel (the portion that turns into a gas when heat is applied without adequate oxygen for combustion) is twice that of coal, therefore, biomass is better suited for conversion to fuel gas than coal.

The wastewater residuals component characteristics are similar in make-up to the biomass data reported by Lewis, indicating dried wastewater residuals would comprise the feedstock for efficient biomass gasification.

Excess heat is produced by properly designed gasification systems. Since the heating value of the pyrolysis product is always equal to the original feedstock heating value and only a small percentage of that heat is required for pyrolysis of the cellulosic material of the new feedstock excess heat is produced in the form of a clean combustible gas.

## Product Gas Composition:

The "typical" produced gas is composed of nitrogen (approximately 55% by volume), carbon dioxide (approximately 16%), carbon monoxide (12% to 30 %), and hydrogen (2% to 10%). Small percentages of light hydrocarbons, oxygen, solid particles, and tar, as well as other elements particular to the process and feed material may also be present. After separation of the solid particles, tar, and organic constituents of the gas, by gas scrubbing, the organic pollutants are transformed into simple molecules ($H_2$ and CO).

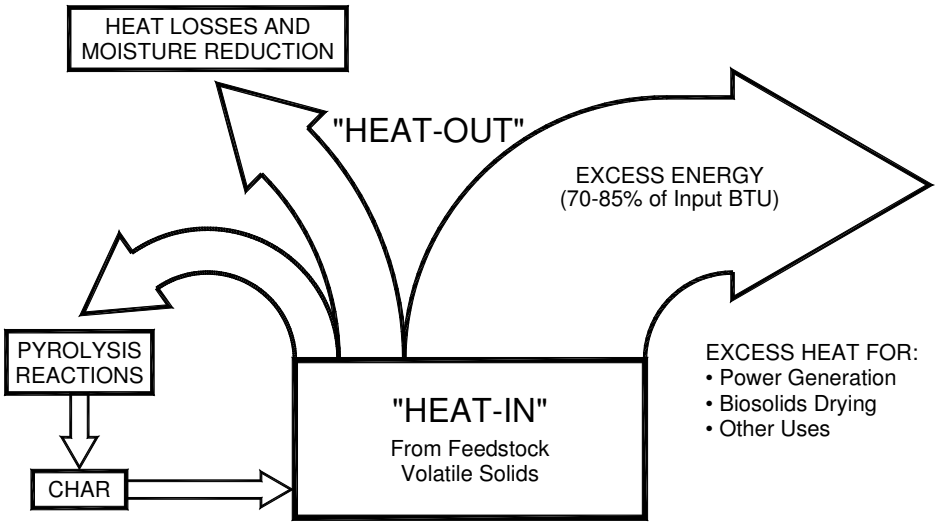


Diagram 1
Simplified Gasification Heat Balance

This diagram provides an illustrative example of the energy demands and excess heat capabilities of a typical biomass gasification energy conversion system based upon data from operational systems. Obviously, performance will vary as a function of feedstock quality, moisture, and the equipment selected.

The control of moisture in the feedstock is critical to efficient gasification. As the moisture level increases the heat available from the char is no longer sufficient to maintain gasification and also vaporize the water in the feed. About 1400 to 1700 Btu's / lb. water evaporated are required for biosolids drying, combustion, and gasification systems.

Reduction in the feedstock moisture concentration will increase overall efficiency of the gasification process. The maximum moisture concentration in the feedstock should not exceed 40% moisture for gasification performance viability. Moisture concentrations of less than 25% are desirable for efficient gasification results.

# Environmental Considerations:

Gasification, the conversion of biomaterial into energy, offers an environmentally sound, outstanding alternative to expensive and environmentally unfavorable disposal of residual organic wastes in landfills. Wastewater treatment residuals, agricultural crop by-products, and manure represent excellent, low-cost fuel for high-efficient gasifiers. The removal and use of these "waste-products" can also help to control non-point source pollution in environmentally sensitive areas.

Since the gasification process uses plant and organic matter or organic residuals to generate electricity and other energy sources, the fossil fuels are in essence, simply replaced with organic matter as a fuel source, creating a cleaner, renewable energy alternative, and reducing air pollution associated with the combustion of fossil fuels. In this way, Biomass fueled energy systems offer the potential to reduce greenhouse gases and have nowhere near the global warming impacts of fossil fuel plants.

Biomass fuels can be referred to as carbon dioxide ($CO_2$) neutral, given that the plant material absorbs as much carbon dioxide during its life as is released even if it were directly combusted. Gasification / pyrolysis technologies can capture/convert $CO_2$ further reducing its impact when compared to direct-burn Bioenergy systems. Since biomass fuels seldom contain elevated concentrations of Sulfur compounds, $SO_x$ emissions are often times zero or very small compared to fossil fuels.

Gasification product gas cleaning trains have typically employed proven wet and dry scrubbing technologies including; cyclones, tray towers, venturi devices, and bag houses. Secondary wastewater treatment effluent has been successfully utilized to scrub product gases from wastewater residual and other gasification feedstocks. At the Hyperion Energy Recovery System provisions were made to add caustic solution to the scrubber water. Full scale testing demonstrated the bicarbonate alkalinity in the secondary effluent was sufficient to neutralize the inlet $SO_2$ and caustic addition was not needed. Scrubber water effluent can be recycled to a treatment plant or treated by adsorption on the carbon rich char generated by the process.

Removal efficiencies for particulate, and tar aerosols have been demonstrated as high as 99.99%. Typically removals range from 96% to 99%. In addition to the minimization of greenhouse gas emissions the following additional environmental benefits are realized:

- Destruction of all pathogens, viruses, and organochlorinated compounds.
- Immobilization of heavy metals in wastewater residuals.
- Significant reduction in odor problems.
- No threat of groundwater contamination.

# Process Variations:

A brief description of gasification process variations follows. Due to the rapid advancement of related technologies this description is far from complete. Updates to this information

will be published as more projects are implemented and technological advancements are made.

Four primary types of gasification systems have been utilized to date: (1) fixed bed reactors, (2) bubbling fluid-bed reactors, (3) circulating fluid-bed reactors, and (4) entrained flow reactors. Variations of these designs include:

- Air/oxygen blown gasifiers, also called direct heated gasifiers that use the exothermic reaction between oxygen and organics to provide the heat necessary to devolatilize the biomass and to convert new residual carbon-rich chars internally in the gasification vessel.

  Air-blown gasifiers typically produce a low calorific-value product gas, 5 to 7 MJ/Nm$^3$ (150 to 200 Btu/ft$^3$) dry. The use of oxygen in lieu of air typically increases the heating value of the gas to 10 to 12 MJ/Nm$^3$ (300 to 350 Btu/ft$^3$). The heat content is an indicator of diluent nitrogen concentration in the product gas.

- Steam gasification, also referred to as pyrolytic gasification or steam reforming, is normally conducted in an indirectly-heated gasifier where the heat necessary for gasification is supplied externally from a hot solid, or heat transfer surface, or superheated steam. A portion of the heat formed in the pyrolysis step is used in an external reactor vessel to supply the heat for the endothermic (heat absorbing) pyrolysis step.

  Steam gasifiers typically produce a medium calorific-value gas, 15 to 20 MJ/m$^3$ (400 to 550 Btu/ft$^3$). Steam Gasification has demonstrated efficiencies of 70% to 85% in converting the organic content of the feed into a fuel gas mixture.

New developments in steam-only gasification now offer simplicity, added flexibility, and increased opportunities for the recycling and conversion of waste material into useful synthetic gas (syngas) with a high percentage of hydrogen. The Ultra-Superheated Steam (USS) process (patents pending), under development by The University of Sheffield and F. Michael Lewis Inc., derives its benefits over conventional oxygen-blown systems by a combination of high exit temperature and a high mole fraction of water vapor. This combination converts the high molecular weight tars and oils that plague conventional gasifiers to low molecular weight syngas. The resulting syngas has a very high fraction of hydrogen, which may be separated out for use in fuel cells and other uses.

The USS process uses an oxygen/steam blend to form a synthetic air to produce a steam flame temperature of 2,000$^o$K (3,140$^o$F) or higher. Prior to this innovation called "fuel-enhanced" gasification the maximum supply steam temperature available was about 2,000$^o$F. At this lower steam temperature a very high fraction of excess steam is required to supply the necessary heat. This excess steam results in low process efficiency due, in part to the added moisture of the steam..

A nominal 200-pound/hour atmospheric pressure, entrained flow, fuel-enhanced USS pilot unit has been operated at Enercon Systems Inc., facility in Ohio. Proofs of concept runs on biomass and coal have been conducted. To date no problems with the USS burner have been reported.

Unique features of the USS process cited by the developers include:

- The USS process is burner-based, not reactor based, offering the end user a wide choice of reactor designs.
- The process is especially applicable in small and mid-sized reactor applications.
- There are no exothermic oxidization reactions within the reactor. Downstream of the USS steam envelope, gasification becomes a steam-only gasification and/or steam reforming process inherently resistant to the production of tars.

These new concept, fuel-enhanced gasifiers offer potentially lower initial costs, easier/ less complex operation, and at the same time significantly improved performance efficiency In fuel-enhanced gasifiers, the heating value of the syngas produced is greater than that of the burned fuel.

## Other Waste to Energy Technologies:

The High Oxidization and Theromphilic (HOT)™ process, patented by Samuel Shepherd uses biologically inert, polyflorinated ether compounds to aerobically digest wastewater residuals at temperatures in excess of 100°F. The totally enclosed process reactor has been tested and reported to reduce the volatile solids level in excess of 60% in a reactor 1/10 the size of a conventional aerobic reactor.

The HOT™ process is exothermic. The reported excess heat generated is about 9,000 Btu/lb. of volatile solids consumed in the raw sludge. This natural generation of heat is available for a variety of uses, including a heat source for other process uses.

The Subiaco "Oil from Sludge" project uses a process called Enersludge™ developed by Environmental Solutions International Ltd. (ESI) In this process dried sludge is heated to 450°C in the absence of oxygen. The vaporized sludge is mixed with the char residue which, as a result of the catalytic reactions produces a fuel grade oil. A portion of the char is consumed to produce the heat to dry the incoming sludge.

ESI estimates the facility will produce 300 liters of oil from each ton of sludge.

The Flex-Microturbine™ developed by Reflective Energies, is designed to run on low Btu biomass gas as produced by anaerobic digestion and lower efficient gasification technologies. This creates markets not currently served by microturbines that require expensive fuel gas compressors to pressurize the feed gas and enables electricity production at significantly reduced cost.

Research and development of Co-Gasification (biomass & coal) and other mixtures is ongoing. Tyson Foods and Renewable Energy are constructing a co-gasification facility to process 82,000 tons annually of chicken litter and approximately 30,000 tons of wastewater sludge in the Chesapeake Bay region.

Fuel cell technology has recently realized significant advancements. Fuel cells convert the energy of electrochemical oxidization of a fuel into electricity. Typically gaseous fuels, such as hydrogen, are feed to the cell's negative electrode, while an oxidant such as oxygen, is fed continuously to the positive electrode. The electrochemical reactions produce potential (voltage) and electrical current analogous to that of a battery.

Until recently, the cost to produce the gaseous fuel has outweighed the cost benefit of the electricity. More efficient, gasification produced hydrogen coupled with advancements in fuel cell materials could significantly reduce this cost incongruity.

## Economics:

The average size of direct-combustion, boiler/steam turbine technology biopower plant is 20 MW. (the largest approaches 75 MW) Operating Biomass Gasification systems are often times smaller than the direct combustion facilities. These small plant sizes lead to higher capital cost per kilowatt of installed capacity and to high operating costs as fewer kilowatt-hours are produced per employee. These factors, combined with low efficiencies have lead to electricity costs of 8 to 12¢ / Kw-hr.

Capital costs for a small capacity (10 MW) biomass fueled gasification plant are estimated to be in the $1,800 to $2,000 / KW range based on constructed facilities prior to 2003. Improvements to the processes, discussed elsewhere in this narrative are expected to lower the capital cost to about $1,300 to $1,400 by 2010.

Biomass gasification systems are also appropriate to provide fuel to fuel cells and hybrid fuel-cell/gas turbine systems, emerging technologies that could alter the entire economic picture especially for hydrogen rich gas produced by ultra-superheated steam fired gasifiers.

Already, there are economic stimuli and tax incentive programs offered by US federal and state governmental agencies for the research, implementation, and operation of biomass gasification, pyrolysis, direct burn and other related Bioenergy technologies. These programs, coupled with the rising cost of wastewater residuals disposal, have a positive impact on the future economic picture for biomass energy conversion systems.

Additional markets may also be realized for the reuse of the carbon-rich char by-products as an activated carbon agent for the treatment of water and/or air contamination.

## Summary:

Biomass Gasification energy conversion technologies offer a clean, renewable energy source and an outstanding alternative to expensive and environmentally unfavorable disposal of organic residual wastes in landfills. While Bioenergy will never replace conventional fossil and nuclear-fueled power generating facilities, every KW of fossil fueled power replaced by these technologies reduces current pollution levels and global warming consequences.

The current capital and operation & maintenance cost associated with biomass gasification systems rank their economic viability low compared to other disposal-only alternatives. However, rising costs of current disposal-only alternatives, coupled with efficiency improvements and inherent environmental advantages in gasification technologies show promise to alter cost/benefit relationships and public perception of the way we handle organic residuals.

Advancements in fuel cell technologies, microturbines, co-gasification, and the potentials for re-use of the inert char by-products represent new markets for biomass gasification systems.

These markets are enhanced by the recent innovation in "fueled-enhanced" steam flame heated gasification systems.

We look forward to future innovations and implementation of projects using these environmentally sound technologies.

Biomass gasification is a beneficial technology "Following Nature's Lead" to produce energy and simultaneously manage our waste handling needs.

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