

Gasifier Manufacturing, LLC

**250 Ton/Day Biomass
Pressurized Linear Starved Air Low
Temperature (LSALT) Gasifier**

GMax-P42



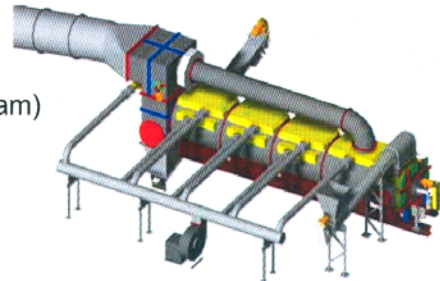
INTRODUCTION

The Phoenix GMax Gasifier is the product of years of development by Phoenix Bioenergy, LLC an innovation oriented company based in Jacksonville Florida that has been focusing its efforts on contributing to the worldwide effort to mitigate global warming by introducing environmentally sustainable biomass power systems as a proven alternative to traditional fossil fuel systems.

With the GMax Gasifier, Phoenix Bioenergy has taken the next step in atmospheric, air blown, and pressurized gasification systems. Based upon field proven equipment demonstrated with nearly 50 different carbonaceous feedstocks the GMax advances the state-of-the art by allowing greater variability on fuel composition and characteristics while maintain optimal performance.

The Phoenix GMax Gasifier Provides

- **Proven Technology - developed early '80s**
 - Successfully tested at 250-300 TPD by DOE & Boeing
 - Held from Market - due to low petroleum \$\$ & low MSW tipping fees
- **Shallow Fluidized Bed Technology**
- **Air blown, but O2 Enriched Capable**
- **Flexible design - fuels and capacities**
 - Tested on MSW, auto shredder residuals, wood chips, bark and combinations of bark, wood chips & paper mill sludge
 - Ag & forestry residuals, high moisture capable
 - 175 TPD piloting scheduled Q1 2009
 - Commercial scale at 250 TPD (90,000 PPH Steam)
 - Readily scaled to 700 and 1000 TPD



PROCESS

GASIFICATION BASICS

Gasification is most commonly understood as starved-air combustion or incomplete combustion. It is heating of solid fuels like wood or coal to release the volatile gases, but without enough air to combust the H_2 and CO , so the fuel-rich syngas can be fired downstream to burn to produce steam, engine power or converted to liquid fuels.

This gas mixture of primarily H_2 and CO is a Synthesis Gas and correctly or incorrectly goes by a variety of names: “wood gas”, “syngas”, “producer gas”, “town gas”, “generator gas”, and others. It’s sometimes also called “biogas”, though biogas more typically refers to gas produced via microbes in anaerobic digestion.

Gasification can be thought of as an early stage of burning without the flame, similar to when charcoal burns, no visible flame is produced, but significant amount of heat is. The objective is to use controlled heat to break the molecular bonds of the feedstock. The input to gasification is most any form of solid carbonaceous material– typically a renewable biomass or coal. All organic carbonaceous material is made up of carbon (C), hydrogen (H), and oxygen (O) atoms in a dizzying variety of molecular forms.

The goal in gasification is to break down this wide variety of molecular forms and reform them into a simple fuel gas of H_2 and CO – hydrogen and carbon monoxide. So a solid material is transformed into a solid carbon char and fuel-rich gases.

Both hydrogen and carbon monoxide are burnable fuel gases. Carbon monoxide is not thought of as a fuel-rich gas, but at high temperatures it is extremely volatile and reacts or combusts in the presence of hydrogen. It actually has very good combustion characteristics to provide heat energy.

Carbon monoxide and hydrogen have about the same energy density by volume. Both are clean burning, as they only need to take on one oxygen atom, in one simple step, to arrive at the proper end states of combustion, CO_2 and H_2O . This is why an engine run on syngas can have such clean emissions.

Gasification can be simple or complex depending on the feedstock, process control and the desired output gas quality. Burning a pile of trees outside in an open field can give complete combustion of the wood and syngas while reducing the physical volume of the wood to an ash. All of the energy is combusted in a heat flame that varies in size based on the wood and other factors like water, rosin, bark, leaves, dirt, etc. Key to a consistent output gas is that the feedstock needs to be homogenous and fed at a steady rate.

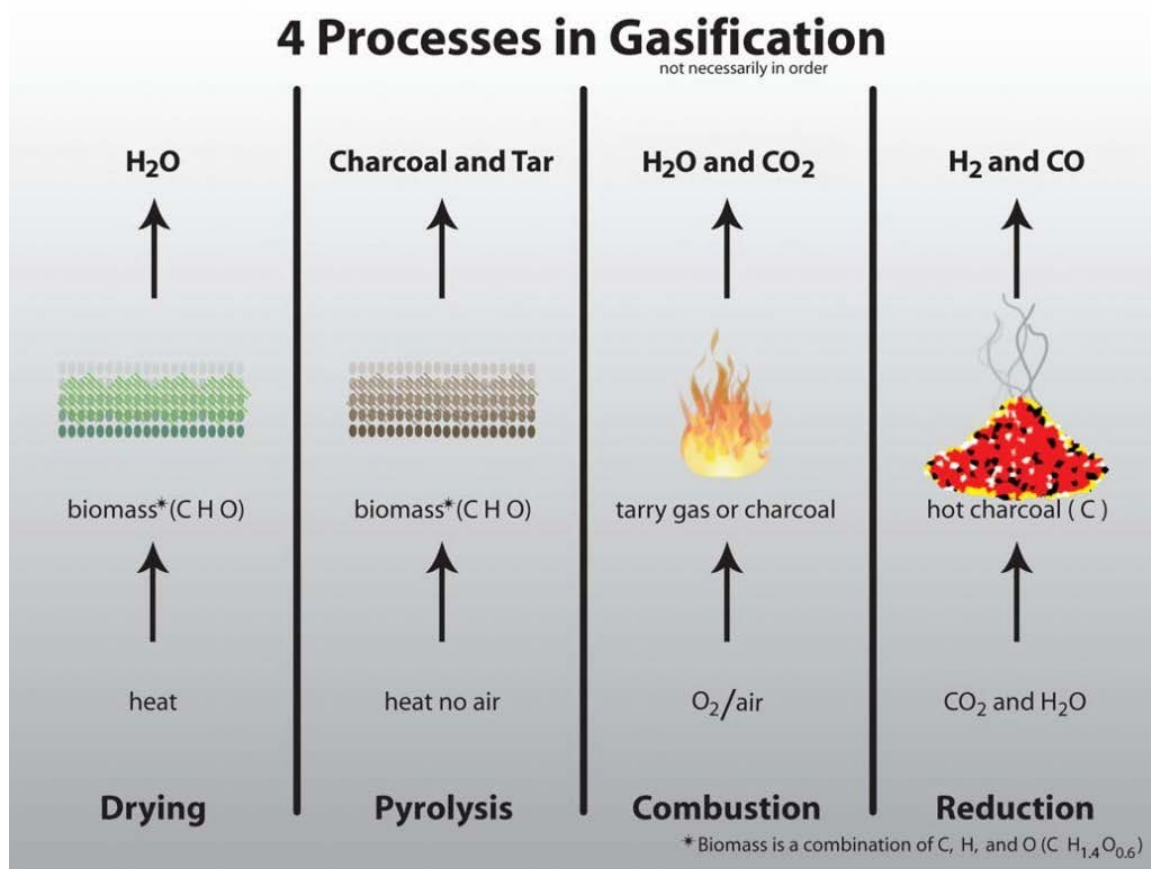
Other factors in “process control” relate to moisture, air, fuel mixing, temperatures, pressure and gas reaction control. As has been proven by demonstration, removing moisture in the drying zone and re-introducing it into the syngas downstream, controlling nitrogen rich input air to minimize NO_x emissions from final combustion, are two techniques that produce the cleanest and highest fuel value syngas.

THE 4 STEPS IN THE PROCESS OF GASIFICATION

Proper gasification is a bit more than the “choked combustion” summary above. It is more accurately understood as “staged combustion”. It is a series of distinct thermal events put together to purposely convert solid organic matter into specific hydrocarbon gases as output.

Simple incomplete combustion is a dirty mess. The goal in gasification is to take control of the discrete thermal processes usually mixed together in combustion, and reorganizes them towards desired end products. In digital terms, “Gasification is the operating system of fire”. Once understood its is possible to pull fire apart and reassemble it into a desired process, as well as a variety of end products.

Gasification is made up for 4 discrete thermal processes: Drying, Pyrolysis, Combustion and Reduction. All 4 of these processes are naturally present in the flame seen when viewing a burning match, or a burning log in a fireplace or stove, though they mix in a manner that renders them invisible to eyes not yet initiated into the reaction processes of gasification. Gasification is merely the technology to control the reactions and isolate these separate processes, so that it might be possible to interrupt the “fire” and pipe the resulting fuel-rich gasses elsewhere.



Drying is the input of low heat to evaporate moisture in the solid fuel before it enters Pyrolysis. Moisture is removed from the material before reactions above 100C (212F) can occur. Eventually all of the water will get vaporized out of the material at some point in the higher temp processes. Where and how this happens is one of the major issues that various

gasifier designs face in their reaction control. High moisture content fuel, and/or poor handling of the moisture internally, is one of the most common reasons for failure to produce clean fuel-rich gas.

Of the four, two of these processes Pyrolysis and Reduction are a bit more complex in gasification. Once understood, the others pieces are readily grasped. Below is the quick description of the thermal reactions.

Pyrolysis is the application of heat (red hot char) to raw, dry biomass, in an absence of air, in order to break it down into charcoal and various tar gases and liquids.

Biomass begins “thermal charring” once its temperature rises above around 240C (460F). The biomass breaks down into a combination of solids, liquids and gases. The solids that remain are commonly called “charcoal”. The gases and vapor liquids are “tars and water”.

The gases and liquids produced during lower temp pyrolysis are simply fragments of the original biomass that break off with heat. These fragments are the more complicated H, C and O molecules in the biomass that are collectively referred to as volatiles. As the name suggests, volatiles are “reactive”. Or more accurately, they are less strongly bonded in the biomass than the fixed carbon, which are the direct Carbon-to-Carbon bonds.

Thus in review, pyrolysis is the application of heat to biomass in the absence of air/oxygen. The volatiles in the biomass are “evaporated” off as tars, and the fixed carbon-to-carbon chains are what remain as solids – otherwise known as charcoal.

Combustion and Drying are the most easily understood of the 4 Processes of Gasification. They do as expected by common understanding, though now they do it in the service of Pyrolysis and Reduction.

Introduction of a small amount of air, oxygen or steam provides Partial Combustion that generates the heat to run reduction, as well as the CO₂ and H₂ to be converted in Reduction to fuel-rich Syngas. Either the tar gases or char from Pyrolysis can fuel combustion. Combustion control and efficiency are the key design elements in the development of a superior gasifier design.

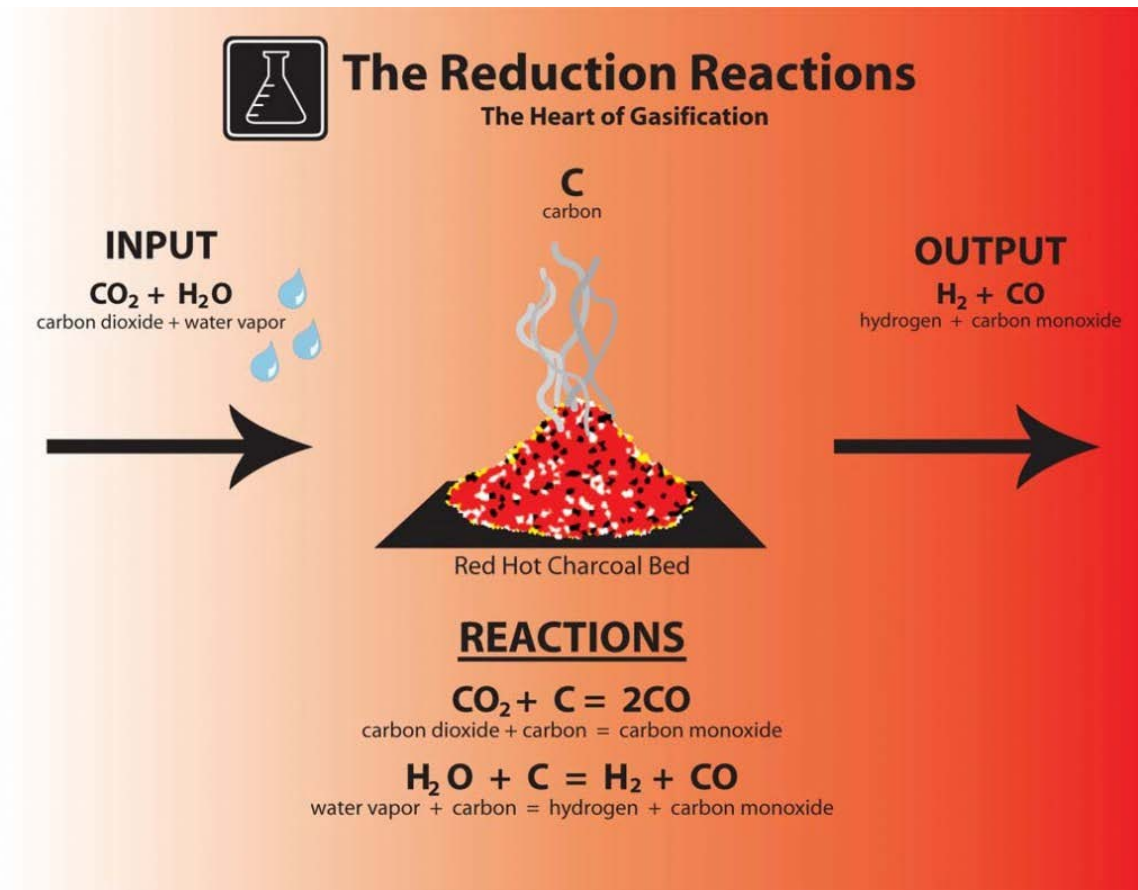
Different gasifier types use one or the other or both. A downdraft gasifier burns the tar gasses from pyrolysis to generate heat to run reduction, as well as produce the CO₂ and H₂O to be reduced in reduction stage. The goal in downdraft combustion is to get good mixing and high temps to burn or crack all the tar gasses before leaving the unit. The char bed and reduction contribute relatively little to the conversion of messy tars to useful fuel gasses. Solving the tar problem is mostly an issue of the reaction dynamics in the combustion zone.

Reduction is the process stripping of oxygen atoms off completely combusted hydrocarbon (HC) molecules, so as to return the molecules to forms that can burn again. Reduction is the direct reverse process of combustion. Combustion is the combination of an HC molecule with oxygen to release heat. Reduction is the removal of oxygen from an HC molecule by adding heat. Combustion and Reduction are equal and opposite reactions. In fact, in most burning environments, they are both operating simultaneously, in some form of dynamic equilibrium, with repeated movement back and forth between the two states.

Reduction in a gasifier is accomplished by passing carbon dioxide (CO₂) or water vapor (H₂O) across a bed of red hot char (C). The hot char is highly reactive with oxygen, and thus strips the oxygen off the gasses, and redistributes it to as many single bond sites as

possible. The oxygen is more attracted to the bond site on the C than to itself, thus no free oxygen can survive in its usual diatomic O₂ form. All available oxygen will bond to available C sites as individual O, until all the oxygen is gone. When all the available oxygen is redistributed as single atoms, reduction stops.

Through this process, CO₂ is reduced to CO. And H₂O is reduced to H₂ and CO or SynGas. Combustion products become fuel-rich gasses again and the ratio can be controlled. This is also referred to as the “Water Shift Reaction,” a fundamental process in gasification. This fuel gas can then be piped off to do desired work elsewhere.



GMax GLOW STATE REACTION CONTROL

Stability. The key to optimal conditions for the thermal forming of Synthesis gas. The GMax technology has evolved to new levels of construction, efficiency and ability to provide a pressurized, consistent Btu, high quality and clean syngas. Just as important as the quality of the Syngas is the process of producing a clean, fuel-rich gas without all the complexities and expense of gas cleanup. Quite simply, most any gasifier can produce a syngas but doing so with positive control of the gas reactions can minimize if not eliminate most of the by-product gases that are difficult to deal with. In the public eye and with many regulatory agencies, the good of gasification is often overlooked or even tainted by the by-product gases from poorly controlled systems.

The attributes of the GMax Gasifier are simple to understand yet enabled by the precision design and construction to offer an extremely flexible gasification system that can be utilized across a range of applications. From simple steam boiler/turbines, to efficient reciprocating engine generators, and pressurized Fischer-Tropsch reactors for producing mixed alcohol fuels and chemical feedstocks. The GMax Gasifier system offers a flexible and adaptable package to suit most syngas application needs.

The GMax Gasifier System has evolved through 30 years of development. Significant development was in conjunction with the U.S. Department of Energy and Boeing Engineering to develop the fundamentals of chamber/auger design and operational efficiency. The **G**low **S**tate **R**eaction (GSR) Control system is a proprietary sensor and PLC control module providing continuous monitoring of air, moisture, temperatures, speed, and gas reactions in each zone of the gasifier.

Process reactions occur quickly and the ability for continuous fine-tuning to maintain adiabatic temperature along the stoichiometric curve is achieved by the GSR Control system and this technology takes the GMax Gasifier into the next realm of performance and operational success.

Another proprietary feature of the GMax Gasifier system are the split gas plenums. Water retards combustion yet requires combustion heat to evaporate. The objective for efficient gasification is to establish an autothermic condition. As moisture is removed, the carbon will start thermal breakdown (much like lit charcoal), which produces CO_2 . The production of CO_2 is the only component that is exothermic so it is the heat source for the continuous process of Combustion. If the gas flow is all one direction then the CO_2 production of heat is carried downstream away from the fuel thus requiring a continuous heat source in Zone 1 such as a natural gas flame. The GMax unit employs an autothermic design.

The first step to any thermal breakdown of a solid material is driving off moisture. Pre-Drying is expensive and can require additional equipment and adds operational costs. In the GMax unit, the patented split-gas plenums with Split Gas Control with Bypass allow a portion of the CO_2 and heat produced in Zone 2 and 3 to flow backwards over the fuel bed in Zone 1 thus providing an enhanced combustion and water shift reaction. Moisture is endothermic and retards the chain of reactions to form syngas. The key to remaining autothermic is precise controls monitoring of temperature and moisture, the responsibility of the GSR Control system.

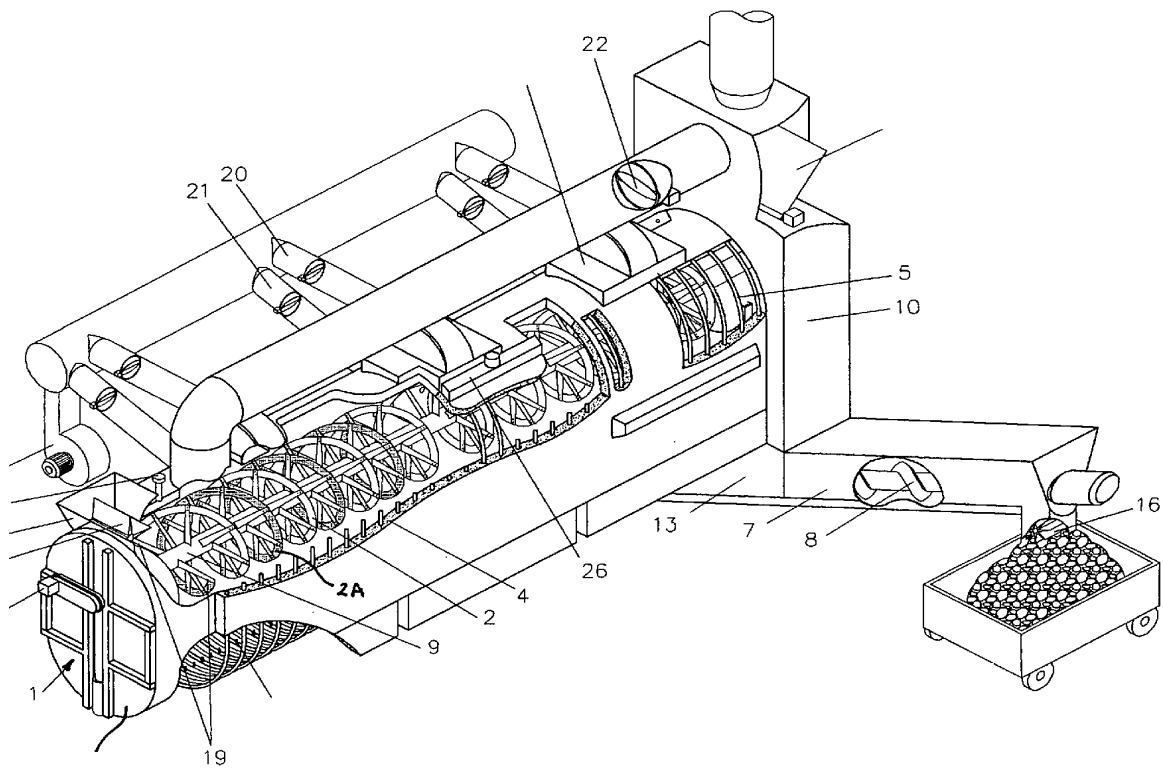
This gas and evaporated water is drawn through and out of Zone 1 into a bypass duct that reintroduces the moisture laden gas into the oxidizer where it is blended with and reacts with the final producer gas as it exits the gasifier driving up the fuel value of the syngas. This drying of the biomass and removal of the water vapor, which absorbs heat too, allows for mixing and pyrolysis to occur closer to the feed section. This also allows more gas reaction time to fine tune the variables for a quality syngas.

The GMax Gasifier system incorporates several patented design features to enhance performance. The primary design is an elongated horizontal chamber with bi-directional auger allowing controlled residence time to control reaction rates for forming high quality syngas. The unique elliptical shape allows for sufficient reaction space between the solid fuel reaction and gaseous formation with PLC controlled mixing from the proprietary auger shape and design.

A second design element integrates sectional control features for the performance of High Temperature Agent Gasification (HTAG). This consists of valve controlled top plenums, downtubes and bed bubblers to absorb radiant energy and temperature into delivery into

partial combustion air, oxygen or steam. The design feature uses reaction heat created within the chamber to preheat reaction air via embedded tubes in the hot refractory lining the GMax Gasifier extending from the top air plenum down the sidewalls into the fuel bed. This feature actively recycles energy and exergy to achieve performance improvements not possible in other gasifiers.

The trick to the most economical operating conditions is to retain heat for Autothermic conditions. This means the heat generated is maintained internally thus requiring no external fuel source other than the renewable feedstock. The GMax is able to accept a wide range of varying fuel moisture conditions and use that moisture to boost syngas btu values. Consider the cost of fuel includes the weight of the moisture and most other technologies require expensive pre-dryers and/or consume a constant natural gas feed to drive off the moisture to vent before gasification can begin.



Select images of components and fully assembled GMax P42 Gasifier



Above: Spiral Feed Transfer Auger
Below Left: Elliptical GMax chamber

Below Right: Installed Auger, Bed Bubblers





Fully assembled GMax Gasifier awaiting installation



Two GMax Gasifiers installed to drive a 150,000 #/hr HRSG

Retrofit of a former Coal fired plant to an 18MW Renewables Biomass Steam Power

