ECONO-POWER INTERNATIONAL CORPORATION
The Clean Coal Gasification Company ^{TM}

RECENT DEVELOPMENTS IN MODULARIZED AIR – BLOWN COAL GASIFICATION SYSTEMS FOR INDUSTRIAL APPLICATIONS

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ABSTRACT

Coal gasification is receiving a significant amount of interest as the Energy Policy Act of 2005 takes effect. Most of the publicized attention is focused on relatively large scale applications for either power generation or for the production of syngas for use as a feedstock in the production of either liquid fuels or other chemical products. These applications typically are oxygen blown gasification with the attendant requirement to include an air separation system in the overall plant design. Recent developments in two- stage, fixed-bed, air-blown gasification systems make this approach very attractive for smaller, industrial scale applications where the inclusion of an air separation plant would drive operating costs to uneconomic levels. Two-stage, fixed-bed, air-blown gasifier plants can reliably and economically support fuel gas production requirements as low as 120 million BTU per hour. These plants typically include modularized systems for removal and recovery of particulates, tars and oils and for the removal of hydrogen sulfide (H_2S). Additional equipment for removal of mercury (Hg) and for H_2S polishing can be included. Projects using this technology are currently under development for a variety of industrial applications including mining and cement kilns, industrial steam boilers, various types of dryers, glass furnaces and IGCC plants.

This paper will discuss the design features of a modularized two-stage, air-blown gasification plant. The paper will also summarize the development status of the industrial applications mentioned above.

BACKGROUND

Coal gas was the first fuel to be distributed by pipeline. The gas produced either as a by product of other processes or as a product in its own right has been used for heating, lighting, power generation and as a feedstock for fertilizer or fuels production for over 100 years. A century or more ago, not far from where this conference is being held, entire towns were heated and lit by coal gas. Certain industries continued to offset natural gas requirements with coal gas produced as a by-product to other processes as late as the 1970's, and, it seems, may be restarting that connection! The discovery of natural gas reserves and the decline of industries which produced coal gas as a by-product eventually led to the use of coal gas essentially ending in the United States.

Coal gasification continued to be a major source of fuel and chemical feedstocks in other parts of the world. The development of the Fisher – Tropsch process led to widespread use of coal gasification in gas-to-liquids fuel production. In the 1930's Germany developed better methods for gasification, including the Lurgi and Winkler designs to provide gas for synthesis of liquid fuels. Both the Wehrmacht and the Luftwaffe depended heavily on fuels produced from coal gas during World War II.

At the end of World War II, the use of international sanctions to attempt to force unpopular forms of governments to reform led to the isolation of The Union of South Africa. South Africa turned to the Lurgi fixed bed air-blown gasifiers to provide synthesis gas for a gas to liquid fuel program which continues today.

In China, the Lurgi and two stage technology arrived, via the USSR in the late 1940's and found almost immediate application in both coal to liquid fuel and gas to fertilizer production. Today, China has the most widespread use of coal gasification in the world. The Chinese began with a basic two stage design and have made improvements over the years. Most of their gasifiers operate at atmospheric pressure and use air as the oxidant rather than employing an air separation plant to produce oxygen. The initial designs were used primarily on anthracite or coke to produce synthesis gas for conversion to ammonia. The Chinese companies worked to improve the basic two-stage design by improving the "coke oven", or distillation, stage at the top of the unit. This design is used to process bituminous and sub-bituminous coals to produce fuel gas. The design has been built in both 3.0 meter and 3.6 meter diameters. It is this air-blown, two-stage, fixed-bed gasifier design which is the basis for the EPIC modularized system.

THE EPIC TWO STAGE GASIFIER

In the lower part of the EPIC two-stage gasifier, producer gas reactions take place between carbon in the char and oxygen in the air to provide a hot gas, which is, predominantly, carbon monoxide and nitrogen. This hot gas rises through the middle level, where some level of hydro-gasification takes place, producing methane, and certain shift reactions take place producing hydrogen and carbon dioxide from carbon monoxide and steam in the gas. In the upper levels the heat causes pyrolisis of the coal that releases oils and tars and finally dries out any water that was in the coal.

The use of coke ovens over the years has provided the experience necessary to maximize the carbon content in the char while removing no more than is necessary of the volatile matter. In this way a more or less smokeless char can be produced and fewer problems created in disposing of the tars and oil produced. See Figure 1 below for the EPIC Two-stage gasifier. (Model 2ST 3.0 shown.)

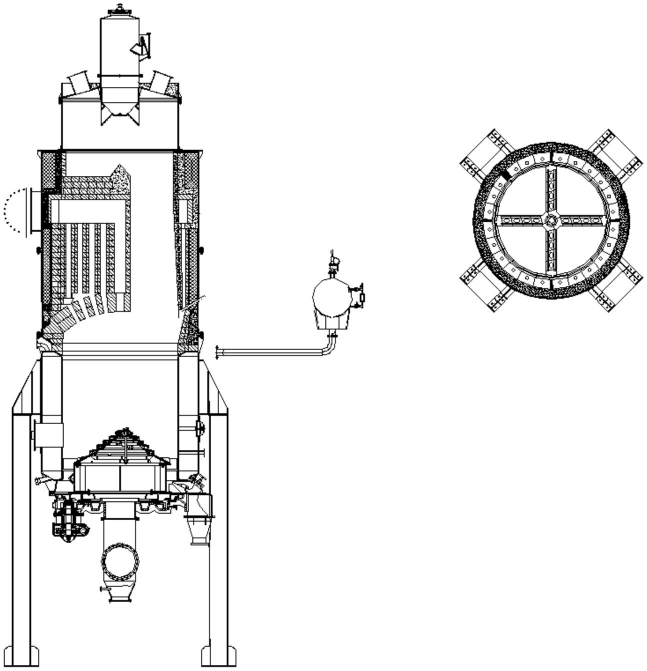

Figure 1. Gasifier Cross-Section

A framework of refractory bricks is built in the upper part of the gasifier that provide large vertical passages through which the coal travels and narrower passages in the brick walls through which some of the gas produced in the lower stage feeds to a lower outlet. The rest of the gas rises through the coal and exits through the top. The gasifier internals are long lasting. The typical life of the refractory is ten years or more.

The lower portion of the gasifier is the reactor where the char is converted to gas by introducing steam and air. This area has a steam jacket to control the inner and outer wall temperatures.

By adjusting the relative amounts of gas exiting the upper and lower levels the amount and quality of the oils and tars can be controlled so that the tar is relatively light and can be easily separated from the gas. This adjustment is made possible by control valves on both the upper and lower gas outlets.

In all gasifiers there will be a quantity of hydrogen sulfide produced which is proportional to the sulfur content of the coal. The efficiency of conversion of the coal to clean gas is about 80-83%, (BTU's in the fuel gas divided by BTU's in the coal feed) but will depend on the amount of sulfur and ash that has to be removed. The sulfur, in particular, contributes to the heating value of the coal, but actually reduces the heating value of the fuel gas because of the hydrogen that is tied to the sulfur in hydrogen sulfide.

Although there is a small loss of efficiency due to the heat lost in the removed ash, the major effect of ash content is a reduction in the output of the gasifier. Typically it is best if the ash content of the coal is no more than 10 to 12% but it can go as high as 18% without adversely affecting the performance of the gasifier. Beyond this, the throughput will be limited to the capacity of the grate to remove the ash.

The higher heating value (HHV) of the fuel gas is primarily dependent upon the coal composition, but, in general, will range from approximately 170 BTU/scf to 200 BTU/scf. The lower heating value (LHV) will be from 3 – 6 % less than the HHV. The 2ST-3.6 gasifier has a nominal rating of 100 million BTU/hr and the 2ST-3.0 gasifier has a nominal rating of 70 million BTU/hr. An installation with two 2ST-3.0 gasifiers operating on Midwestern bituminous coal would produce between 125 million and 140 million BTU per hour. It is the two unit plant using the 3.0 meter gasifiers which is the focus of this presentation.

PLANT DESIGN

The EPIC Industrial Coal Gasification System (ICGS) consists of three major sections: gasification comprising the coal feeding system, gasifiers with compressed air and steam feed streams, and ash conveying system; tar and particulate removal system including equipment to separate the oils and tars from the recirculating water and to inject the tars, oils and any captured coal dust into the gasification zone of the gasifiers; the hydrogen sulfide and mercury removal systems with ancillary equipment to produce a dry sulfur product.

Gasification

The gasification section includes coal handling to transport the coal from a receiving station or day bin to feed hoppers atop the gasifiers and through a lock hopper into the gasifier feed tube. Depending on local requirements, the plant layout could use mechanical conveying and simple receiving hoppers or even rail cars or barges for storage. In this case, a day bin with a pneumatic conveying system is included. The pneumatic system includes a pressure conveyor under the day bin to transport coal to the gasifier feed bins. The conveyor system is programmed to keep the feed bins full. Figure 2 shows the coal day bin with the pneumatic conveyor vessel which conveys coal to the feed bins. Figure 3 is a typical pneumatic conveying pressure vessel.

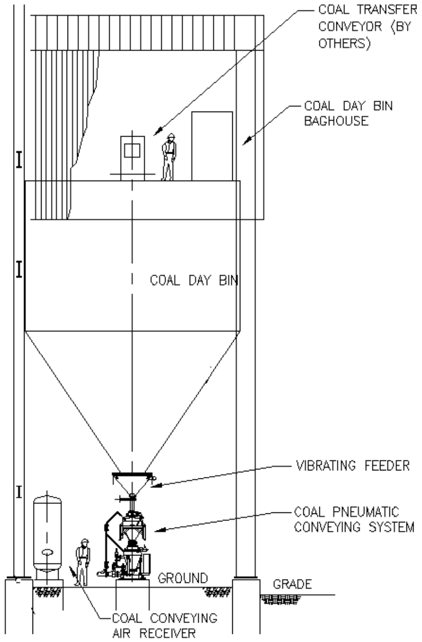

Figure 2. Coal Day Bin with Conveyor

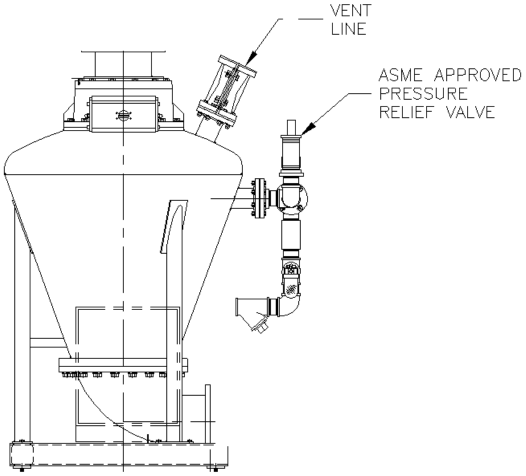

Figure 3. Pneumatic Conveying Denseveyor (Courtesy of Macawber)

The feed tube extends into the gasifier and terminates in small chutes which direct the coal into the passages formed by the refractory brick sections in the center portion of the gasifier. Figure

4 shows the coal feed section of the gasifier system with a portion of the pneumatic conveying system from the day bin.

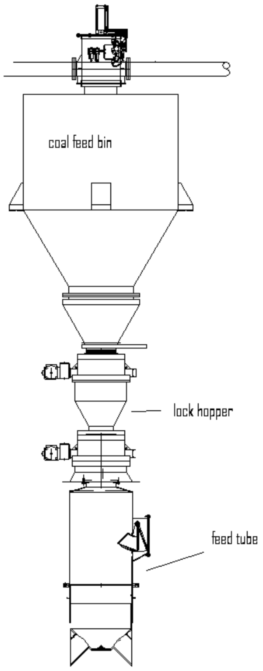

Figure 4. Coal Feed Bin, Hopper and Tube

The coal is converted to char, or coke, in the refractory lined portion of the gasifier and the char is gasified in the lower portion. The char is ultimately reduced to ash which is removed by the grate at the bottom of the gasifier. Ash exits through outlet chutes on either side of the gasifier which are piped to pneumatic conveyor pressure vessels from which the ash is conveyed to a disposal silo. Mechanical conveying could also be used for ash transport.

The pipe at the bottom of the gasifier has connections for both compressed air and saturated steam. The air and steam are fed to the gasification zone through openings in the grate. This provides for proper dispersion of the air and steam into the char. Figure 5 shows the gasifier with the grate, water jacket, and ash conveying system. Figure 6 shows the grate assembly.

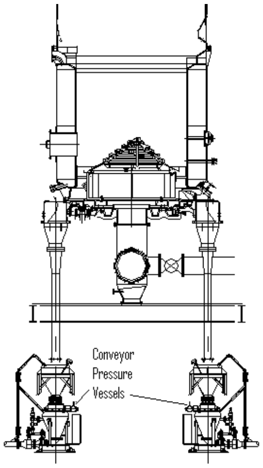

Figure 5. Gasifier with Ash Outlet System

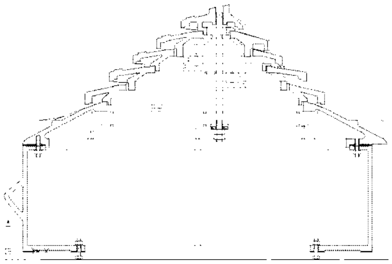

Figure 6. Gasifier Grate

The gasifiers need both compressed air and steam. In this two gasifier design, one compressor provides air for both of the gasifiers. The compressor plant is located between the gasifiers. If only one gasifier is in operation the excess compressed air is simply vented through an exhaust silencer outside the enclosure. Figure 7 shows the gasifier air compressor and the air piping.

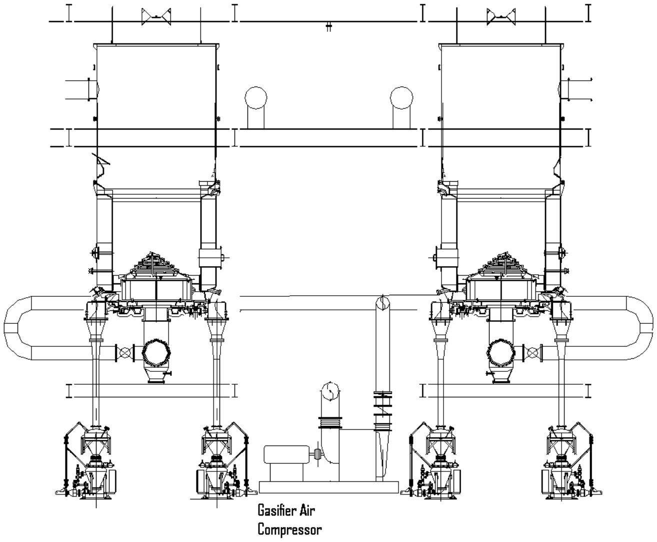

Figure 7. Gasifier Air Compressor

Steam for the gasifiers is provided by Once Through Heat Recovery Steam Generators (HRSG). The HRSG for each gasifier is located after the lower gas cyclone in order to reduce the particulate loading to the HRSG.

Tar and Particulate Removal System

The design of this system is based on a two gasifier, modular plant with a common overall gas clean-up system.

The fuel gas leaves the gasifier in two streams, an upper gas stream which comprises approximately 40% of the total gas, and the lower gas stream which exits from the side of the gasifier.

The upper gas will have the light tars and oils and any coal dust that is carried from the top section of the gasifier. Streams from the two gasifiers are fed to opposite sides of the upper gas separator. The upper gas separator collects any coal dust and the tars and oils. The combined tar, oils and dust is drained to the tar/oil tank. The slurry in this tank is injected into the gasification section of the gasifier. Figure 8 shows the upper gas separator and the tar/oil tank.

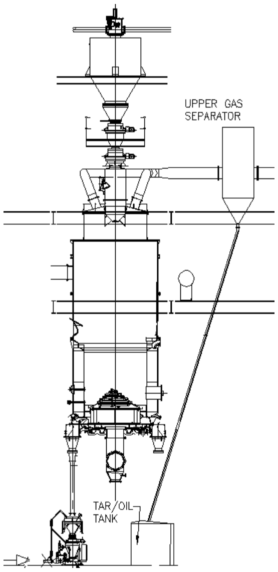

Figure 8. Upper Gas Separator & Tar/Oil Tank

The lower gas exits the gasifier at the side and flows into a cyclone to remove any large particulate. The fuel gas exits the cyclone upward and enters the HRSG. These items are shown in Figure 9.

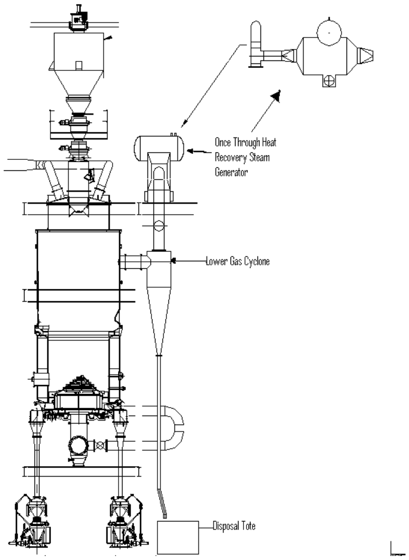

Figure 9. Lower Gas Cyclone with Tote and Once Through Steam Generator

From the HRSG the lower fuel gas stream from the two gasifiers is combined with the outlet flow from the upper gas separator and enters the quench venturi. The quench venturi removes another portion of the particulate and adiabatically saturates the combined fuel gas stream. The recirculation water for the quench venturi is combined in a loop with the mist entrainment separator which follows the venturi. This liquid recirculation stream has a side stream which flows to the tar/water separator. The fuel gas exits the mist entrainment and enters a wet electrostatic precipitator which removes any remaining tar and oil and further reduces the particulate concentration. The parts of this system are shown in Figure 10.

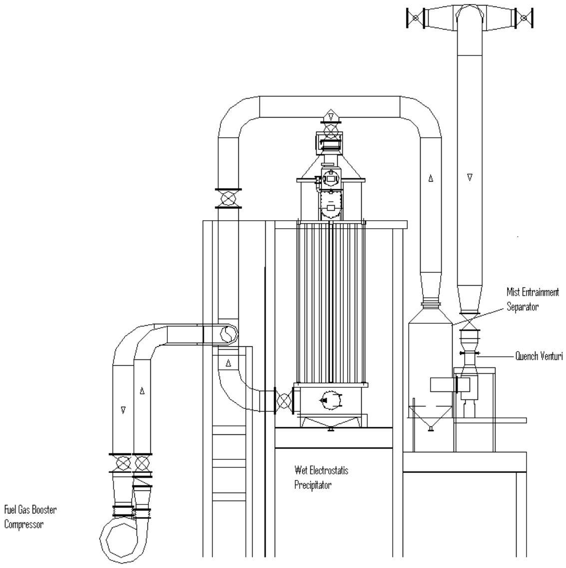

Figure 10. Quench Venturi, Mist Entrainment Separator and Wet Electrostatic Precipitator and Fuel Gas Booster Compressor

The tar/water separator feeds the separated tar and oil to the tar/oil tank for injection into the gasifier. The filtrate water goes to the gas liquor recycle tank which provides make-up to the venturi loop. Particulate from the tar/water separator is moved to a rolling tote for disposal with the ash.

Mercury and Hydrogen Sulfide Removal System

The fuel gas exiting the wet ESP is saturated and at a temperature between 150 – 200^{o}F. Because both the mercury removal bed and the Redox type hydrogen sulfide removal system operate at a temperature of 100^{o}F, it is necessary to cool the fuel gas. There is also a requirement to boost the pressure of the fuel gas at some point, in order to allow for distribution of the product. The latest EPIC design places these two functions between the tar and particulate removal system and the mercury and hydrogen sulfide removal system. The condensate from the gas cooler is collected and directed back to the venturi liquor loop.

After the booster compressor and cooler the fuel gas passes through an activated carbon adsorption bed in which the carbon is pretreated with sulfur (an example is shown in Figure 11). This bed removes any mercury in the gas and fixes it in the bed as mercuric sulfide. The outlet concentration of mercury in the fuel gas is designed to be below detectable levels.

Figure 11. Mercury Adsorption Bed
(Courtesy of US Filter)

From the mercury bed the fuel gas enters an absorber tower in which it is contacted with a buffered alkaline solution, typically sodium carbonate and sodium bicarbonate. The key to a reduction – oxidation, or redox, process is the formation of sodium hydrosulfide. This reaction has its best kinetics at 100^{o}F and will not take place at temperatures much above 130^{o}F. The concentration of hydrogen sulfide in the cleaned fuel gas is < 10 ppm. If the hydrogen sulfide needs to be reduced below this level, polishing with carbon adsorption beds pretreated with sodium can be installed. A typical layout for these systems is shown in Figure 12.

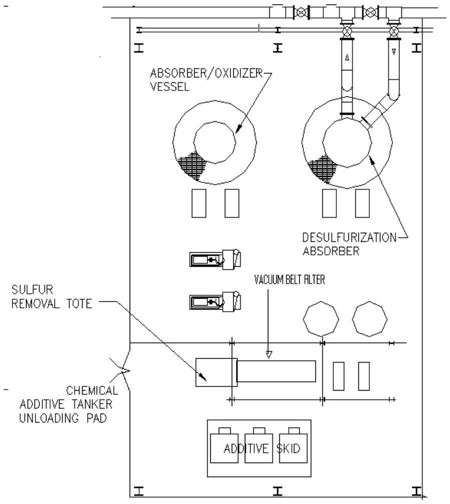

Figure 12. Hydrogen Sulfide Removal System

The absorption liquor is circulated from the absorption tower to an oxidation vessel. Here air is introduced to oxidize the sodium hydrosulfide and other constituents to produce elemental sulfur and sodium bicarbonate. The sulfur is removed from the oxidation tank as slurry and is pumped to a system which further dries the sulfur and recovers the absorption liquor. This system can be a vacuum filter, a centrifuge or a melter/separator. The final sulfur product is essentially a dry powder.

The fuel gas leaves the absorber and is reheated in a heat exchanger that is supplied with the low pressure steam from the gasifier steam jackets. The condensate is captured and returned to the gasifier steam drums. A small boiler feed treatment package is used to maintain the quality of the water in this loop.

The reheated fuel gas goes through a measuring station which determines the heating value and the flow rate and is delivered to the customer at that point.

The overall plant plan and elevation views for the nominal 140/120 million BTU/hr facility are shown in Figures 13 & 14.

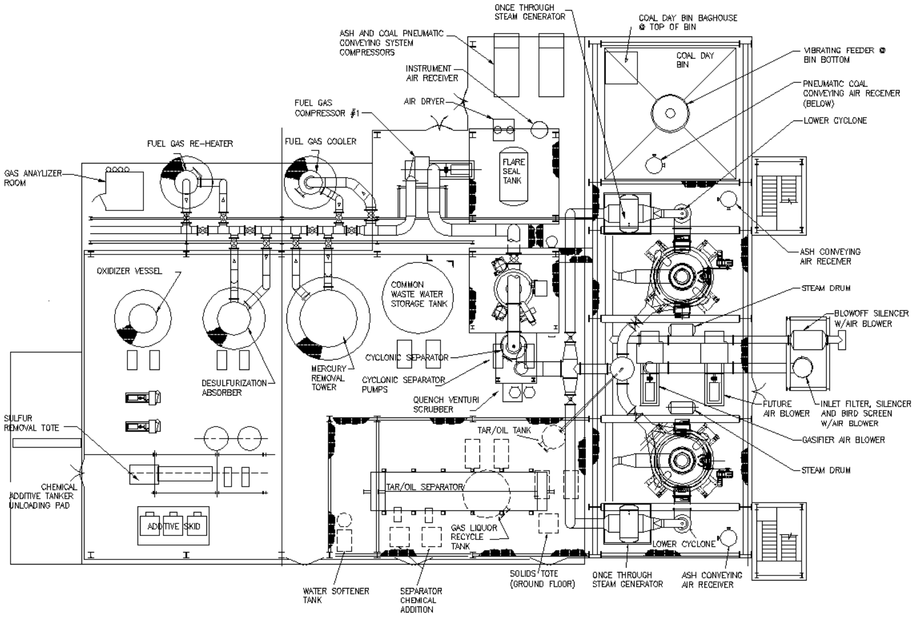

Figure 13. 140 Million BTU per Hour Facility Plan

The elevation view in Figure 14 also shows the flare system for the plant. The flare allows the fuel gas to be disposed in the event of an upset condition either in the gasification facility or in the customer's plant. In the case of an upset that prevents the customer from accepting the fuel gas, the gas is directed to the vent from the delivery point. In the event of a condition that prevents treating the fuel gas in the tar and particulate removal system or in the hydrogen sulfide removal system, the fuel gas is directed to the flare from the gasifier outlet. In either case, the gasifiers would be shut down. Complete shut down of the gasifiers can be achieved with in fifteen minutes of any upset. The flare can also be used briefly during start-up of the gasifiers.

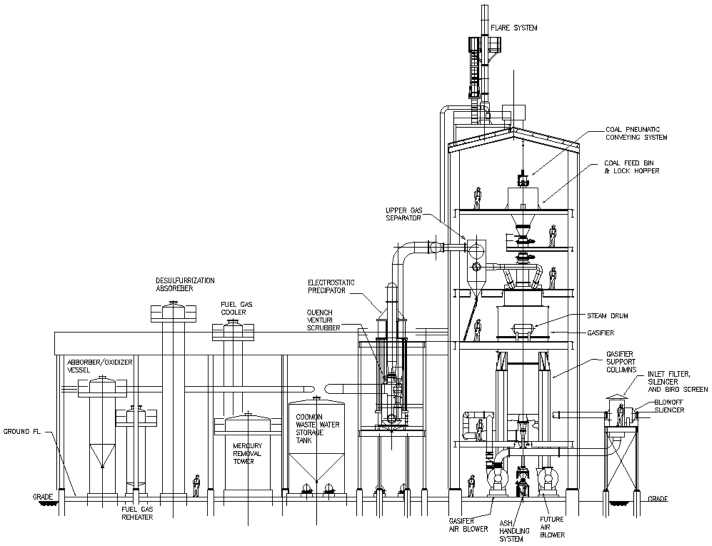

Figure 14. 140 Million BTU per Hour Facility Elevation

MODULARIZATION OF THE DESIGN

A key feature of the EPIC design is the modularity and scalability. This is evident in several facets of the system.

First, the plant can be divided into sections, as described in this paper, for design, procurement and installation. This allows the option of having sub-vendors install and guarantee their own systems.

Second, the plant is designed in such a way that larger facilities are multiples of the basic two gasifier building block. The nominal 140 MM BTU/hr output is based on sub-bituminous Powder River Basin (PRB) coal. Older coals such as Illinois basin or eastern bituminous yield somewhat lower heating values for the fuel gas, meaning lower output in terms of BTUs per hour. The actual output will be a function of the specific coal and the number of modules installed.

Finally, the entire plant has no vessel or equipment, including the gasifier, that is over 14 feet in its critical dimension. That is, all of the equipment can be shipped either fully assembled or in preassembled sections. This minimizes field labor and reduces the erection schedule. This helps keep the capital costs under control.

COMBUSTION PROPERTIES OF FUEL GAS

Recently, certain studies have brought to light some very interesting facts regarding the combustion products of fuel gases. First, the perception that burning lower BTU fuel gas leads to derating boilers and other devices has been shown to be incorrect. Second, a study of thermal NO_x creation has shown a significant reduction when firing a coal based fuel gas.

For some time, there has been a perception that because fuel gases have a lower heating value than natural gas, (typically 170 to 200 BTU/scf LHV for fuel gas vs 910 to 940 BTU/scf LHV for natural gas), there will be a higher gas flow through the boiler or combustor. This is not, in fact, the case. Because the fuel gas requires less oxygen for combustion the total exhaust flows are basically the same with natural gas or fuel gas. The reduced demand for oxygen reduces the amount of combustion air required to achieve the same stoichiometric ratio. This, in turn, reduces the amount of nitrogen introduced with the combustion air. The net effect is to offset the increased volume of fuel. The charts below show the total exhaust flow of a combustor for two cases: 1) a total heat input of 150 MM BTU/hr using either natural gas or fuel gas produced from a Midwestern bituminous coal, and 2) 141.5 MM BTU/hr using either natural gas or a fuel gas produced from PRB coal.

Figure 15 shows the first case. In this instance the calculated total exhaust flow is 42,065 scf/min for the natural gas and 41,619 scf/min for the fuel gas. This is a difference of less than 1% of the total. What is <u>really</u> interesting is that the exhaust flow is actually <u>lower</u> with the fuel gas. This could actually lead to an improvement in boiler performance.

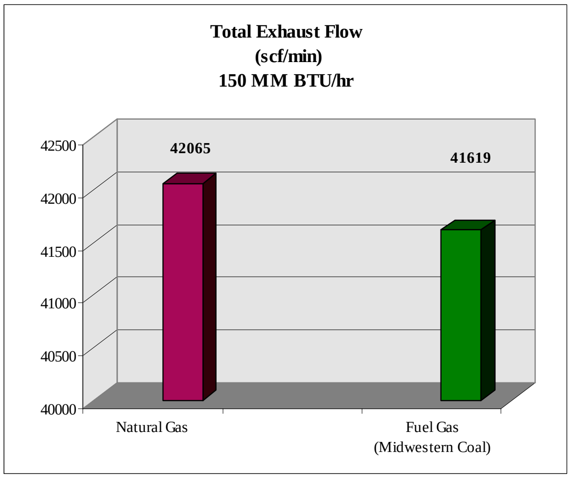

**Figure 15. Total Exhaust Flow for 150 MM BTU/hr Heat Input
Natural Gas vs Midwestern Coal Fuel Gas**

Figure 16 shows the case for 141.5 MM BTU/hr heat input with natural gas compared to a PRB coal based fuel gas. Here the total flow is 39,690 scf/min vs 39,670 scf/min. The difference is within the accuracy of the calculation.

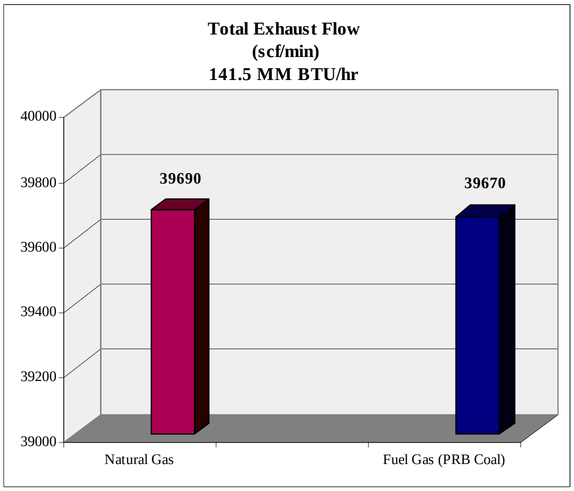

**Figure 16. Total Exhaust Flow for 141.5 MM BTU/hr Heat Input
Natural Gas vs PRB Coal Fuel Gas**

The second effect is the suppression of thermal NO_x formation in burners. EPIC recently commissioned a study jointly performed by Fossil Energy Research Corporation and Reaction Engineering, Inc. to characterize the relative emissions of NO_x in various types of combustors when firing fuel gas compared to natural gas firing. Figure 17 shows the predicted flow rates of thermal NO_x in lbs/hr for natural gas, PRB based fuel gas and Illinois coal based fuel gas for the burners in an industrial boiler. The reduction in thermal NO_x formation is between 60% and 75 %.

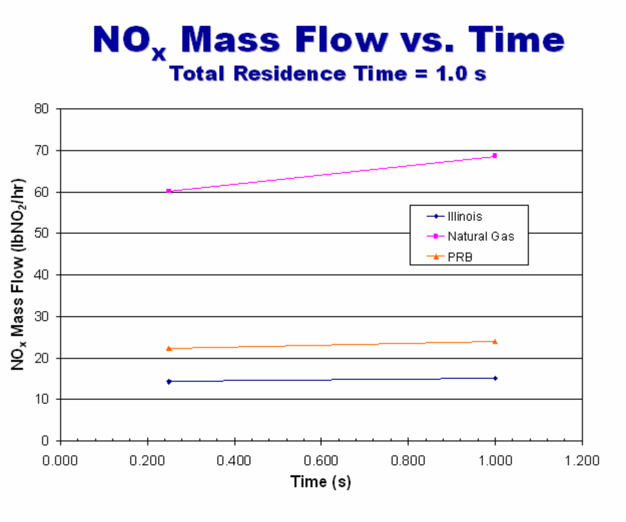

Figure 17. Thermal NO_x Flow in Boiler Burners
For Natural Gas, PRB Fuel Gas and Illinois Coal Fuel Gas

Figure 18 shows thermal NO_x concentration as a function of Frame 7FA gas turbine combustor residence time for natural gas, PRB based fuel gas and Illinois coal based fuel gas. This model assumes that the inlet temperature to the turbine is controlled to be the same for all cases. The reduction in NO_x formation with the fuel gases averages around 50%.

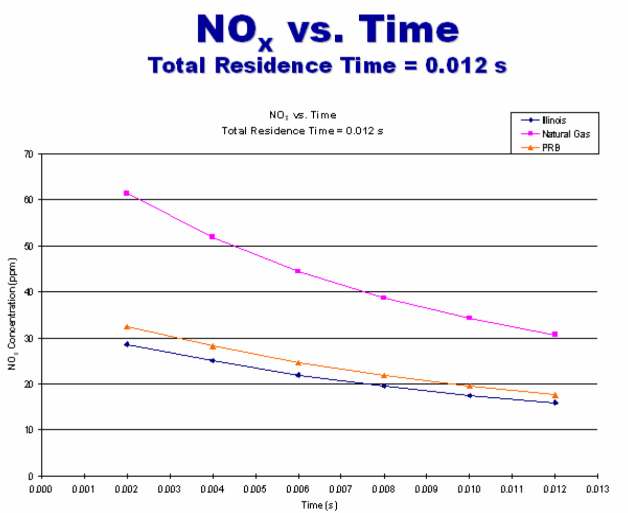

Figure 18. Thermal NO_x Concentration vs Time
For Frame 7FA Turbine
(Constant Turbine Inlet Temperature)

Figure 19 shows the mass flow of thermal NO_x for the same study.

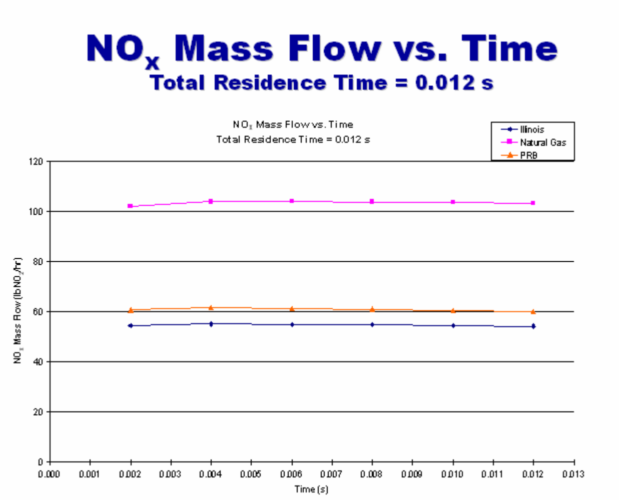

Figure 19. Thermal NO_x Mass Flow vs Time
For Frame 7FA Turbine
(Constant Turbine Inlet Temperature)

INDUSTRIAL APPLICATIONS FOR FUEL GAS

Fuel gas can be substituted for natural gas in any virtually application where natural gas is currently used. The only requirement is that the customer have reasonable availability of coal that can be gasified.

Virtually any boiler can be converted to fuel gas firing. This would include stoker boilers which have been converted to natural gas firing, have gas burners installed, or are facing conversion in order to reduce particulate and SO_x emissions. Given the reduction in thermal NO_x, another interesting application is for boilers which have been de-activated because they could not meet extremely low NO_x, limits in non-attainment areas. Conversion to fuel gas could yield a 70% reduction before any post combustion treatment.

Figure 20 shows a typical stoker boiler conversion where the stoker bed is replaced by a single large gas burner.

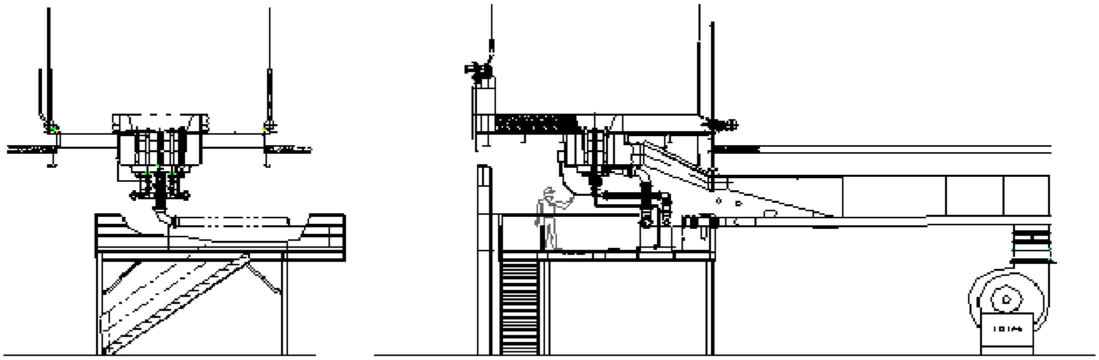

Figure 20. Stoker Boiler Conversion to Gas Using a Single Burner (Courtesy AUS, Inc.)

The drawing sections in this presentation are from the Front End Engineering Design package prepared for a facility to provide fuel gas for supplemental firing of kilns at an iron mine. The fuel gas will also be used in ore dryers. This is a typical installation in the mining and minerals area. In some cases, this segment can have lower conversion costs because the sulfur concentration in the product fuel gas can be somewhat higher. In the mineral processing area, projects are under development for lime kilns and ore roasters.

The emergence of an ethanol market has several projects under development that would use coal gasification to provide 400 to 800 MM BTU/hr for boilers to produce process steam for the ethanol production.

IGCC is a market segment that is typically thought of as being dominated by the larger scale, oxygen-blown gasifier systems. However, there are a growing number of projects in the 200 - 400 MW range which are excellent candidates for the EPIC system. The current reference plant for oxygen-blown gasifiers is a 600MW plant using two Frame 7 turbines. The EPIC air-blown system can economically support projects using a single Frame 7 or smaller turbines.

Yet another application relates to NO_x reduction. For smaller coal fired boilers which are using over firing with natural gas to reduce NO_x emissions, a switch to fuel gas can stabilize fuel costs and further reduce emissions.

Under the right circumstances even utilities can derive a benefit from the smaller, modular EPIC system. In some cases utilities who switched to PRB coal in order to achieve SO_2 compliance without installing scrubbers have found that supplemental firing with natural gas is required to achieve the same total output with the lower heating value of the PRB coal. The EPIC two-stage, air-blown gasifier system can convert the PRB coal to fuel gas and displace the natural gas while stabilizing fuel costs and helping to reduce NO_x emissions.

A final feature of the EPIC system is that it can be used with supplemental fuels such as wood chips or shredded tires or biomass. These supplemental fuels can be used in mixtures with coal of up to 40% supplemental matter. Figure 21 shows a receiving and feed system to blend coal and supplemental fuel.

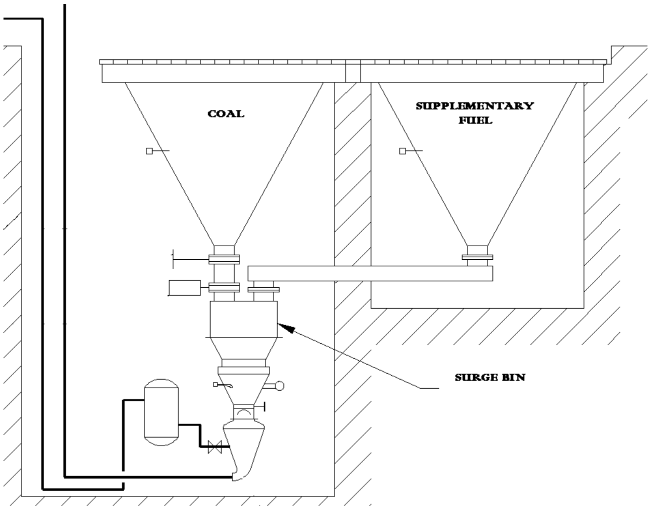

Figure 21. Dual Fuel Feed System

CONCLUSIONS

The EPIC two-stage, fixed-bed, air-blown gasifier system makes coal gasification available to a market segment hitherto not been served, that is, the industrial market of under 1500 MM BTU/hr demand. Other key conclusions follow:

- The system is fully scalable and can be installed for applications from 120 MM BTU/hr and up.
- The system consists of proven subsystems, each of which has many years of proven performance.
- Substitution of fuel gas for natural gas does not require a derating of boilers and may actually improve the performance.
- Substitution of fuel gas for natural gas not only can stabilize costs, but can reduce NO_x emissions.

The EPIC two-stage, fixed-bed, air-blown gasifier system is available for broad use in many applications.