Gasification Based Biomass Co-Firing
Phase I

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Prepared by
Nexant
San Francisco, CA

Principal Investigators
Babul Patel, Nexant Inc., 101 Second Street 11th Floor, San Francisco CA 94105
Kevin McQuigg, Primenergy, LLC, 3172 N. Toledo Street, Tulsa, OK 74158
Robert Toerne, WKE Corp., 145 N. Main Street, Henderson, KY 42419
John Bick, TXU Energy, 1601 Bryan Street, Dallas, TX 75201
Dr. Philip Goldberg, DOE-NETL, 626 Cochrans Mill Road, Pittsburgh, PA 15236

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ABSTRACT

Biomass gasification offers a practical way to use this widespread fuel source for co-firing traditional large utility boilers. The gasification process converts biomass into a low Btu producer gas that can be used as a supplemental fuel in an existing utility boiler. This strategy of co-firing is compatible with variety of conventional boilers including natural gas and oil fired boilers, pulverized coal fired conventional and cyclone boilers. Gasification has the potential to address all problems associated with the other types of co-firing with minimum modifications to the existing boiler systems. Gasification can also utilize biomass sources that have been previously unsuitable due to size or processing requirements, facilitating a wider selection of biomass as fuel and providing opportunity in reduction of carbon dioxide emissions to the atmosphere through the commercialization of this technology.

Nexant Inc., with its team member, Primenergy LLC., and utility partners Western Kentucky Energy Corp. (WKE), and TXU Energy Services, with guidance from Dr. Philip Goldberg of NETL, has undertaken the engineering and economic evaluation of the biomass gasification and co-firing technology under the Department of Energy's Biomass Co-firing program. US DOE's Biomass Program within the office of Energy Efficiency and Renewable Energy sponsored and co-funded this project under a cost share cooperative agreement DOE DE-FC26-00NT40898. This study evaluated two plants: WKE's Reid Plant and TXU Energy's Monticello Plant for technical and economical feasibility. These plants were selected for their proximity to large supply of poultry litter in the area.

The Reid plant is located in Henderson County in southwest Kentucky, with a large poultry processing facility nearby. Within a fifty-mile radius of the Reid plant, there are large-scale poultry farms that generate over 75,000 tons/year of poultry litter. The local poultry farmers are actively seeking environmentally more benign alternatives to the current use of the litter as landfill or as a farm spread as fertilizer.

The Monticello plant is located in Titus County, TX near the town of Pittsburg, TX, where again a large poultry processor and poultry farmers in the area generate over 110,000 tons/year of poultry litter. Disposal of this litter in the area is also concern.

This project offers a model opportunity to demonstrate the feasibility of biomass co-firing and at the same time eliminate poultry litter disposal problems for the area's poultry farmers.

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EXECUTIVE SUMMARY

Integration of poultry litter gasification with conventional PC fired power plant

The purpose of this federally co-funded project is to demonstrate the technical and economical feasibility of biomass gasification and co-firing in an existing pulverized coal fired utility boilers. The primary focus is to use poultry litter as a fuel for the gasification process. However, any other biomass-based fuel that meets the sizing requirements and can be easily transported to the stand-alone gasifier is suitable for this application. Specific objectives of this project are:

- To support commercialization of a biomass co-firing technology that utilizes biomass, agricultural waste and/or farm animal wastes in an environmentally benign, technically practical, and economical application
- To evaluate the technical and economic impact of gasification based co-firing on the existing class of fossil fuel fired boilers currently within proximity of animal waste and agricultural biomass resources of reliable consistency and delivery rates needed for economic operation
- To determine possible modifications, if any, required in either the proposed gasification or boiler technology, for effective utilization of the biomass sources available
- To evaluate these factors specifically for the two plants selected: Reid Plant operated by Western Kentucky Energy Corp., and Monticello Plant operated by TXU Energy
- To develop cost and schedule estimates for implementation at these sites
- To implement such a facility at these sites, provided that the technical and economical evaluations of this study indicate that a useful demonstration of the proposed biomass gasification and co-firing is technically feasible and economically viable

Fuel Supply

The Reid plant is located adjacent to a large poultry processing plant in southwestern Kentucky with over 500 poultry farmers within a 50-mile radius of the plant and estimated litter supply of over 75,000 tons per year.

Monticello plant is located in northeastern Texas with similar large poultry processing plant and estimated litter supply of over 110,000 tons per year. Samples of litter form the both of these areas were analyzed and were comparable to litter analysis found in literature.

Primenergy has analyzed poultry litter samples from various sources, and have estimated an average heating value of the as received litter to be about 10,460 kJ/kg (4,500 Btu/lb) and 14,420 kJ/kg (6,200 Btu/lb) on dry basis, making litter as an acceptable biomass fuel source.

Existing Utility Boilers

Reid Plant Boiler: The existing Reid Plant boiler is a Riley Stoker forced draft, pulverized coal (PC) fired boiler built in 1964. The boiler is rated at 313,000 kg (690,000 lbs) of steam/hr at 90.6 Bars and 513ºC (1300 psig and 955ºF) at the super heater outlet. Primary fuel for the boiler is compliance coal from the local Kentucky coalmines. The boiler was recently converted to a dual fuel system that gives boiler capability of switching to natural gas firing during the NOx mitigation season from May to October.

Monticello Boiler: The unit 1 boiler at the Monticello plant is a Combustion Engineering tangentially fired reheat boiler. The boiler is rated at 1,450,000 kg (3,200,000 lbs) of steam/hr at 248 bars and 814ºC (3600 psig, 1005ºF) at the super heater outlet. The reheat flow is 1,270,000 kg (2,800,000 lbs) of steam/hr at 814ºC and 38 bars (1005ºF and 550 psig). The boiler fuel is 60% Texas lignite from the nearby mine and 40% low sulfur Powder River Basin (PRB) coal from Wyoming.

Proposed Gasifier

The proposed gasifier is a Primenergy KC-18 system consisting of fuel receiving and storage system, fuel feed system, gasifier(s), hot gas filtration system and a two stage after burner combustion system. A single KC-18 will handle 7.6 t/h (8.4 tons/hr) of poultry litter. The KC Reactor/Gasifier is a sub atmospheric pressure, fixed bed, air blown, updraft gasifier. The project evaluated a single KC-18 gasifier for the Reid plant application and twin KC-18 gasifier system for the Monticello plant.

In each gasifier, fuel is introduced by a water-cooled screw conveyor that discharges into the drying and heating zone of the gasifier. The gasification process is controlled by the proportioned injection of gasification and combustion air in a manner that supports efficient gasification. Residence time in the gasifier is varied by a control system that is adjusted to achieve the desired gasification temperature and minimize carbon content of the ash discharged from the gasifier. The use of mechanical bed agitation, precise gasification air control and zoning produces a clean, combustible gas with heating value of between 3,170-5,220 kJ/M^3 (85 to 140 Btu/cu. ft.). In order to minimize impact of the external gasifier on the existing boiler operation, the gases are filtered through hot ceramic filters to remove particulates and other contaminants.

Ash from the poultry litter gasification retains phosphorous and potassium present in the litter while the fuel bound nitrogen is lost with the gasification products. The ash has potential value as P&K fertilizer. The project has investigated potential application and market for the gasifer ash.

Boiler Gasifier Integration

The low Btu gas from the gasifier (producer gas) is at 840ºC (1550ºF) and has a calorific value of about 4,100 kJ/M^3 (110 Btu/std. cu. ft.) The gas is burned in a two-stage combustor, which raises the temperature of the gas to about 1275ºC (2330ºF). The gas can be fed into any existing boiler at a suitable location as additional or supplemental heat input. For the Reid and Monticello plant, the cleaned hot gases can be fed above the existing coal burners, allowing the reduction of the coal, the primary fossil fuel fired into the boiler.

It is estimated that for the Reid case, about 8~10% of heat input can be provided from the gasifier gases, which can allow Reid operators to reduce proportionate amount of coal to the boiler. Similarly, for the Monticello plant ~1% of the heat input into the boiler can be provided with the twin gasifier system.

Conclusions

Due to low sulfur content in the poultry litter, and two-stage combustion process, the gasifier is expected to reduce the SO_2 and NO_x emission from the boiler. With the hot gas filtration system, clean producer gas can be fed into the existing boiler, thus reducing particulate loading on the gas filtration system such as electrostatic precipitator (ESP) or bag house filters of the existing boiler.

Poultry litter is a renewable energy resource. Any fossil fuel fired boilers can proportionately reduce their fossil fuel consumption by gasification based co-firing and can claim a reduction in greenhouse gas emissions (CO_2) from their boiler. The process is technically feasible. Project was able to get concurrence from respective boiler vendors on feasibility of installing additional gas burners on the boiler to fire producer gas from the gasifier. The size and locations of these burners are boiler dependent.

Although, this approach is technically feasible, current economic conditions, and low fuel prices for the coal, primary boiler fuel in the cases examined, did not provide economic incentives for the two utilities (WKE and TXU) to proceed with the demonstration phase of this work. A demonstration phase can provide an opportunity for actual construction of gasifiers at the sites selected and demonstration of the technical feasibility and economic evaluation of gasification based cofiring concept.

1 Introduction

This proposed study is to evaluate technical and economical feasibility of integrated biomass gasification and co-firing in an existing utility boiler. The project examined two different sites: Reid Plant boiler operated by Western Kentucky Energy and Monticello Plant operated by TXU Energy. Primary focus of the study was to utilize poultry litter as a fuel for external gasification and feed the resulting low Btu producer gas into the existing utility boiler at these sites. Specific objectives of this project are:

- To evaluate the technical and economic feasibility of gasification based co-firing on the existing class of fossil fuel fired boilers currently within range of animal waste and agricultural biomass sources of reliable consistency and delivery rates needed for economic operation
- To determine possible modifications, if any, required in either the proposed gasification or boiler technology, for effective utilization of the biomass sources proposed
- To evaluate these factors for two specific cases: for the Reid Plant operated by Western Kentucky Energy Corp. and Monticello Plant operated by TXU Energy.
- To develop detailed cost and schedule estimates for implementing gasification based biomass co-firing at these two facilities.
- Future implementation of such a facility if all of the estimates and evaluations indicate that a useful demonstration of the proposed biomass gasification and co-firing technology can be economically justified.
- To support commercialization of biomass co-firing technology that utilizes biomass, agricultural waste and farm animal wastes in an environmentally benign, technically practical application, provided it is economically viable.

1.1 Background Information

The technical and economic feasibility study was conducted for WKE's Reid plant located in Henderson County, KY, and for TXU Energy's Monticello plant located in Titus County, TX. Detailed background information on the Reid plant, Monticello plant and Primenergy's fixed bed updraft gasifier is provided in Section 3. For both cases Primenergy, LLC, KC-18 series gasifiers were selected, a single KC-18 for the Reid plant and twin KC-18 system for the Monticello case were considered. Nexant, Primenergy and Western Kentucky Energy (WKE) for the Reid case and Nexant, Primenergy and TXU evaluated a gasification system to be located in the vicinity of the existing boilers to provide producer gas as a supplemental fuel and to displace a portion of the primary boiler fuel, coal and / or natural gas.

1.2 Gasification Based Cofiring Concept

The gasification based cofiring can best be represented by the following schematic in figure 1-1. As shown in the schematic, the primary boiler fuel and the biomass fuel are treated and utilized separately. This approach avoids the traditional problems associated with cofiring, where biomass is directly introduced in to an existing boiler, namely fuel handling and fuel delivery into the boiler, boiler slagging and altered ash characteristics and based on moisture content of the biomass an altered combustion pattern within the boiler.

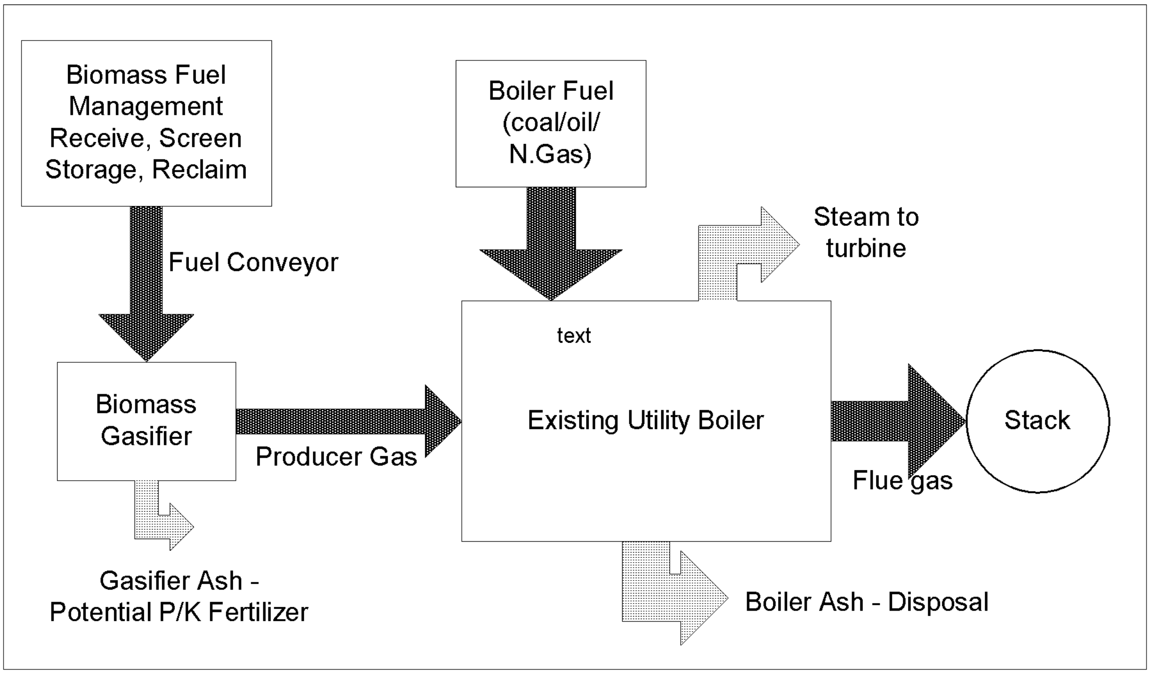
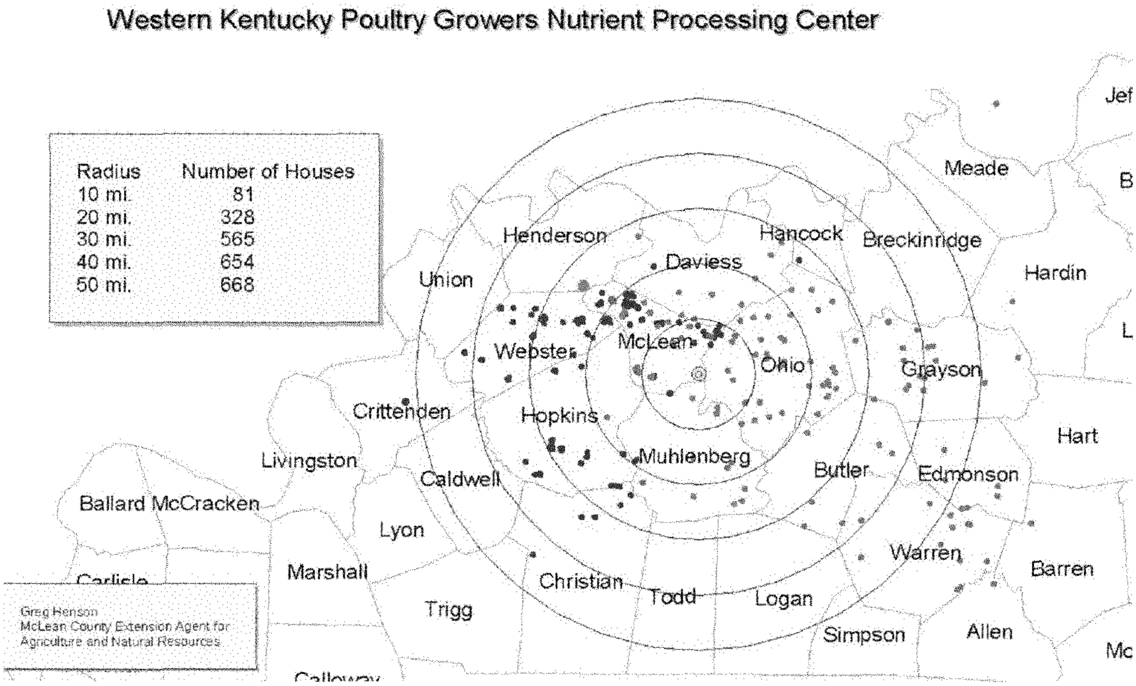


Figure 1-1 Gasification Based Biomass Co-firing System Diagram

1.3 Western Kentucky Energy Case

The WKE's Reid plant is located near Henderson, Kentucky. It is a 63 MWe coal-fired unit with a pulverized coal-fired Riley Stoker boiler. The boiler uses Western Kentucky coal. The boiler has maximum continuous capacity (MCR) of 313,000 kg (690,000 lbs) of steam/hr at 90.6 Bars and 513°C (1300 psig and 955°F) at the super heater outlet.

The Reid plant operated by WKE in Henderson County is in an ideal location for the proposed demonstration project since it is adjacent to a Tyson Foods chicken processing plant and associated chicken farms. The total yield of poultry litter from the farmers in the vicinity is expected to be a greater than 75,000 tons per year. Figure 1-2 show concentration of poultry farmers within 50-mile radius in Western Kentucky, with center at McLean County, about 20 miles from the Reid plant.[1] The map shows that within 50-mile radius, there are 668 poultry houses. These poultry farmers are primarily associated with the Tyson Foods plant near the Reid plant in Robards, KY. Another poultry producer, Purdue Farms operate a large processing plant in Cromwell, KY, about 65 miles due southeast from the Reid Plant. Poultry farmers associated with Purdue Farms may overlap in this map.



Radius	Number of Houses
10 mi.	81
20 mi.	328
30 mi.	565
40 mi.	654
50 mi.	668

Greg Henson
McLean County Extension Agent for Agriculture and Natural Resources

Figure 1-2 Poultry Supply in Vicinity of Reid Plant

For the Reid plant a single gasifier with 8 tons/h of litter (54,000 tons/year) was considered. This provided about 10% of the total boiler energy input from the gasification based cofiring. A detailed technical and economical analysis for this case is provided in Section 3.

1.4 TXU Energy Case

TXU Energy's Monticello Plant is located near the cities of Mount Pleasant and Pittsburg in Titus County, TX. The Monticello is a 3-unit coal/ Texas lignite fired plant. For this study, Monticello Unit 1 was selected. The unit 1 Monticello boiler is a Combustion Engineering tangentially fired reheat boiler. The boiler is rated at 1,451,500 kg (3,200,000 lbs) of steam/hr at 250 Bars (3600 psig) and 540ºC (1005ºF) at the super heater outlet. The reheat flow is 1,270,000 kg (2,800,000 lbs) of steam/hr at 540ºC (1005ºF) and 40 Bars (550 psig). The boiler is fueled by 60% Texas lignite from the nearby mine and 40% low sulfur Powder River Basin (PRB) coal from Wyoming.

The Monticello plant is also an ideal location for poultry litter supply. Table 1-1 below shows estimated poultry, broiler, and pullets production within six county regions around the Monticello plant. [2]

Table 1-1 Poultry production estimate by Texas Agricultural Department (1997)

County	Camp	Titus	Franklin	Morris	Wood	Total
Total broilers/pullets and other chickens	50,359,409	18,223,679	15,081,030	5,783,000	14,183,669	**103,630,787**

Estimating about 1 kg (2 lbs.) of litter and bedding material per bird, there is estimated 100,000 t/y (105,000 tons/year) of litter supply in the vicinity of the plant. Pilgrim's Pride, the large poultry processor in Mount Pleasant and Pittsburg, TX estimates that there is nearly 200,000 tons/year of litter supply in the 80 km (50-mile) radius of the plant.

For TXU case, we designed gasifier for a feed rate of 14,350 t/h of litter or about 115,000 t/year of litter consumption. This rate produces about 2% of the total energy input to the Monticello Unit 1 boiler.

1.5 Primenergy Gasifier

The Primenergy gasifier is a fixed-bed updraft system. Because this gasifier is a sub atmospheric and an updraft device, it is a comparatively lower cost system than other types of gasifiers. In the updraft system most of the tars are cracked by partial oxidation of the product gas, which increases the temperature of the product while reducing the condensable long chain and cyclical hydrocarbons to fragments. Figure 1-3 is a schematic of the Primenergy gasifier.

The Primenergy gasifier has already been used for electricity generation in stand-alone plants. Typically it is installed to gasify biomass, with the gas being combusted immediately and ducted to a heat recovery steam generator (HRSG). The HRSG then generates the steam for use in a turbine. The largest design for a single Primenergy gasifier is 100×10^6 kJ/h (100×10^6 Btu/hr). Multiple gasifiers can be installed to increase overall system capacities. Typical capacities of the electricity generating systems based upon the Primenergy gasifier are less than 15 MWe, and the typical HRSG steam conditions have been at or below 60 Bars (850 psig).

These stand-alone plants have been installed to manage rice hulls and rice straw, wood waste, switchgrass, and other feeds. The gasifier has shown that it can successfully handle materials up to 50-55 percent moisture, although the product gas quality suffers with high moisture feedstock. Testing for the Southeast Regional Biomass Energy Program (SERBEP) has demonstrated the substantial feedstock flexibility of this system.

Among the Primenergy gasification applications is the 300 t/d (330-ton/day) rice hull gasifier installed for Cargill Rice Milling of Greenville, MS. This installation delivers sufficient heat to a HRSG to generate 5 MW of electricity, and 6,800 kg/h (15,000 lb/hr) of process steam. Key to this installation are methods for removing virtually all of the ash as bottom ash while generating a gas that is substantially free of tars through partial oxidation of the gas exiting the gasifier itself. Other applications of this system with different fuel exhibit similar characteristics.

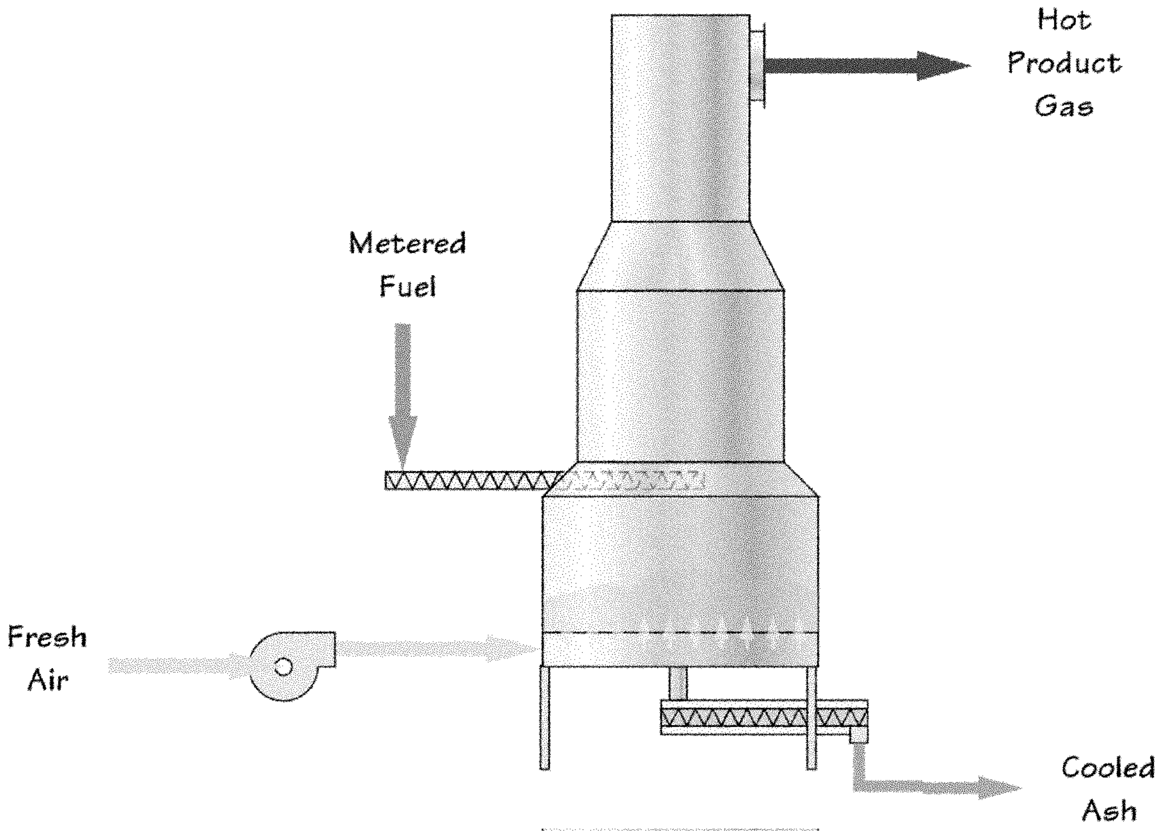


Figure 1-3 Primenergy Gasifier – simplified sketch

1.6 PHASE I Organization, Tasks and Schedule

The gasification based biomass co-firing project has reviewed and evaluated technical feasibility and economical viability of building and operating poultry litter gasifier at WKE's Reid plant near Henderson, KY, and TXU Energy's Monticello plant near Mount Pleasant and Pittsburg, TX. The project has reviewed the existing plant design and operation; evaluated available poultry litter supply, and prepared preliminary engineering design; specification and plant layout for construction and installation of the gasifier systems. The project also estimated impact on plant emissions due to cofiring. Based on the engineering design, plant layout, and fuel cost, project has prepared a pro-forma cost analysis for both WKE and TXU cases.

The overall project was planned for two phases. Under Phase I, the project has addressed feasibility and economic issues. If economically viable and if desired by the respective utility/ plant owners, a Phase II actual demonstration of the technology can be pursued. At present, due to unfavorable economics, the two participating utilities, WKE and TXU have not committed to the Phase II.

During the Phase I, the project team undertook a detailed feasibility study of integrating the existing utility boiler plant with Primenergy's gasifier unit utilizing poultry litter as primary feedstock. Project Organization for the Phase I study is shown here in figure 1-4.

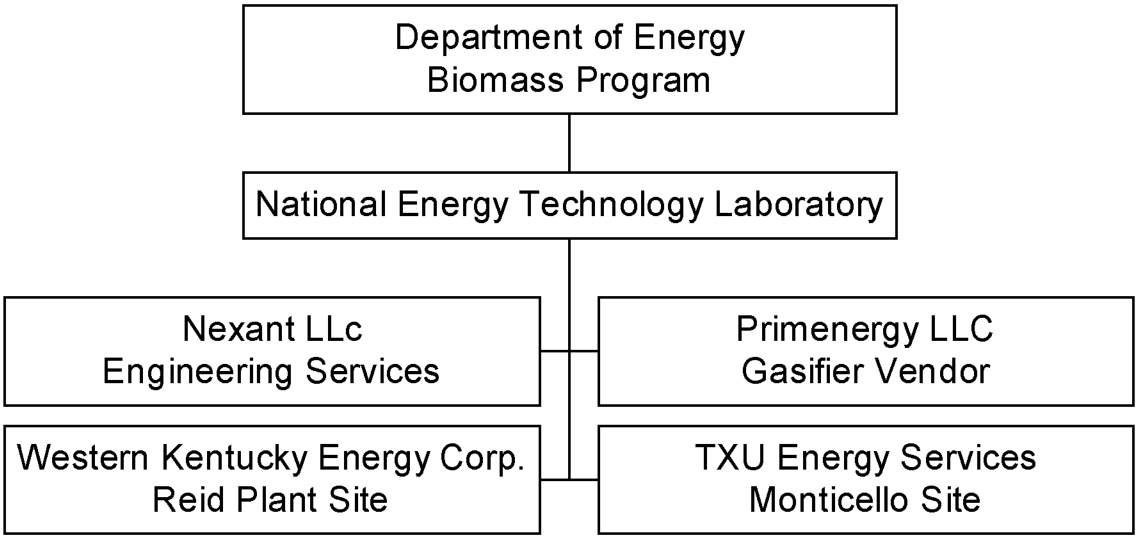


Figure 1-4 Project Organization Chart

The specific tasks that were performed under Phase I are:

- Conceptual engineering of the gasification facility, including the fuel handling aspects of the facility
- Equipment selection, integration with existing boiler and plant layout
- Fuel characterization, including proximate and ultimate analysis of the poultry litter, Btu content, moisture and size variation, ash characterization.
- Fuel availability assessments, focusing upon the availability of low, zero, and negative cost biomass. This effort is concentrated on locally available poultry litter, but project has also examined other biomass in the area.
- Modeling of the existing boiler to determine any de-rating issues

- Economic assessment of gasification-based co-firing evaluating the fuel cost implications on the overall cost of power generation

A detailed work plan by major tasks for Phase 1 is provided here. Figure 1-5 illustrates the logical flow of work undertaken in this program. At each of these stages, criteria for proceeding to the next stage were established. When the concept met all of the technical requirements than economical feasibility was assessed. The market analysis is based on both the technical and economic data developed by the project.

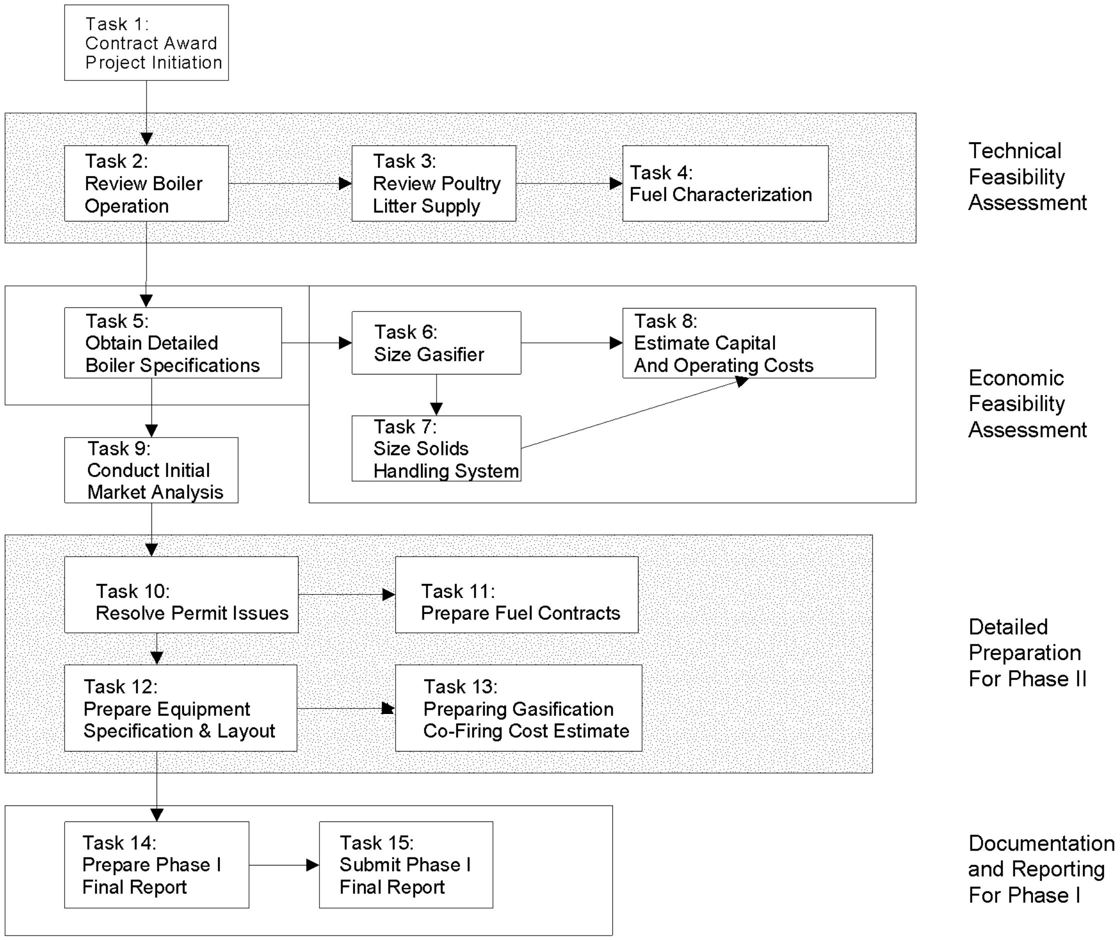
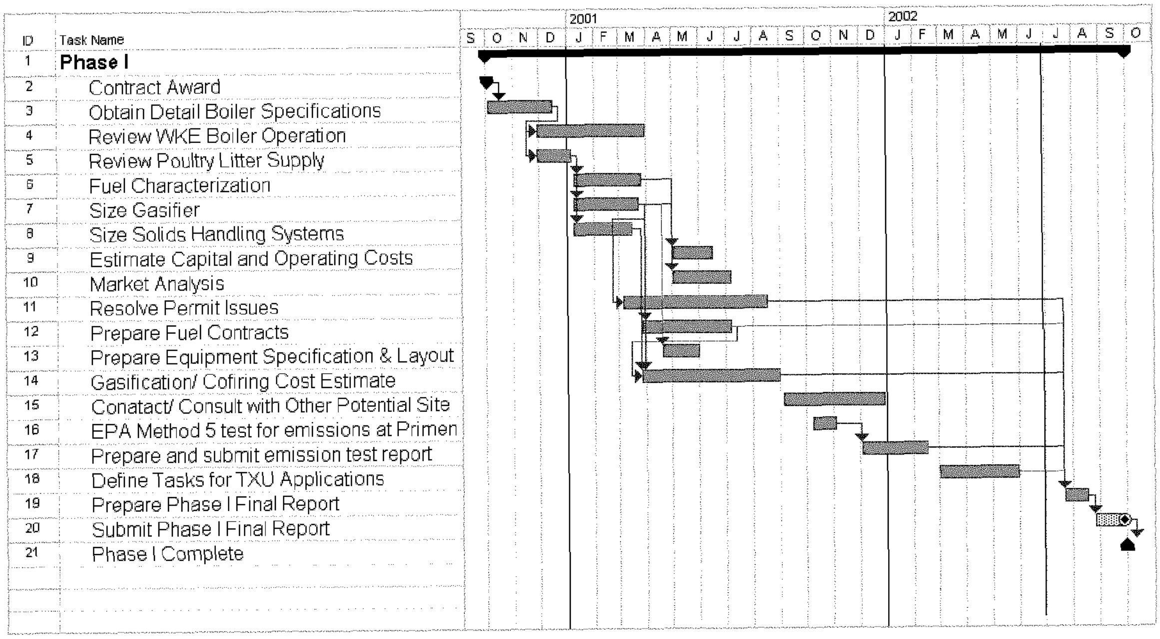


Figure 1-5 Interrelationships of Tasks in Phase I

The schedule for the proposed tasks is shown in 1-6.



ID	Task Name
1	**Phase I**
2	Contract Award
3	Obtain Detail Boiler Specifications
4	Review WKE Boiler Operation
5	Review Poultry Litter Supply
6	Fuel Characterization
7	Size Gasifier
8	Size Solids Handling Systems
9	Estimate Capital and Operating Costs
10	Market Analysis
11	Resolve Permit Issues
12	Prepare Fuel Contracts
13	Prepare Equipment Specification & Layout
14	Gasification/ Cofiring Cost Estimate
15	Conatact/ Consult with Other Potential Site
16	EPA Method 5 test for emissions at Primen
17	Prepare and submit emission test report
18	Define Tasks for TXU Applications
19	Prepare Phase I Final Report
20	Submit Phase I Final Report
21	Phase I Complete

Figure 1-6 Project Milestone Schedule

2 Technology Evaluation

Understanding the gasification approach to co-firing requires a review of the current status of co-firing, the issues raised and the lessons learned, and the consequent market position of direct combustion co-firing. Identifying how gasification addresses the unresolved issues of direct combustion co-firing facilitates this understanding.

2.1 Overview of Co-firing Technologies

There are two principal co-firing technologies that have been tested in the power plant boilers with some success. But long-term continuous co-firing has not been adopted due to unresolved issues identified in Section 2.2.

2.1.1 Low Percentage Co-firing:

Low percentage co-firing is typically designated as blending <5 percent biomass (mass basis) with coal as primary fuel for the boiler. The biomass component is typically <2 percent of the heat input to the boiler.

There have been several low percentage co-firing tests and demonstrations, including the following:

- Colbert Fossil Plant, TVA
- Shawville Generating Station, GPU Genco
- Kingston Fossil Plant, TVA
- Plant Hammond, Georgia Power Co.
- Plant Yates, Georgia Power Co.

These tests and demonstrations provided critical results for co-firing. They demonstrated that co-firing at low percentages does not impact boiler stability, operability, or efficiency. Further, it does not impact airborne emissions.

2.1.2 Direct Combustion Co-firing with Separate Feed Systems

There have been several demonstrations of co-firing using separate feeding of biomass into the boiler. In these demonstrations the biomass is reduced in particle size to an acceptable level (typically 6 mm or <1/4" for wood waste) and then pneumatically transported into burner systems of the boiler. In these systems, biomass typically supplies about 5 to 10 percent of the heat input to the boiler, or 10 to 20 percent of the mass input of fuel to the boiler. This approach has been tested by co-firing with wood waste and with processed switch grass at following facilities:

- Seward Generating Station, GPU Generating Co (wood waste)

- Greenidge Station, NYSEG (wood waste)
- Plant Kraft, Savannah Electric (wood waste)
- Blount St. Station, Madison Gas & Electric (switch grass)

These tests all documented the fact that if separate feeding were employed and if there was no impact on the coal delivery system, boiler capacity would not be impaired by co-firing. In cases where biomass was substituted for coal in coal burners, capacity impacts did occur as a consequence of substituting a low Btu fuel for a high Btu fuel. However, in most cases the biomass injection was independent of the coal injection. Co-firing provided capacity assistance, particularly in conditions where wet coal was being burned. Particle size becomes a concern. Wood waste particles must be < 6 mm (<1/4") while switch grass must undergo maximum particle size reduction to achieve acceptable minor dimension values. Concerns are both for the kinetics of combustion and the aerodynamic properties of the fuel, keeping the fuel from simply falling in to the bottom ash pit.

While co-firing with separate feeding resolved the capacity issue, it provided additional benefits as well as concerns. Boiler efficiencies were reduced modestly, based upon the moisture in the fuel and the hydrogen content of the fuel. When co-firing at 10 percent by heat input, there was no need to increase the excess air to the system, and there was no increase in the air heater exit temperature. Unburned carbon increases were modest, and statistically insignificant. Emissions were reduced. SO_2 emissions were reduced as a function of co-firing a sulfur-free fuel. NOx, emissions were reduced consistently in wall-fired PC boilers and in cyclone boilers; the data on these emissions are not as consistent in tangentially fired PC boilers. Opacity emissions improved in some cases, but not in others.

2.1.3 Issues remaining to be resolved with co-firing

The low percentage co-firing tests identified two issues: pulverizer capacity and ash management. When the capacity of a boiler is limited by the capacity of the pulverizers, co-firing can have significant impacts on overall system capacity. Ball and race mills experienced increased feeder speeds and increased amps and power consumption. Bowl mills experience decreased mill outlet temperatures and increased amps. A 3 percent co-firing level can decrease capacity by as much as 6 to 8 percent when pulverizer limitations are severe. When co-firing is practiced, the biomass fly ash is commingled with the coal fly ash. While many types of biomass are very low in ash, some are not. Further, there is a definitional issue with respect to ASTM Specification C-618, the pozzolan specification. That document clearly defines fly ash as coal fly ash. While the history of that specification includes considerations for excluding municipal waste fly ash from use in concrete mixtures, the consequence is to prevent the sale of any co-firing or biomass firing fly ash in concrete mixtures.

Co-firing that uses separate injection and direct combustion does avoid the fuel feed system limitations but does not address the issue of commingled ash. Consequently, for plants selling fly ash, the high-end concrete market may remain unavailable.

2.2 Gasification Technologies

Direct combustion does not represent the only method of co-firing biomass with an existing fuel. Biomass can be gasified to produce a combustible gaseous product that can also be used in existing boilers.

Biomass gasification and pyrolysis is a technology that has existed for over 100 years. Research into this technology was particularly active in the 1920's and 1930's, when the use of biomass for vehicular travel was being pursued. With the advent of low cost oil and natural gas, interest in biomass gasification waned. However, with the dramatic oil price shocks of the 1970's and with subsequent environmental pressures, interest in biomass gasification has become substantial and several new projects have been put forward for funding and financing.

The principles of thermal gasification for biomass have been well established. The reaction sequences include fuel-drying, pyrolysis to produce gaseous compounds and chars, and reactions of those gaseous compounds and chars to form the producer gas product. Pyrolysis of biomass is the degeneration of cellulous, lignin and the other biomass building blocks that produces a full range of compounds ranging from hydrogen and methane to long chain condensable hydrocarbons, commonly referred to as tars. Secondary reactions include the steam-carbon reaction producing CO and H_2 from the char (eq. 2-1), the water-gas shift reaction to increase the H_2 content in the gas (eq. 2-2), and the Boudouard reaction generating CO from the char and the $C0_2$ in the product gas (eq. 2-3).

$$C + H_20 \Leftrightarrow CO + H_2 \qquad \text{(eq. 2-1)}$$

$$CO + H_20 \Leftrightarrow H_2 + C0_2 \qquad \text{(eq. 2-2)}$$

$$CO_2 + C \Leftrightarrow 2C0 \qquad \text{(eq. 2-3)}$$

The tars formed typically begin to condense out of the gas at about 425°C (800°F). To prevent this, the gas can be maintained at elevated temperatures so the tars can be combusted with the gas, cracked into non-condensable components by passing the tar laden gas over a catalyst at elevated temperatures, or scrubbed out of the gas.

Most of the char is combusted in the gasifier system to provide heat for the pyrolysis. Any char not completely converted to gas is usually discharged with the ash products. Inorganic matter (e.g., potassium in the ash) may remain in the solid phase or may exit with the gas in the vapor phase.

Pyrolysis takes place without the presence of free oxygen, i.e. air; while gasification is done under sub-stochiometric conditions, with less than required amount of oxygen for complete combustion. The use of air will dictate the heating value of the product gas. Pyrolysis of biomass in the absence of air will provide a medium calorific value gas while air blown gasification systems will provide a low calorific value gas. If air is present, the ratio of free oxygen input to biomass feed is typically around 0.30.

The simplest air gasifier is the updraft (counter flow) gasifier, in which air is introduced to the biomass through grates in the bottom of the furnace. Rather high temperatures are generated initially where the air first contacts the char, but the combustion gases immediately enter a zone of excess char, where any CO2 or H20 present is reduced to CO and H_2 by the excess carbon. As the gases rise to lower temperature zones, they meet the descending biomass and pyrolyze the mass in the range of 205°C (400°F) to 480°C (900°F). Continuing to rise, they contact wet, incoming biomass and dry it. The counter flow of gas and biomass exchanges heat so that the gases exit at low temperatures.

Simplicity is a major advantage of these systems, and countercurrent gasification has long been employed both for biomass and coal. The original Lurgi gasification system is an updraft gasifier. However, the updraft gasifier has several drawbacks. First, the gasification zones, while maximizing mass transfer, also produce a gas sufficiently low in temperature to contain a wide variety of chemicals, tars, and oils that are generated in the pyrolysis zone. Because of the low gasifier exit temperatures, these contaminants can be allowed to condense in cooler regions of the gasifier exhaust pathway designed for this purpose, before the producer gas is transferred for co-firing in the boiler.

Alternatively, the producer gas can be partially oxidized to elevate its temperature above the tar condensation limit. For this reason, this gas is generally used in the "close-coupled" mode in which it is mixed immediately with air and a portion burned completely to CO_2 and H_20. The close-coupled mode is quite suitable for supplying a biomass gas to existing coal, oil or gas furnaces. The higher temperature at the gasifier grate may melt the ash and produce slagging on the grates with feedstock such as rice hulls and corncobs.

Primenergy, of Tulsa, OK, currently is a leading supplier of updraft or countercurrent gasifiers. Their technology has been applied to a wide variety of biomass including wood waste, rice hulls, switch grass, and other biomass feedstocks. These types of gasifiers have been installed in a variety of applications throughout the world, including a significant number of cogeneration applications. Initial gasification runs using poultry litter in the Primenergy gasifier indicates that these environmental and operating issues can be controlled to acceptable levels, but this performance needs to be verified for the conditions when the gasifier is coupled with existing boiler and can be tested.

The process proposed for this application is an air blown gasification. In this system, coarse biomass is processed in a thermal gasifier, with the product gas being fired in a boiler. The gas will be unconditioned and fired at elevated temperatures 540°C -875°C (e.g., 1,000°F -1,600°F). If conditioning is required, the gas may be cleaned and partially quenched prior to use.

When this technique is used in coal-fired boilers, separate gas burners are required. Similarly, if this technique were used in natural gas-fired boilers, separate burners designed for low Btu gas would be necessary. Air-fuel ratios for natural gas combustion and for low Btu gas combustion are sufficiently different, and gas volumes are different, to make this adjustment necessary.

Gasification-based co-firing has not been widely practiced. However it is the basis for this proposed activity.

2.3 Hot Gas Filtration System

Hot-gas cleanup and filtration technologies play an important role in the gasification process. The main difference between hot gas cleanup systems (HGCUs) and conventional particulate removal technologies (ESP and baghouses) is that HGCUs operate at higher temperatures (500 to 1,000°C) and pressures (1 to 2 MPa), which eliminates the need for cooling of the gas.

HGCU technologies include ceramic candle filters, ceramic cross-flow filters, screenless granular-bed filters, acoustic agglomerators and hot electrostatic precipitators.

In a ceramic candle filter system, the hot gases from the gasifier flows from the outside of the candle to inside. The particulates are collected on the outside surface of the candles, and the clean gas flows to the top of the pressure vessel and the stack through the gas outlet. Periodic cleaning of the candles is done by injecting nitrogen or other inert gases from the blowback air reservoir.

Typical HGCUs can meet up to 99.9 percent removal efficiency of particulates larger than 10 microns.

2.4 Environmental Impact of Gasification

The greenhouse gases, primarily carbon dioxide, (CO2), methane (CH4), and pollutants namely nitrous oxide (NOx), sulfur dioxide (SO2) and particulates which are associated with industrial and agricultural activities, affect earth's environment and have significant impact on the climate. Table 2-1 shows selected greenhouse gasses that have been present in Earth's atmosphere due to both natural and human activities prior to pre-industrial period and the current period.[3]

Table 2-1 Selected Greenhouse Gases Prior to 1850 v/s 1994

	Carbon Dioxide	Methane	Nitrous Oxide
Pre Industrial Concentration (Prior to 1850)	278 ppmv	700 ppbv	275 ppbv
Concentration in 1994	358 ppmv	1720 ppbv	312 ppbv
% Change from Pre-industrial times	29%	146%	13%

One way to reduce these green house gases is to displace some of the carbon that is now emitted to the atmosphere from the combustion of fossil fuels with carbon derived from renewable resources. No new net atmospheric buildup of CO_2 or methane occurs in biomass combustion when the biomass is grown on a sustainable basis, because the released carbon dioxide is largely compensated by the amount of carbon dioxide withdrawn from the atmosphere during photosynthesis in the growth cycle.

Table 2-1 shows that the global average methane concentration in 1994 has more than doubled since pre-industrial times. One source of methane is from anaerobic decomposition of organic material in livestock and poultry manure. The reduction of methane released to the atmosphere can be achieved by installing recovery systems that extract methane as a fuel from the anaerobic digestion of liquid manure, but it is profitable only for large farms in warm climates where anaerobic processes can be more readily sustained. Alternatively, this manure can be converted in a gasification system to recover useful energy and, at the same time, reduce methane emissions.

The poultry litter has been gasified and tested for emission by Primenergy at their Tulsa, OK commercial size test facilities in accordance with US EPA standards. The unabated test data collected during the demonstration testing are presented here in Table 2-2 for evaluation.[4] The test was conducted on the stack after burning the producer gas from the gasifier in the heat recovery steam generator. This data were collected by a third party stack testing outfit for Primenergy.

As shown in the table, the gasification process can be used to reduce the amount of greenhouse gases and other pollutants that result from decaying biomass while producing useful thermal energy and displacing the fossil fuel.

Table 2-2 Unabated Emissions Data for Poultry Litter Test Gasification Run

Component	Value
NO, ppmvd	477
CO, ppmvd	0.88
SO_2, ppmvd	193
Non-methane hydrocarbons, ppmvd	2.46
Particulate matter, gr/dscf	0.33
O_2, ppm dry volume	11.5

Source: CETCON, INC. " Summary of Results: Test No. C1", September 15, 1997.

Under cofiring, application, the litter can be used to reduce other pollutants from the coal plant by reducing the amount of coal burned. The following table 2-3 provides a comparison between the coal plant emissions and expected emissions from gasification and controlled combustion of the producer gas in a boiler.

2.4.1 Comparison of Coal v/s Litter Burn

Typical coal and litter samples and expected emissions from the two sources can be estimated. In estimating the emissions presented in Table 2-3, following assumptions are made:

- S in coal is elemental S and hence ends up as SO_2 in complete oxidizing environment normally present in a coal fired boiler. S in the litter is compound S and as such, some of it remains in the ash as Alkaline sulfates. Hence, the calculated 1.02 kg/MJ (2.14 lbs/MMBtu SO_2) is high end SO_2 when gasifying litter. It is expected that may be 50% of the S will remain in the ash, as evident from elemental analysis of ash with 4% SO_3 in the ash. Thus, litter gasification in a cofiring application can reduce SO_2 from high sulfur burning coal plant.

- On GJ (MMBtu) basis, carbon is about the same in litter and coal, and hence CO_2 emissions from litter or coal are a wash. However, from life cycle perspective, CO_2/ Carbon is considered closed loop for biomass, and hence no new net CO_2 is introduced in to atmosphere from the chicken/ litter cycle.

- N in the coal is elemental N and all NOx produced is thermal NOx due to combustion in the air. Litter has high bound nitrogen that is gasified into amines, amines, urea, etc. If burned in regular boiler in an oxidizing atmosphere, it will generate very high NOx – as much as 2000 ppm. But by external after burn in a reducing atmosphere, the amines, amines, urea, etc. are broken down into elemental N and water/CO2. Primenergy expects NOx from gasifier to be less than 0.40 lbs/MMBtu.

- Gasifier will generate about 4 times the ash on MMBtu basis. However, this is organic ash – with high P and K compound and as such has good value as fertilizer as well as supplement to animal feed. We are investigating after market for the ash to offset the cost of acquiring the litter.
- Litter does not have any detectable level of heavy metals, such as Hg, As, Pb, Cd, etc. Hence, there will not be any detectable level of these heavy metals in the gasifier producer gas.

Table 2-3 Coal and litter composition and expected emissions

Coal	per kG (per lb)	kg/MJ (lbs/MMBtu)	Expected Combustion Products	kg/MJ (lbs/MMBtu)	Comments
LHv kJ/kg (Btu/lbs)	11,826 (11,200)	-		-	
S	0.01 (0.03)	0.96 (2.23)	SO_2	1.92 (4.46)	
C	0.29 (0.64)	24.38 (56.72)	CO_2	89.39 (207.99)	
H	0.02 (0.05)	1.73 (4.02)	H_2O	15.55 (36.16)	
N	0.01 (0.02)	0.58 (1.29)	NOx	0.34 (0.78)	(as reported)
Ash	0.05 (0.12)	4.57 (10.63)	Ash	4.57 (10.63)	
Litter					
LHv kJ/kg (Btu/lbs)	4,435 (4,200)				
S	0.00 (0.01)	0.51 (1.07)	SO_2	0.60~1.02 (1.25 ~2.14)	Calculated Assuming 50% remain in ash
C	0.11 (0.25)	25.18 (58.57)	CO_2	92.34 (214.76)	
H	0.01 (0.03)	2.76 (6.52)	H_2O	24.88 (58.71)	
N	0.01 (0.03)	2.56 (5.95)	NOx	0.17 (0.36~0.40)	Estimate –after burn
Ash	0.09 (0.19)	19.66 (45.71)	Ash	19.66 (45.71)	

From Table 2-3, it is evident that the biomass offers a unique opportunity in energy production, with benefits of life cycle reduction in carbon dioxide and better management of methane from the agricultural waste.

3 Project Evaluation

3.1 WKE Case

3.1.1 WKE Reid Plant

The WKE's Reid plant is located near Henderson, Kentucky. It is a 63 MWe coal-fired unit with a pulverized coal-fired Riley Stoker boiler. The boiler uses Western Kentucky coal. The boiler has maximum continuous capacity (MCR) of 690,000 lbs./hr of steam at 1300 psig and 955 deg. F.

Detailed Specifications of the boiler vendor and a boiler schematic (Figure 3-1) are provided here.

Reid Plant Boiler Specification by Riley Stocker Co.[5]

Location	Henderson Co. KY
WKE Contract	B2502
RILEY Boiler Contract No	B2502
RILEY Fuel Burning Contract No	TM6833.
RILEY Boiler Serial No	3456
Year Built	1964
Rating based on burning specification coal	
Maximum Continuous Steam Capacity (MCR)	690,000 lbs./hr
Peak Steam Capacity, (for four hrs.)	760,000 lbs./hr
Type of Furnace Operation	Pressurized
Drum Design Pressure	1475 psig
Economizer design Pressure	1525 psig
Operating Pressure at Super heater Outlet	1300 psig
Steam, Temperature at Superheater Outlet	955°F
Furnace Volume	50,250 cuft
Heat Release (at 690,000 lbs./hr. capacity)	16,600 Btu/cuft/hr
Heat Release (at 760,000 lbs./hr. capacity)	19,400 Btu/cuft/hr
Heating Surfaces (Per Manufacturer's Stamping Sheet)	
Boiler	4,020 sq. ft
Water Walls	12,100 sq. ft
Superheater	32, 330 sq. ft
Economizer	4,200 sq. ft
Air Heater	82,400 sq. ft
Approximate Water Capacity To Normal Water Level	500, 788 lbs.
Approximate Water Capacity For Hydrostatic Test	827,253 lbs.

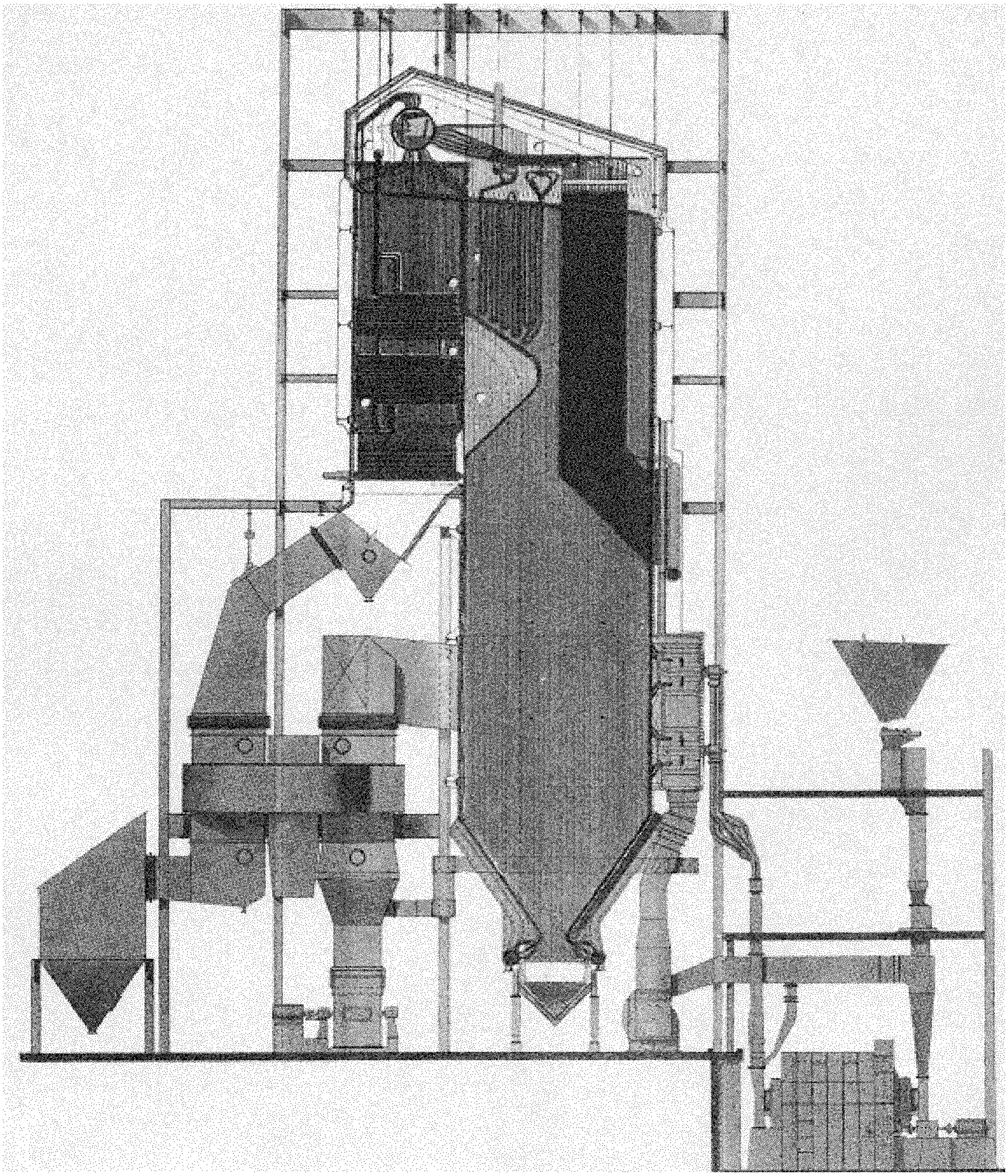


Figure 3-1 Reid Plant Boiler Schematic

690,000 lbs/hr –1475 psig design pressure, 1300 psig operating pressure
955 F Steam, Fuel: Kentucky Coal

3.1.2 Reid Plant Boiler Data

Boiler Operating Data

The boiler operating data at 50% and at 100% plant load when burning coal were obtained from the plant. Table 3-1 list the summary of the boiler operating data.

Table 3-1 Reid Plant Boiler Operating Data

Power	FD Fan Dish Pres	Furnace Press	Windbox Press	Sec SH Gas Press	Primary SH Gas Press	Air Flow lbs/hr	Econ Gas Temp	Excess O2
MW	Pa (" H2O)	Pa (" H2O)	Pa (" H2O)	Pa (" H2O)	Pa (" H2O)	kg/h x (Lbs/hr x) 10^3	Deg C (Deg F)	%
36	22.1 (9)	9.84 (4)	17.22 (7)	9.84 (4)	8.6 (3.5)	195 (430)	217 (423)	4.4
37	23.4 (9.5)	9.84 (4)	18.45 (7.5)	10.6 (4.3)	7.9 (3.2)	195 (430)	218 (425)	6
35	23.4 (9.5)	9.84 (4)	18.45 (7.5)	10.3 (4.2)	7.9 (3.2)	199 (439)	221 (430)	6
60	29.5 (12)	14.8 (6)	22.1 (9)	15.7 (6.4)	12.3 (5)	278 (613)	241 (465)	2.8
61	30.8 (12.5)	16 (6.5)	23.4 (9.5)	16 (6.5)	13 (5.3)	295 (651)	243 (469)	2.9
61	30.8 (12.5)	15.3 (6.2)	22.1 (9)	16 (6.5)	12.8 (5.2)	293 (645)	238 (460)	2.4
62	32.0 (13)	16 (6.5)	23.4 (9.5)	16.7 (6.8)	13.5 (5.5)	304 (670)	247 (476)	2.8

3.1.3 Gasifier Material and Energy Balance

After reviewing the available poultry litter supply in the vicinity of the Reid Plant, the gasifier for the Reid plant study is sized for 7.5 t/h (8.4-ton/hr) capacity. This is a one single KC-18 gasifier. Material and energy balance for the KC-18 has been prepared and a summary of it is attached with detailed balance in the Appendix of this report. The gasifier will be located on south side of the Reid plant, underneath the coal conveyor belt. Layout drawings of the gasifier and fuel silos are provided in the Appendix.

The following two tables, table 3-2 and table 3-3 provides material and energy balance for specific streams. Refer to the stream number in the process flow diagram provided in the Appendix A for the WKE case. The detailed material and energy balance for each stream in the PFD is also provided in Table A-2 in the Appendix A.

Table 3-2 Material Balance for the Gasifier

Selected Stream	**1**	**2**	**3**	**4**	**7**	**8**	**11**
Name	**GASIFIER**	**GASIFIER**	**GASIFIER**	**GASIFIER**	**HOT GAS**	**ID FAN**	**OVERFIRE**
	FEED	**Comb Air**	**Bot. Ash**	**GAS**	**FILTER**	**EXHAUST**	**GAS**
Pressure, Pa ("w.c. -g)	--- ---	-4.92 (-20)	--- ---	-0.062 (-0.25)	-2.46 (-10)	1.97 (8)	1.72 (7)
Temperature, °C (°F)	25 (77)	27 (80)	149 (300)	843 (1,550)	750 (1,382)	750 (1,382)	1,316 (2,400)
Molecular Weight kg/kg mole or lb/lb mole	---	28.68	68.87	24.89	24.58	24.58	26.89
Component	kg/h (lb/h)	kg/h (lb/h)	kg/h (lb/h)	kg/h (lb/h)	kg/h (lb/h)	kg/h (lb/h)	kg/h (lb/h)
Carbon	2 080 (4,582)		280 (616)				
Hydrogen	229 (505)						
Nitrogen	215 (473)						
Oxygen	1 526 (3,361)						
Sulfur	36 (80)						
Carbon Monoxide				1 642 (3 617)	1 642 (3 617)	1 642 (3 617)	270 594
Carbon Dioxide				4 017 (8 847)	4 017 (8 847)	4 017 (8 847)	6 202 (13 644)
Hydrogen				185 (408)	185 (408)	185 (408)	88 (193)
Water (vapor)		115 (253)		2 416 (5 322)	2 945 (6 486)	2 945 (6 486)	3 908 (8 608)
Nitrogen		8 982 (19 785)		9 197 (20 257)	9 197 (20 257)	9 197 (20 257)	14 483 (31 900)
Oxygen		2 719 (5 989)					
Sulfur Dioxide				73 (160)	73 (160)	73 (160)	
Ash	1 634 (3 599)		1 914 (4 215)				
Water (liquid)	1 907 (4 200)						
TOTAL	7 627 (16 800)	11 816 (26 028)	2 193 (4 831)	17 529 (38 720)	18 058 (39 776)	18 058 (39 776)	24 950 (54 956)

Table 3-3 Energy Balance for the Gasifier

Selected Stream	1	2	3	4	7	8	11
Name	**GASIFIER FEED**	**GASIFIER Comb Air**	**GASIFIER Bot. Ash**	**GASIFIER GAS**	**HOT GAS FILTER**	**ID FAN EXHAUST**	**OVERFIRE GAS**
TOTAL kg/h (lbs/h)	7 627 (16 800)	11 816 (26 028)	2 193 (4 831)	17 529 (38 720)	18 058 (39 776)	18 058 (39 776)	24 950 (54 956)
Heat of Combustion LHV kJ/kg (Btu/lb)	9 567 (4 110)			2 223 (955)	2 165 (930)	2 165 (930)	533 (229)
Combustion Energy GJ/h (MMBtu/h)	72.85 (69)			38.9 (37)	38.9 (37)	39.0 (37)	13.3 (13)
Thermal Energy GJ/h (MMBtu/h)	--			20.7 (19.6)	20.7 (19.6)	19.25 (18.25)	46.3 (43.9)
Total Energy GJ/h (MMBtu/h)	72.85 (69)		{-6.9} (-6.6)	59.6 (56.6)	59.6 (56.6)	60.4 (57.25)	60 (56.9)
FLOW RATE m3/s (scfm)	---	2.73 (5 740)	---	4.65 (9 838)	4.83 (10 235)	4.83 (10 235)	6.1 (12 928)

The overall gasifier efficiency is estimated at 82.5% based on heat input from poultry litter and supplemental fuel in the over-fire gas v/s heat energy out to the boiler from the producer gas.

The heat out put from the gasifier will vary based on the quality of the fuel and moisture content of the litter. For the design and equipment sizing, the numbers in the above tables are used.

3.1.4 Gasifier Boiler Integration

Babcock Borsig Power Inc. was contracted by the project to perform preliminary engineering study to determine

- Size and number of penetrations required for the flow of the producer gas from the gasifier into the boiler.
- Feasible locations for the penetrations in order to minimize the impact on the existing boiler equipment and boiler operations.
- Producer gas pressure requirements at the penetrations.
- Required stiffening and strengthening at the penetrations.

Details of BB Power findings and sizing criteria were provided in a separate report.[6] The BB Power report is included in Appendix C. Following is the brief summary of the BB Power findings:

- The biogas from the gasifier is burned at the over-fire combustion chamber located at the boiler penetration. The combustion takes place in a reducing atmosphere and the hot gases will be entering the boiler at 1320ºC (2400 ºF).

- The gas flow provided by the gasifier is at 32.3 m^3/s (79 350 ACFM).

- The gas pressure requirement at the penetrations is at a minimum of 1.72 Pa (+8”of W.C.).

- The selected velocity by BBPower at the boiler penetrations is 45.7m/s (150 ft/sec)

- Four penetrations of 0.5m (20 inch) inside diameter will meet the total flow cross sectional area requirements of $0.7m^2$ ($8.8 ft^2$).

- The designed locations for these penetrations are on the lower sidewalls of the furnace, two penetrations on each side, just below the bottom of the windbox level. The windbox and existing eight (8) burners are located at the front of the boiler.

- The furnace expansion at the location of the penetrations from the ambient rest position to the rated conditions is 108 mm (4.25 inch) downward at the bottom and 19 mm (0.75 inch) toward the side and front. This expansion and lateral movement will be restrained with expansion joints. Primenergy’s cost estimate includes these expansion joints.

The penetration locations are provided in a schematic in the Appendix. Also a nomogram for penetration sizing based on the gas flow and number of penetration is provided for evaluation purposes.

3.1.5 Overall Plant Energy Balance

The following table 3-4 provides overall energy balance when the gasifier is integrated with the existing boiler. Since the turbine heat rate and electrical generation is based on the boiler output, the power output attributable to the gasifier is proportional to heat input from the gasifier to the boiler.

The annual electricity generated, poultry litter consumed and ash from the gasifier is calculated based on boiler and gasifier availability factor. It is assumed that the Reid boiler will be operated at capacity with 70% availability and that the gasifier will be available 90% of the time at 100% capacity when the Reid boiler is on line. Thus, overall gasifier contribution to the power generation is at 63% availability factor (0.7x0.9=0.63).

Table 3-4 Energy Balance and Power Production for Reid Plant

Item		Units
Poultry Litter	7.45 (8.20)	t/h (tons/hr)
Heating Value (LHV)	9,768 (4,200)	kJ/kg (Btu/lb)
Natural Gas	20.9 (46)	kg/h (lbs/hr)
Heating Value (LHV)	50,007 (21,502)	kJ/kg (Btu/lb)
Ash Produced	1.96 (2.16)	t/h (tons/hr)
Total Boiler Heat Input @ 65.8 MW	700,359 (663.3)	MJ/h (MMBtu/hr)
Heat Input to Boiler - Gasifier	60,079 (56.9)	MJ/h (MMBtu/hr)
Boiler Efficiency (from BB Power)	86.90 (86.90)	%
% Input from Gasifier	8.6% (8.6%)	%
T/G Output (design)	65,851 (65,851)	kWe
Turbine Heat Rate (@ design pt.)	9,358 (8,863)	kJ/kWe (Btu/kWe)
T/G Output Due to Gasifier	5,648.9 (5,648.9)	kWe
Less Aux Load for Gasifier	410.0 (410.0)	kWe
Total Gasifier Output Eq. kWe	**5,238.9 (5,238.9)**	kWe
Boiler Availability Factor	70% (70%)	%/year
Gasifier Capacity Factor	90% (90%	)%/year
Total Poultry Litter Usage	41,091 (45,254)	tpy (tons/yr)
Total NG Usage	115,255 (253,865)	kg/y (lbs/y)
Total Ash Produced	10,814 (1,910)	tpy (tons/yr)
Total Power Produced	**28,912,496**	kWh/y

3.1.6 Solids Handling Systems

Concept for poultry litter receiving, storage and delivery was developed for the Reid plant site. Moisture content of the litter is a major material handling consideration because high moisture content can cause clogging of the fuel conveyance systems including bucket elevators, silos and air-conveyors. The moisture content of freshly collected litter is about 24 percent for the litter crust and about 32 percent for the total clean out. The corresponding wet bulk density is measured at about 492 kg/m^3 (830 lbs/cu. yd) for crust and 575.5kg/ m^3 (970 lbs./cu. yd) for clean out.

Three different concepts for material handling have been evaluated for the Reid plant site.

- Conventional receiving and storage buildings with mechanical belt conveying to the day storage and to the gasifier
- Conventional receiving building with long term storage silos and pneumatic conveying into the gasifier
- Conventional receiving building with long term storage silos and mechanical belt conveying

Dynamic Air Inc. of St. Paul, MN conducted tests for pneumatic conveying of poultry litter in August 2001. The test results indicated that the poultry litter particles 12 mm (½”) and larger may bridge in a silo and cake sporadically in a dilute phase air conveying. The test results also indicate that poultry litter 6 mm (¼”) and smaller can be conveyed easily. However bed depth in the test silo was much less than 2.5 m (8 ft) that is the deepest bed depth recommended for storing poultry litter.

Litter is to be received in covered trucks at the Reid Plant site or other similar site. The truck will dump the load in an enclosed fuel unloading building.

Detailed cost estimate and auxiliary power consumption for each option was developed by contacting major equipment vendors. The major vendors contacted were Dynamic Air, Nol-Tec Industries, Saxlund International, Delta Ducon, Ward Equipment, Inc. The equipment cost supplied by the vendor was used to develop total installed cost of complete material handling system. The summary of the cost estimate is provided in table 4-1 in Section 4 Economic Analysis. The layout plans with the proposed mechanical and pneumatic conveying are provided in the Appendix A for the WKE case.

3.1.7 Permit Issues

Based on the past plant operating data for the Reid plant, the following is expected performance with poultry litter cofiring. Total Heat Input to the Boiler from Coal as reported for 1998 was 2.7x10^12 kJ (2.60x10^6 MMBtu). Assuming similar level of heat input under cofiring, the following figures 3-2 provides breakdown of heat to the boiler from coal and poultry litter.

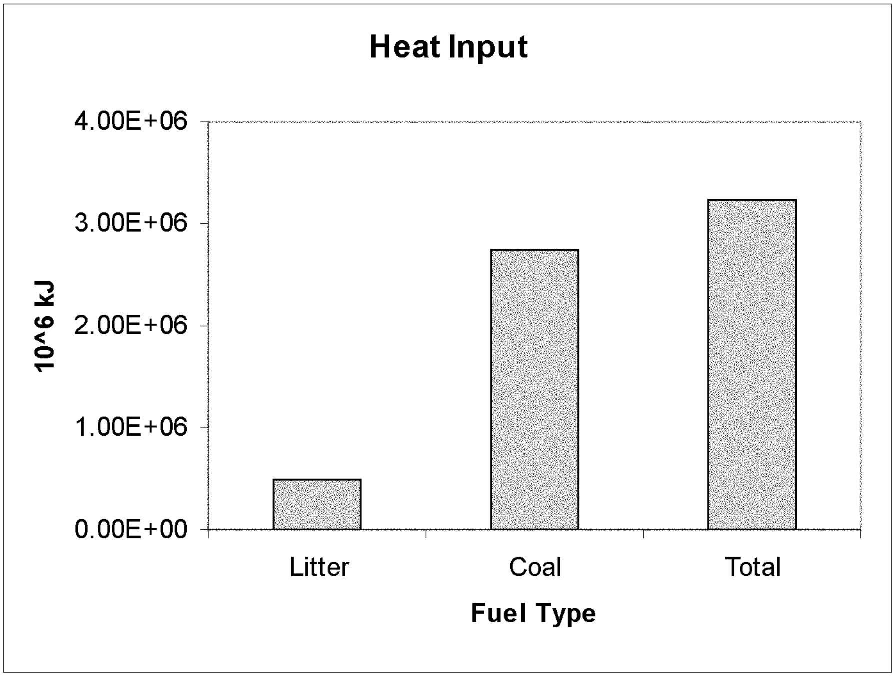


Figure 3-2 Heat input to the boiler with cofiring

NOx Emissions: Due to bound nitrogen in the poultry litter (urea/ ammonia), straight combustion of litter with excess air at high temperature would produce very high NOx. It could be as high as > 2000 ppmv of NOx. But in gasifier with the low temperature of 815°C (~1500°F) and reducing atmosphere the ammonia, amine and urea in the litter are released into the gas stream. With the over fire staged combustion (again in reducing atmosphere) these compounds will break down to N_2 and H_2 and CO. From the past test run by Primenergy the NOx levels (preliminary) were in the range of 270~300 ppmv or 0.174 kg/GJ (0.404 lbs/MMBtu) on HHV basis. This NOx level is lower than older PC fired boilers with regular burners and it is comparable to the boilers with new Low NOx burners using coal as a fuel. Thus the gasification based cofiring for the Reid boiler can be considered as 8~10% of the fuel input to the boiler going through an equivalent low NOx burner. Figure 3-3 show NOx contribution form gasifier to the existing boiler and expected overall NOx emission under cofiring conditions.

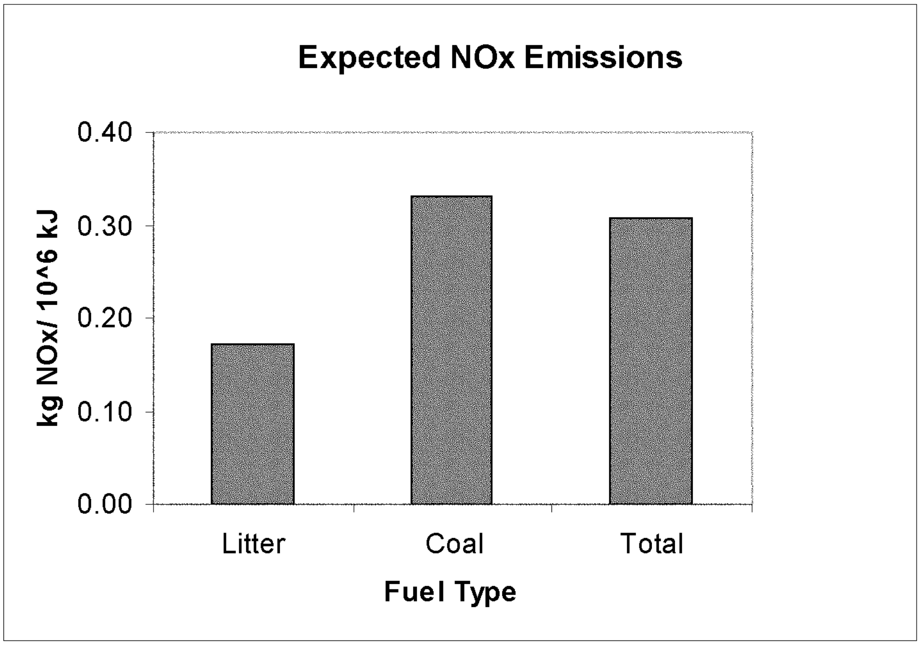


Figure 3-3 Expected NOx emissions with cofiring

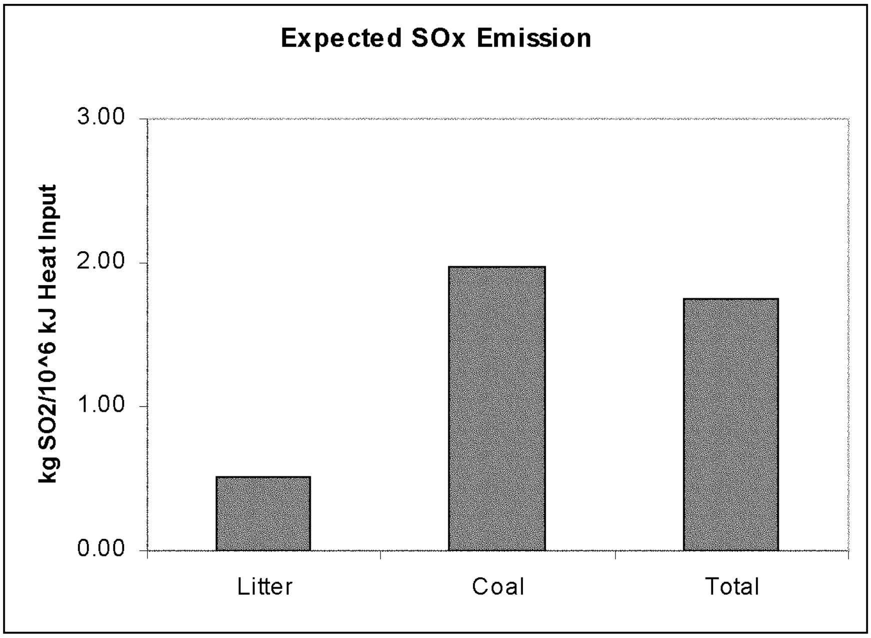


Figure 3-4 Expected SO_2 emissions with cofiring

SO2 Emissions: Poultry litter has less than 0.5% S. The Kentucky coal is about 2%~2.5% S. Thus, any heat input from low sulfur litter will reduce the SO_2

emissions from the boiler. As figure 3-4 show, the sulfur in the litter is about 0.5kg/GJ v/s S in coal at >2 kg/GJ. In addition, most of the sulfur in coal is in elemental form and forms SO_2/SO_3 in an oxidizing atmosphere. While, S in the litter is already in a bound form of sulfates and sulfides and hence it is expected to remain in the ash as sulfur compound, thus reducing amount of SO_2 emission even further when cofiring.

Chlorine: Primenergy has not conducted specific tests on chlorine from the gasifier and no comparable literature data are available. But with the high alkali content of the litter most of the chlorine should remain as salt (Na/K/Ca/Mg) in the ash - again due to low temperature gasification in a reducing environment. The ash analyses of the litter sample indicate that >90% of chlorine is retained in the ash. Further evaluation of chlorine in the gasifier gases by Primenergy has been planned.

Heavy Metals: Due to organic nature of the litter, there is very little, if any heavy metals. Elemental analyses of the litter and ash samples have not detected any mercury and insignificant amount of arsenic, etc. Hence, there is no burden of heavy metals from the gases entering the boiler from the gasifier.

Odor: By storing the litter in the enclosed building or the silos and using enclosed belt or pneumatic conveying and recycling this air as underfire combustion air, the project is expected to eliminate or minimize the odor from the litter.

Poultry litter is a renewable energy resource. The Reid plant will be able to reduce its fossil fuel consumption by 8~10% and can claim a reduction in greenhouse emissions (CO_2) from the boiler. Due to low sulfur content in the poultry litter, and two staged combustion process, the gasifier is expected to reduce the SO_2 and NOx by over 5% from the boiler. With the hot gas filtration system, clean gas is fed into the existing boiler. This will reduce particulate loading on the electrostatic precipitator (ESP). Also, litter does not contain heavy metals, i.e. Hg, Cd, Pb, etc., 8% reduction in coal burning will reduce heavy metals in the stack gases by proportionate amount.

A further discussion of emissions due to coal v/s litter is provided in the Results and Discussion section of this report.

3.1.8 Fuel Contracts

Contacts with two local haulers were established for the Reid plant case. Both haulers have shown interest and are willing to work with the project. For any similar project, the best strategy is to establish contracts with the haulers rather than individual farmers. Project recommends continue pursuing the local haulers for fuel supply. The haulers provided firm written estimates. Current estimate from both of these haulers for the liter supply is $10 / ton for up to 20 000 tons of litter/year and at $12/ton additional 30 000-40 000 tons of litter delivered at the plant. The fuel cost was developed for economic analysis using an estimate of $12/ton of litter delivered to the Reid plant. A sensitivity analysis was also generated with varying the cost of litter delivered at the site. The economic pro-forma and sensitivity analysis are included in the Results and Discussion section of this report.

3.1.9 Major Equipment List

A preliminary equipment list is prepared for the litter receiving, storage and transport to the gasifier island based on concepts described above. Primenergy prepared the gasifier island equipment list and cost estimate.

Material handling equipment list was developed using input from the vendors and from the site layout requirements. Table 3-5 provides major gasifier equipment and sizing. Table 3-6 provides litter receiving, storage and conveyance equipment and sizing.

Table 3-5 Gasifier Island Equipment List

Equipment	Quantity	Size/ Capacity	Supplier/ Vendor
Fuel Feed Rotary Valve	1	7.5 t/h – 3.75 kW	Primenergy
Fuel Infeed Auger	1	3.75 kW	
KC-18 Gasifier	1	7.5 t/h	
Agitator	1	3.75 kW	
Ash Discharge Auger #1	1	2.t/h - 2.25 kW	
Ash Discharge Auger #2	1	2. t/h - 2.25 kW	
Ash Cooling Auger	1	2. t/h - 3.75 kW	
Ash Silo	1	4.5m D x 7.5m H	
Underfire Air Fan	1	180 m^3/Min – 30 kW	
Cooling Water Pump	2	230 l/min - 7.5 kW each	
Hot Gas Filter	1	750C, 300 m^3/Min	
Fly Ash Discharge Valve	2	0.7 kW each	
Final Ash Conveyor	1	7.5 kW,	
ID Fan	1	750C, 300 m^3/Min, 185 kW	
Overfire Combustion Chamber	1	Refractory Lined -	
Overfire Air Fan	1	20C, 35 m^3/Min, 20 kW	
Air Compressor	1	200 m^3/Min, 75 kW	
Combustion Air Heater	1	2.5mx3.7m	
Refractory Lined Piping	As Req'd.		
Expansion Joints for boiler Penetrations	4	510 mm diameter each	
Pipe Supports	As Req'd		
MCC Unit	1	30 CB Minimum	
DCS Unit	1	150 Analog, 50 Digital I/O	
Operator Consoles	2	N/A	▼

Note: Primenergy will package the entire gasification island system and equipment. Hence, individual vendors for major equipment in the gasifier island are not listed.

Table 3-6 Material Handling System Equipment List

Equipment	Qty.	Size/ Capacity	Vendors
Fuel Storage Silos	2	9.1mx21.5m, 750 t each	Walker Equip., Industrial Accessories, Chicago Conveyor
Vibrating Screen/ Grizzly	1	3mx2.5m	Martin Engineering, Chicago, IL
Fuel Unloading Pit	1	3mx2.5mx3m	Saxlund International, Delta Ducon, Ward Equip.
Screw Conveyor	1	10 kW	Delta Ducon, Ward Equip
Bucket elevator	1	0.5mx40m H, 5 kW	Delta Ducon, Newton Conveyors
Fuel Diverter Valve	1	0.5kW	Delta Ducon, Ward Equip
Fuel Storage Building	1	12mx8mx11m	Local Construction Contractor
Fuel Storage Bldg. Ventilation System	1	10 kW	ScrubAir, BSM Ventilation
Fan Blower for Fuel Conveyor	1	5 kW	Saxlund International, Delta Ducon, Ward Equip.
Rotary Valve	2	5 kW	Ward Equip.
Fuel Day Silo	1	5mx10m	Primenergy
Cyclone Separator	1	95% Eff., 1.2mx2.4m	Ducon Technologies
Separation Screen	1	15 mm Mesh	Delta Ducon, Ward Equip
Hammer Mill	1	37.5 kW	Stedman Machine, CPM Crop, CS Bell Co.
Hammer Mill Air System	1	12 kW Air Fan	Stedman Machine, CPM Crop, CS Bell Co.
Silo Unloader	1	11.5 kW	Delta Ducon, Ward Equip
Silo Discharge Conveyor	1	7.5 kW	Nordberg, Inc., Newton Conveyors
Metering Bin Discharge Screw	1	5 kW	Primenergy.
Bucket Elevator	1	3.75 kW, 0.8mx1mx15m	Saxlund International, Delta Ducon, Ward Equip.

3.1.10 Equipment Layout

The proposed equipment layout for the fuel handling system and the gasifier island are provided in the Appendix A the WKE case.

3.2 TXU Energy Case

3.2.1 TXU Monticello Plant

TXU Monticello plant is a three unit coal fired plant. For the Biomass cofiring project, Unit 1 was selected as a case study. The following picture in figure 3-5 shows Unit 1 side elevation.

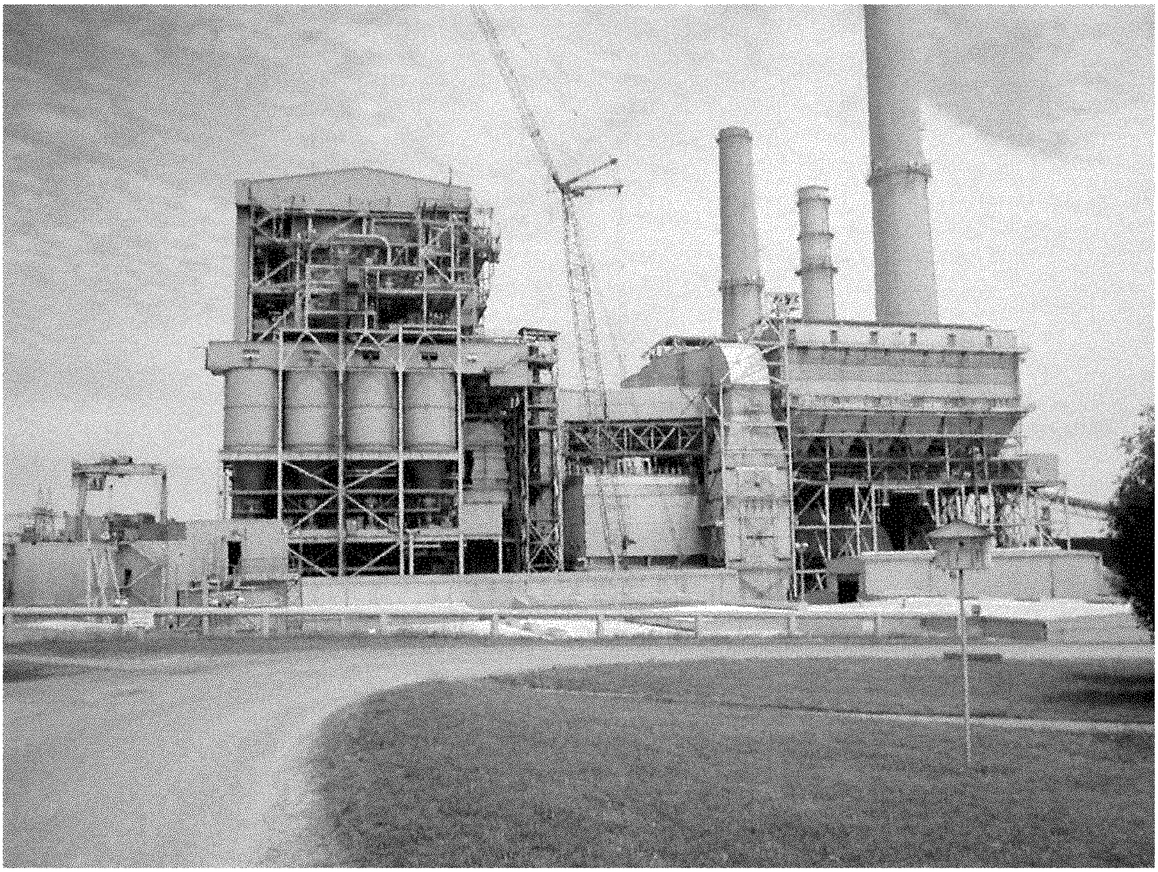


Figure 3-5 Monticello Plant Unit 1

Monticello Unit 1 is a Combustion Engineering (Alstom) tangentially fired pulverized coal unit burning a blend of Texas lignite and Wyoming sub-bituminous Powder River Basin (PRB) coal. The design specifications for the unit 1 boiler are provided in Table 3-7.

3.2.2 Monticello Unit 1 Boiler Data

Table 3-7 Design Specifications for Monticello Unit 1

Boiler Parameters	Units	Control Point	MCR
Fuel		Texas Lignite	Texas Lignite
Evaporation	kg/h (Lbs/h)	1 451 496 (3 200 000)	1 825 709 (4 025 000)
FW Temp	°C (°F)	248 (478)	261(501)
FW Pressure (calc)	kPa (psig)	25 943 (3 750)	28 135 (4 068)
SH Outlet Temp	°C (°F)	541 (1 005)	541 (1 005)
SH Outlet Press	kPa (psig)	24 877 (3 595)	26 462 (3 825)
SH Pressure Drop	kPa (psig)	1 075 (141)	1 633 (222)
Reheat Flow	kg/h (lbs/h)	1 276 409 (2 814 000)	1 596 645 (3 520 000)
Reheat inlet Temp	°C (°F)	288 (550)	300 (572)
Reheat Inlet Press	kPa (psig)	3 838 (542)	4 798 (682)
Reheat Outlet Temp	°C (°F)	541 (1 005)	541 (1 005)
Reheater Press Drop	kPa (psig)	193 (28)	241 (35)
Economizer Press Drop	kPa (psi)	96.5 (14)	148 (21)
Gas Drop - Furnace to Econ	Pa ("wg)	616 (2.45)	918 (3.65)
Gas Drop Econ Outlet to AH Outlet	Pa ("wg)	1 208 (4.80)	1 724 (6.85)
Gas Temp Entering AH	°C (°F)	429 (805)	460 (860)
Gas Temp Leaving AH	°C (°F)	164 (327)	177 (351)
Gas Temp Leaving AH	°C (°F)	155 (311)	169 (336)
Air Temp Air Heater	°C (°F)	29 (85)	29 (85)
Air Temp Leaving	°C (°F)	372 (701)	388 (730)
Air Press Air Heater	Pa ("wg)	1 988 (7.90)	2 605 (10.35)
Amb. Air Temp	°C (°F)	26.5 (80)	26.5 (80)
Excess Air Econ	%	20	20
Fuel Fired	kg/h (Lbs/h	308 896 (681 000)	379 203 (836 000)
Efficiency	%	82.69	82.06

Although the design specifications for the Monticello plant call for Texas lignite as primary fuel, the current fuel for the plant is blend of Texas lignite and Wyoming coal from the Powder River basin (PRB sub-bituminous coal). The normal blend is 60% Texas lignite and 40% PRB coal. Table 3-8 provides the current fuel analysis for the Monticello plant.

Table 3-8 Monticello Boiler Fuel Analyses

	Texas Lignite	PRB Coal	Units
Fuel HHV	15 719 (6 767)	18 084 (8 220)	kJ/kg (Btu/lb)
C	39.20	46.52	%
H	2.99	3.16	↓
O	11.04	15.04	
N	0.58	0.70	
S	0.61	0.48	
Ash	14.31	6.44	
Moisture	31.27	27.66	
Total	100.00	100.00	

3.2.3 Gasifier Material and Energy Balance

After reviewing the available poultry litter supply in the vicinity of the Monticello plant, the gasifier for the Monticello unit 1 plant is sized for 14.4t/h (15.8-ton/hr) capacity. This is two KC-18 gasifier systems with common fuel conveying and storage system as well as common ash silo and single duct of fuel gas to the unit 1 boiler. Material and energy balance for the KC-18 has been prepared and a summary of it is included in Table 3-9 with detailed balance in the Appendix of this report. The gasifiers and fuel storage system will be located on south side of Unit 1 near the current Document Control Center (DCC). The fuel gases from the gasifiers will be filtered and cooled to 350°C (650°F) and transported to the boiler in refractory lined piping.

Possible alternate site for the gasifier is east of the rail rod tracks in the vicinity of the long-term coal storage area.

The following two tables 3-9 and 3-10 provides material and energy balance for specific streams. Refer to the stream number in the process flow diagram provided in the Appendix B TXU case.

Table 3-9 Material Balance for the gasifier

Selected Stream	1	2	3	5	7	8	11
Name	Gasifier Feed	GASIFIER AIR	GASIFIER BOTTOM ASH	SYNGAS SCRUBBER EXHAUST	ID FAN EXHAUST	OVERFIRE & REOX AIR	COMB PROD TO BOILER
Pressure kPa ("w.c.-g)	----	6.29 (25.0)	----	- 2.52 (-10.0)	2.01 (8.0)	3.78. (15.0)	1.510 (6.0)
Temperature °C (°F)	25 (77)	25 (77)	149 (300)	760 (1 400)	350 (662)	25 (77)	1 304(2 379)
Molecular Weight kg/kgmole (or lbs/lb mole)	---	28.68	75.25	24.39	24.39	28.68	28.33
Component	kg/h (lb/hr)	kg/h (lb/hr)	kg/h (lb/hr)	kg/h (lb/hr)	kg/h (lb/hr)	kg/h (lb/hr)	kg/h (lb/hr)
Carbon	4 604 (10 151)		420 (927)				
Hydrogen	462 (1 019)						
Nitrogen	472 (1 041)						
Oxygen	3 236 (7 135)						
Sulfur	100 (221)		50 (111)				
Chlorine							
Fuel Gas							
Carbon Monoxide				4 669 (10 293)	4 669 (10 293)		
Carbon Dioxide				7 996 (17 628)	7 996 (17 628)		15 331 (33 799)
Hydrogen				440 (971)	440 (971)		
Water (v)		231 (510)		4 897 (10 795)	4 897 (10 795)	197 (435)	9 247 (20 386)
Nitrogen		18 059 (39 813)		18 531 (40 854)	18 531 (40 854)	15 414 (33 982)	50 950 (112 326)
Oxygen		5 467 (12 053)				4 666 10 287	3 653 (8 053)
Sulfur Dioxide				100 (221)	100 (221)		
Hydrogen Chloride							
Ash	1 912 (4 216)		1 864 (4 110)				
Lime							
Water (l)	3 596 (7 927)						
TOTAL	14 383 (31 710)	23 757 (52 376)	2 335 (5 147)	36 633 (80 761)	36 633 (80 761)	20 277 (44 704)	79 181 (174 564)

Table 3-10 Energy balance for the gasifier

Selected Stream	1	2	3	5	7	8	11
Name	Gasifier Feed	GASIFIER AIR	GASIFIER BOTTOM ASH	SYNGAS SCRUBBER EXHAUST	ID FAN EXHAUST	OVERFIRE & REOX AIR	COMB PROD TO BOILER
TOTAL	14 383 (31 710)	23 757 (52 376)	2 335 (5 147)	36 633 (80 761)	36 633 (80 761)	20 277 (44 704)	79 181 (174 564)
AVAIL ENERGY VALUE (LHV-Hv) kJ/kg (Btu/lb)	10 561. (4 537)			2 749. (1 181)	2 749. (1 181)		
AVAILABLE ENERGY GJ/h (MMBtu/hr)	151.9 (143.85)		13.8 (13.06)	100.7. 95.35	100 7. 95.35		
SENSIBLE ENERGY GJ/h (MMBtu/hr)				37.4 (35.43)	15.7 (14.90)		129.7 122.86
FLOW RATE M3/s (scfm)		5.45 (11 551)		9.88 (20 940)	9.88 (20 940)	4.65 9 859	18.39 (38 968)

3.2.4 Gasifier Boiler Integration

Alstom Inc. (current holder of Combustion Engineering boiler technology) was contacted by the project for engineering recommendations. Since the total energy input from the gasifier to the boiler was about 2% of boiler MCR ratings, Alstom did not require engineering evaluation of the boiler heat transfer characteristics. Location of boiler penetration was discussed with Alstom. Alstom recommended that with tangentially fired boiler, the gas burners can be located on any of the four walls of the boiler at any of the existing burner level or just above it.

3.2.5 Overall Plant Energy Balance

The following table provides overall energy balance when the gasifier is integrated with the existing unit 1 boiler. Since the turbine heat rate and electrical generation is based on the boiler output, the power output attributable to the gasifier is proportional to heat input from the gasifier to the boiler.

The annual electricity generated, poultry litter consumed and ash from the gasifier is calculated based on boiler and gasifier availability factor. The Monticello plant is a base loaded unit with annual capacity factor of over 80%. For the power generation and cost analysis purpose, it is assumed that the Monticello unit 1 boiler will be operated at capacity with 80% availability and that the gasifier will be available 90% of the time at 100% capacity when the unit 1 boiler is on line. Thus, overall gasifier contribution to the power generation is at 72% availability factor (0.8x0.9=0.72). Table 3-11 show power generation contribution due to gasifier.

Table 3-11 Energy Balance and Power Production for Monticello Case

Item			Units
Poultry Litter	14.53	(16.00)	t/h (tons/hr)
Heating Value (LHV)	9,768	(4,200)	kJ/kg (Btu/lb)
Natural Gas	-	-	kg/h (lbs/hr)
Heating Value (LHV)	50,007	(21,502)	kJ/kg (Btu/lb)
Nominal Ash in Litter	18~23	(18~23)	%
Ash Produced (@23% Level)	3.34	(3.68)	t/h (tons/hr)
Total Boiler Heat Input @ 65.8 MW	4,865,794	(4,608)	MJ/h (MMBtu/hr)
Heat Input to Boiler - Gasifier	127,127	(120.4)	MJ/h (MMBtu/hr)
Boiler Efficiency (CE-Nameplate)	82.61	(82.61)	%
% Input from Gasifier	2.6%	(2.6%)	%
T/G Output (design)	543,189	(543,189)	kWe
Turbine Heat Rate (@ design pt.)	9,429	(8,930)	kJ/kWh (Btu/kWh)
(Estimate from Design data)			
T/G Output Due to Gasifier	13,482.7	(13,482.7)	kWe
Less Aux Load for Gasifier	700.0	(700.0)	kWe
Total Gasifier Output Eq. kWe	**12,782.7**	**(12,782.7)**	kWe
Boiler Availability Factor	80%	(80%)	%/year
Gasifier Capacity Factor	90%	(90%)	%/year
Total Poultry Litter Usage	91,631	(100,915)	tpy (tons/yr)
Total NG Usage	-	-	kg/y (lbs/y)
Total Ash Produced	21,075	(23,210)	tpy (tons/yr)
Total Power Produced	**80,622,887**	**(80,622,887)**	kWh/y

3.2.6 Solids Handling Systems

The concept of delivery, receiving, and storage of ‘poultry litter’, which is referred to as ‘fuel’ from this point on, has been developed for the Monticello plant site. The moisture content of the fuel is a major consideration because high moisture content can cause clogging of the fuel conveyance systems including hoppers, bucket elevators, silos, and pneumatic conveyors. The moisture content of the freshly collected fuel is about 24 percent for the crust, and about 32 percent for the total clean-out. The corresponding wet bulk density is about 492 kg/m^3 (830 lb/cu. yd) for crust, and 575.5 kg/m^3 (970 lb/cu. yd) for total clean-out.

Two different approaches for fuel handling have been evaluated for the Monticello plant site:

- Fully automated system with minimal human operation
- Partially automated system with some human operation

In the fully automated approach, no part of the system would require any human intervention during normal operation. The entire fuel handling system, starting from the fuel receiving process down to the fuel feeding into the metering bins, is operated automatically. This eliminates the operational expenses due to the additional personnel needed to operate the non-automatic parts of the fuel handling system.

In the partially automated approach, one part of the fuel transfer operation from the long-term storage is carried out by the plant operating personnel. The truck delivery is for 10 hours a day from Monday through Friday. For the rest of the period during a week, the fuel is fed from the long-term storage to the feed hopper by plant operating personnel. This reduces the initial cost of providing for the automated facility, but increases the operational expenses due to the additional personnel needed to operate the non-automatic parts of the fuel handling system.

Detailed cost estimates for each approach have been developed by contacting major equipment suppliers and manufacturers. The major suppliers/ manufacturers contacted include Nol-Tec Industries, Newton Conveyors, Inc., Cleburne, TX, Goodman Conveyor Co. Belton, SC, Pennsylvania Crusher Corp, PA, ROXON Oy, Hollola, Finland, Jeffrey Specialty Equipment, Woodruff, SC, PEBCO (Cleveland Armstrong), Paducah, KY, Conveyor Eng & Mfg. Co., Cedar Rapid, Iowa, West Salem M/C Co., Salem, OR, Martin Engineering, Chicago, IL, Prok International, Vancouver, BC, Canada, Compass Equipment, Oroville, CA, and Western States Industrial Technologies, Inc. Tahoe Vista, CA. The equipment cost supplied by the vendors was used to develop total installed cost of the complete fuel handling systems. The summary of the cost estimate is presented in the table 4-7 in the Economic Analysis section. The system process flow diagrams, and plant facilities and equipment arrangement drawings are presented in the Appendix B.

All the fuel storage, transfer, and feed areas are fully enclosed with covers to contain the odor.

The fuel is supplied to the gasifier plant at a normal continuous rate of 14.5 t/h (16 tons per hour).

a. Fully Automated System

The fully automated fuel handling process consists of the following steps:

- Delivery and Receiving. A number of bottom-dump trucks collect fuel from off-site sources and deliver to the site inside a fuel receiving building
- Transfer to Long-Term Storage. Fuel is then transferred to a long-term storage silo
- Shredding and Size Reduction. Fuel is then withdrawn and fed into a shredder where it is reduced to size 6 mm (¼ in.) and smaller
- Transfer to Short-Term Storage. Shredded fuel is then transferred to a day-storage silo for short-term storage
- Metering and Feeding to Gasifier. Fuel from the day silo is then transferred to two metering bins where it is weighed and fed into the gasifier.

Delivery and Receiving: The fuel from off-site locations is shipped into the Fuel Receiving Building into which the access to the trucks is provided by a light-weight and quick-opening automatic door. The bottom-dump trucks then drop the fuel on to a horizontal screw conveyor through a vibrating hopper and a variable opening gate. The variable opening gate facilitates fuel transfer at a controlled rate. The fuel delivery and receiving process operates 10 hours a day for 5 days a week. In order to supply fuel at the normal continuous rate of 14.5 t/h (16 short tons per hour) to the gasification plant, the delivery and receiving process is designed for a nominal capacity of 50t/h (55 short tons per hour) and a peak capacity of 55 (60) tons per hour. This provides for a margin of approximately 10 percent.

The fuel Receiving Building is 18m x 6m (60 ft by 20 ft.) The receiving hopper, gate, and the screw conveyor are located below the grade level.

Transfer to Long-Term Storage: The fuel is then transferred to the long-term Storage Silo. The screw conveyor transports the fuel on to a bucket elevator, which elevates the fuel to the top of the Storage Silo. The long-term Storage Silo has a capacity of 5 days storage, is made of concrete, and is 24.4m (80 ft.) in diameter and 7.6m (25 ft.) tall. The long-term storage ensures continuous fuel supply in case of any long-term interruption in fuel deliver and receiving. To store fuel uniformly within the large-diameter silo, a horizontal distribution conveyor belt is used, which rotates over the top of the silo. As the delivery and receiving process, the process of transferring to long-term storage is also designed for a nominal capacity of 50 (54) tons per hour and a peak capacity of 55 (60) tons per hour.

Shredding and Size Reduction: For efficient gasification, the fuel is required to be sized to 6 mm (¼ in.) and smaller. The fuel from the Storage Silo is fed to a shredder through a vibrating hopper and a variable opening gate. The shredding process is designed for a nominal capacity of 14.5 t/h (16 short tons per hour) and a peak capacity of 18 t/h (20 tons per hour). This provides for a 25 percent margin.

Transfer to Short-Term Storage: Shredded fuel is then transferred to the Day Silo for short-term storage. The short-term storage Day Silo has a capacity of about 12 hours storage, is made of steel, and is 7.6 m (25 ft.) in diameter and 7.6 m (25 ft.) tall. Due to the small granular nature of the fuel, a pneumatic conveying system is used to transfer the fuel. The conveying system is designed for a nominal capacity of 16 short tons per hour and a peak capacity of 20 tons per hour. The short-term storage ensures continuous fuel supply in case of any short-term interruption in the shredding and size reduction process.

Metering and Feeding to Gasifier: The fuel from the Day Silo is fed to two vibrating hoppers each with a variable opening gate. The gates allow the fuel to drop to two conveyor belts. The two conveyor belts transfer the fuel to two metering bins for weighing and finally feeding the gasifier. The process is designed for a nominal capacity of 16 short tons per hour and a peak capacity of 20 tons per hour.

b. Partially Automated System

The partially automated fuel handling process consists of the following steps:

- Delivery and Receiving. A number of side-dump trucks collect fuel from off-site sources and deliver to the site inside the long-term Fuel Storage Building.
- Shredding and Size Reduction. Fuel is then withdrawn and fed into a shredder where it is reduced to size 6 mm (¼ in.) and smaller
- Transfer to Short-Term Storage. Shredded fuel is then transferred to a day-storage silo for short-term storage
- Metering and Feeding to gasifier. Fuel from the day silo is then transferred to two metering bins where it is weighed and fed into the gasifier.

Delivery and Receiving: The fuel from off-site locations is shipped into the long-term Fuel Storage Building into which the access to the trucks is provided by a lightweight and quick-opening automatic door. The side-dump trucks then drop the fuel into a fuel receiving bin. In addition to delivering fuel directly into the receiving bin, trucks also simultaneously deliver fuel at another location within the building for storage purpose. A number of dozers then spread and store the fuel uniformly.

Shredding and Size Reduction: The fuel delivered directly to the receiving bin is then dropped to a shredder through a vibrating hopper and a variable opening gate. Since the fuel delivery and receiving process operates 10 hours a day for 5 days a week, the dozers feed fuel into the bin during the remaining hours of the week. This is a non-automatic operation, and requires operator action during 118 hours of a 168-hour week, i.e., for more than 70 percent of the time the operation is manual.

The Fuel Storage Building is 45m x 30m (150 ft by 100 ft.) The receiving hopper, gate, and the shredder are located below the grade level.

Transfer to Short-Term Storage: Shredded fuel is then transferred to the Day Silo for short-term storage through a belt conveyor.

Metering and Feeding to Gasifier: The fuel from the Day Silo is fed to two vibrating hoppers each with a variable opening gate. The gates allow the fuel to drop to two conveyor belts. The two conveyor belts transfer the fuel to two metering bins for weighing and finally feeding the gasifier.

3.2.7 Permit Issues

Based on the past plant operating data for the Monticello plant Unit 1, the total Heat Input to the boiler from coal and lignite, as reported for 1998 was 44.6x10^12 kJ (44.3x10^6 MMBtu). Assuming similar level of heat input under cofiring, the following figure 3-6 provide expected heat input to the boiler from coal and poultry litter.

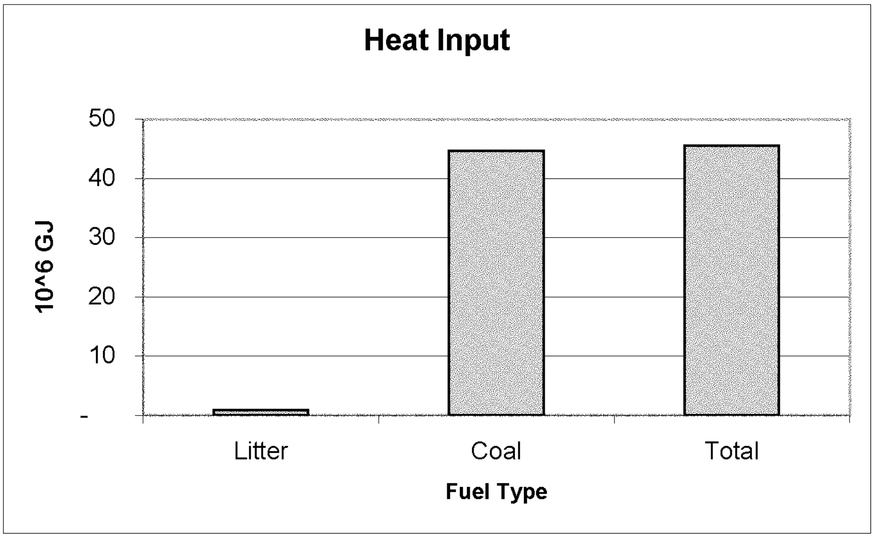


Figure 3-6 Heat input to the boiler with cofiring

NOx and SOx Emissions: Figure 3-7 provides as reported NOx and SOx emissions from the Monticello unit 1 during 1998. Since, heat input from poultry litter as shown above is insignificant compared with the heat input from primary fuel, lignite and coal, the biomass cofiring is not going to make any significant impact on the overall plant emissions. Hence, at present, no separate calculations are carried out to determine actual emissions under cofiring. As far as the permit issues are concerned, no changes to the permit are expected and no reissue of permit is required. The gasification based cofiring can be conducted under the existing permit.

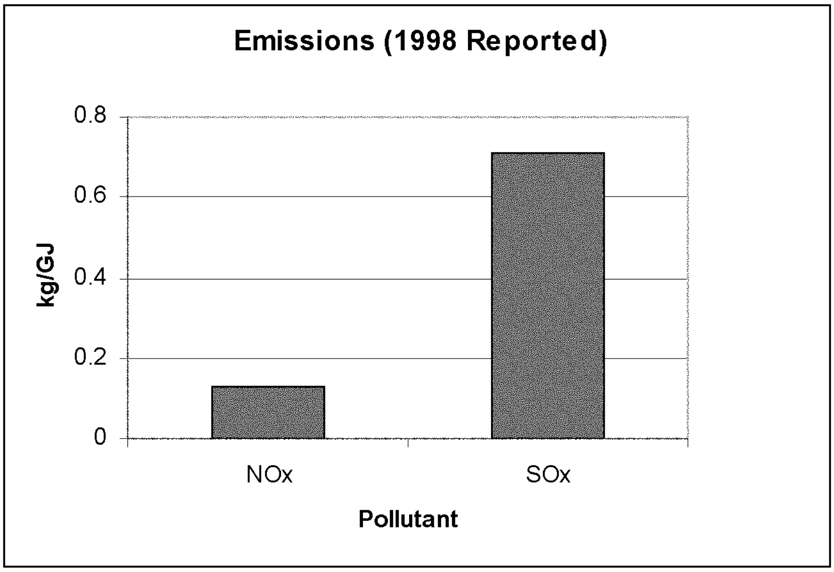


Figure 3-7 Reported NOx and SOx emissions at Monticello Plant

Chlorine: As discussed under WKE's Reid plant, chlorine will not be an issue under cofiring.

Heavy Metals: Due to organic nature of the litter, there is very little, if any heavy metals. Elemental analyses of the litter and ash samples have not detected any mercury and insignificant amount of arsenic, etc. Hence, there is no burden of heavy metals from the gases entering the boiler from the gasifier.

Odor: By storing the litter in the enclosed building or the silos and using enclosed belt or pneumatic conveying and recycling this air as underfire combustion air, the project is expected to eliminate or minimize the odor from the litter.

Poultry litter is a renewable energy resource. The Monticello plant will be able to reduce its fossil fuel consumption by 1~2% and can claim a reduction in greenhouse emissions (CO_2) from the boiler.

3.2.8 Fuel Contracts

Contacts with local haulers and Pilgrims' Pride were established by TXU for the Monticello case. Pilgrims Pride has shown interest and is willing to work with the project and TXU. For economic analysis $8/ton for poultry litter is used for the Monticello case.

3.2.9 Major Equipment List

A preliminary equipment list is prepared for the litter receiving, storage and transport to the gasifier island based on concepts described above. Primenergy prepared the gasifier island equipment list in Table 3-12 and the cost estimate.

Material handling equipment list was developed using input from vendors and from site layout. Due to larger size and site layout, consideration was given to both long term on site storage as well as partially and fully automated system as described in Section 3.2.6.

The material handling equipment list in Table 3-13 was developed using input from the vendors and from the site layout.

Table 3-12 Gasifier Island Equipment List

Equipment	Quantity	Size/ Capacity	Supplier/ Vendor
Fuel Feed Rotary Valve	2	7.5 t/h – 3.75 kW	Primenergy
Fuel Infeed Auger	2	3.75 kW	
KC-18 Gasifier	2	7.5 t/h each	
Agitator	2	3.75 kW	
Ash Discharge Auger #1 for each gasifier	2	2.t/h - 2.25 kW	
Ash Discharge Auger #2 for each gasifier	2	2. t/h - 2.25 kW	
Ash Cooling Auger	2	2. t/h - 3.75 kW	
Ash Silo	1	5.5m D x 10 m H	
Underfire Air Fan	2	180 m^3/Min – 30 kW	
Cooling Water Pump	3	250 l/min - 7.5 kW each	
Hot Gas Filter	2	750C, 300 m^3/Min	
Fly Ash Discharge Valve	4	0.7 kW each	
Final Ash Conveyor	2	7.5 kW,	
ID Fan	2	750C, 300 m^3/Min, 185 kW	
Overfire Combustion Chamber	2	Refractory Lined -	
Overfire Air Fan	2	20C, 35 m^3/Min, 20 kW	
Air Compressor	1	250 m^3/Min, 100 kW	
Combustion Air Heater	2	2.5mx3.7m	
Refractory Lined Piping	As Req'd.		
Expansion Joints for boiler Penetrations	8	510 mm diameter each	
Pipe Supports	As Req'd		
MCC Unit	1	40 CB Minimum	
DCS Unit	1	200 Analog, 75 Digital I/O	
Operator Consoles	2	N/A	↓

Note: Primenergy will package the entire gasification island system and equipment. Hence, individual vendors for major equipment are not listed.

Table 3-13 Material handling equipment list

Equipment	Qty	Size/Capacity	Potential Manufacturer
Fuel Storage Building	1	150' x 120'	Local construction contractors
Bull Dozer	2	20 tons per hour front end loader	CAT, John Deer, IH
Trucks - side dump	3	20 ton capacity; 40' long	Various
Receiving Bin (from truck)	1	Concrete - 30' x 10' x 5' high	Local construction contractors
Feed Hopper (from Bin)	1	Steel - as shown	On site erection per vendor dwgs
Hopper Vibrator	3	Motorized	Martin Engineering, Chicago, IL
Motorized Slide Gate (from Hopper)	3	1- for receiving bin hopper 2 - for day silo hoppers	PEBCO (Cleveland Armstrong), Paducah, KY
Shredder	1	20 tons per hour; reduced to max size 1/4"	ROXON - SANDVIK, Finland
Inclined Conveyor Belt	1	300' long; inclined at 22 degrees; 48"W	Nordberg, Milwaukee, WI. Newton Conveyors, Inc. Cleburne, TX
Bucket Elevator (with Belt) (not used)	1	16" wide x 130' long	Newton Conveyors, Inc. Cleburne, TX
Day Storage Silo	1	25' dia x 25' tall - steel construction	
Hopper	2	Steel - as shown	
Horizontal Conveyor Belt	2	Each - 10 tons per hour; 36" wide; 20' long	Nordberg, Milwaukee, WI. Newton Conveyors, Inc. Cleburne, TX

3.2.10 Gasification Plant Layout

After consultation with the plant personnel and TXU management, it was decided that two feasible locations for the gasifier island should be given consideration. The primary location is north side of the unit 1 boiler near the existing document control center. This location is about 250 m (800') from the boiler. Drawings for the plant layout and gas piping to the boiler are provided in appendix B. Alternate arrangement is to locate the gasifier island in the northeast corner of the site, near the existing ash disposal and east of the railroad tracks. This arrangement will increase the gas piping length to 600 m (2000'). Except for the piping layout, the major equipment arrangement will remain the same. No separate drawings for alternate arrangement are developed.

4 Economic Analysis

4.1 Reid Plant Case

4.1.1 Capital and O&M Cost Estimates

Primenergy developed capital cost for the gasification plant and supporting equipment required for the gasifier. Nexant developed detailed concept for the fuel receiving, storage and transport to the gasifier. Cost for this system was estimated by contacting vendors and requesting written quotes. Installation cost was established based on bulk material estimates and vendor input. Table 4-1 provide summary of the capital cost for three different material handling system configurations.

Table 4-1 Capital Cost Estimates for the Fuel Storage and Conveying

Material Handling System	**8 t/h System**		
Conveying System	**Mechanical**	**Pneumatic**	**Alternate Mechanical**
Truck Unloading	$ 65,220	$ 75,000	$ 200,969
Long Term Storage	$ 433,170	$ 450,000	$ 882,716
Day Storage	$ 94,437	$ 90,000	$ 228,911
Additional Equipment/Parts	$ 94,587	$ 60,000	$ 99,000
Conveying	$ 375,000	$ 250,000	$ 434,710
Trench construction/ Cover	$ 130,000	$ -	$ -
On Site Construction	$ 481,000	$ 250,000	$ 258,456
Total	**$ 1,673,414**	**$ 1,175,000**	**$ 2,104,762**

The following table 4-2 is the total capital cost for the entire system, including boiler modification and on site construction management for WKE case.

Table 4-2 Total Capital Cost for WKE's Case

Item	**Cost $**	**Cost $**
Conveying Systems	**Mechanical**	**Pneumatic**
Primenergy Equipment and Site Installation	$ 6,951,847	$ 6,951,847
Material Handling Equipment	$ 1,673,414	$ 1,175,000
Boiler Penetrations/ Other Eng.	$ 250,000	$ 250,000
Contingency (5% of above)	$ 443,763	$ 418,842
WKE Construction Management (12 week Construction Phase)	$ 144,000	$ 144,000
Total Capital Cost	**$ 9,463,024**	**$ 8,939,689**

Table 4-3 provides an estimate for the fuel and O&M cost for the gasifier system.

Table 4-3 Operation, Maintenance and Fuel Cost Estimate - WKE Case

Item		Units	Cost	Basis
Gasifier Fuel & Ash				
Poultry Litter	7.45 (8.20)	t/h (tons/hr)	$10.90 ($12.00)	$/t ($/ton)
Heating Value (LHV)	9,768 (4,200)	kJ/kg (Btu/lb)	$1.12 ($1.43)	$/GJ ($/MMBtu)
Natural Gas	20.9 (46)	kg/h (lbs/hr)		
Heating Value (LHV)	50,007 (21,502)	kJ/kg (Btu/lb)	$5.68 ($6.00)	$/GJ ($/MMBtu)
Nominal Ash in Litter	20-26	%		
Ash Produced (@26% ash)	1.96 (2.16)	t/h (tons/hr)	$1.82 ($2.00)	$/t ($/ton)
Credit for sale of Ash (year 3+)			($5.45) (($6.00))	$/t ($/ton)
Boiler Availability Factor	70%	%/year	(assumed)	
Gasifier Capacity Factor	90%	%/year		
Total Poultry Litter Usage	41,091 (45,254)	tpy (tons/yr)	$543,050	/year Litter Cost
Total NG Usage	115,255 (253,865)	kg/y (lbs/y)	$32,752	/year NG Cost
Total Ash Produced & cost	10,814 (11,910)	tpy (tons/yr)	$23,819	/year (year (1,2)
Ash Credits (year 3+)			($71,457)	/year (year 3+)
Net Gasifier Output Eq. kWe	**5,238.9**	kWe		
Total Power Produced	**28,912,496**	kWh/y		
Fuel Cost (year 1,2)	**$ 0.021**		**$599,621**	**/year (year 1,2)**
Fuel Cost (year 3+)	**$ 0.017**		**$504,344**	**/year (year 3+)**
Operation				
Operation Manpower	2.50	man-year	$15.00	/hr
OH Multiplier	1.50		$22.50	/hr
Operation Payroll Cost	**$ 0.004**	**$/kWh**	**$117,000**	**/year**
Utility				
Water	3.41 (54.02)	l/s (gpm)	$0.53 ($2.00)	$/kl ($/1000 gal)
Air (Accounted as Aux Load)				
Electricity (-do-)				
Utility Cost	**$ 0.001**	**$/kWh**	**$35,774**	**/year**
Annual Maintenance	**$ 0.005**	**$/kWh**	**$144,562**	**/year**
Total O&M Cost	**$ 0.010**	**$/kWh**	**$297,337**	**/year**
Operating Cost of Power				
Fuel & O&M Cost (year 1,2)	**$ 0.031**	**$/kWh**	**$896,957**	**/year**
Fuel & O&M Cost (year 3+)	**$ 0.028**	**$/kWh**	**$801,681**	**/year**

The delivered litter cost was developed by contacting local farmers and also requesting written quotes from local haulers who traditionally haul litter for the farmers. The maintenance cost was based on EPRI guideline for typical power plant with 5 mills per kWh produced. To minimize operating cost of the gasifier, the controls are to be integrated with the existing control room. Thus the plant operating personnel can operate the gasifier from the control room with no additional personnel. The total burden on the plant operation, including material handling for the poultry litter and ash removal was estimated at 21/2 men equivalent.

Two separate estimates were developed. It is assumed that during the first two years of operation, no market for the gasifier ash is available. Thus $2/ton of disposal cost was assigned to the electricity production cost. Since, the ash is a valuable P&K source, it can be sold to local farmers as a supplemental fertilizer. Nominal revenue of $6/ton was assigned for year 3 analyses.

As shown in the above table, the fuel and O&M cost for the first two years of operation is calculated at 3.1c/kWh and for subsequent years it is 2.8c/kWh. This cost can be considerably reduced, if the litter can be procured at lower or negative price and higher price can be commended for the ash. A sensitivity analyses based on these and other financial factors is provided in the Appendix.

4.1.2 Financial Pro Forma

The levelized cost of the electricity is calculated using financial parameters in table 4-4:

Table 4-4 Input Financial Parameters

Financial Factors		
Inflation rate (annual)	3	%
Fuel escalation rate (annual)	0	%
Start of construction	2003	
Years of construction	1	
Debt	80	%
Return on Debt	7.5	%
Return on Equity	12	%
Base year (for economic reporting)	2002	
Book life	20	years
Capacity factor (0.70x0.90=0.63)	63	%

Table 4-5 Levelized Cost of Electricity for WKE Case

Economic Summary **(Costs are in thousands of mid-2002 dollars)**	
Item	**$ Cost**
Total plant cost (TPC)	4,732
Cost of land	0
Organizational and startup expenses	126
Working capital	169
AFUDC	-4
Fuel cost, $/GJ	1.12
($/MM Btu)	(1.43)
Allocation of TPC over design/const. years	
Year	
1	1.00
2	0.00
Annual fixed O&M costs	259
Annual variable O&M costs @100% CF	10
Power output (kWe) @ design capacity	5,239
Heat rate, kJ/kWh	13.883
(Btu/kWh)	(13,148)
Constant dollars levelized Cost of Electricity (COE), mills/kWh	
Capital	**17.8**
O&M	**9.2**
Fuel	**14.0**
COE $/kWh	**0.041**
(mills/kWh)	**(41.0)**

4.1.3 Sensitivity Analysis for Reid Plant Case

The price of electricity produced from the biomass gasifier is dependent upon capital cost, fuel cost and fixed O&M cost for the gasification operation. The table 4-6 on next page provides sensitivity analysis for changes in some of these parameters.

Table 4-6 COE Sensitivity Analyses for Reid Case

Case	Litter Cost	Ash Credits	Capital Cost	WKE Cost	Interest	Period	Fuel	O&M	Capital	Total
	$/ton	$/Ton			%	Years	c/kWh	c/kWh	c/kWh	c/kWh
Base Case	12	(6)	$9,500,000	$ 4,750,000	7.5%	10	1.74	1.03	2.39	5.17
2	8	(6)	$9,500,000	$ 4,750,000	7.5%	10	1.12	1.03	2.39	4.54
3	10	(8)	$9,500,000	$ 4,750,000	7.0%	15	1.35	1.03	1.80	4.18
4	12	(10)	$9,500,000	$ 4,750,000	7.0%	15	1.58	1.03	1.80	4.41
5	6	(12)	$8,900,000	$ 4,450,000	7.0%	15	0.56	1.03	1.69	3.28
6	8	(12)	$8,900,000	$ 4,450,000	7.5%	10	0.87	1.03	2.24	4.14
7	10	(14)	$8,900,000	$ 4,450,000	7.0%	10	1.10	1.03	2.19	4.32
8	12	(16)	$8,900,000	$ 4,450,000	7.0%	10	1.33	1.03	2.19	4.55

One of the variables for the cost of electricity is cost of litter. The other variable is disposal cost of ash. As previously mentioned, the ash from the gasifier can be a useful source as a P&K based fertilizer. If the ash was sold as a fertilizer, it will contribute toward reducing the cost of electricity production. The figure 4-1 provides impact of litter cost and benefit of ash credits.

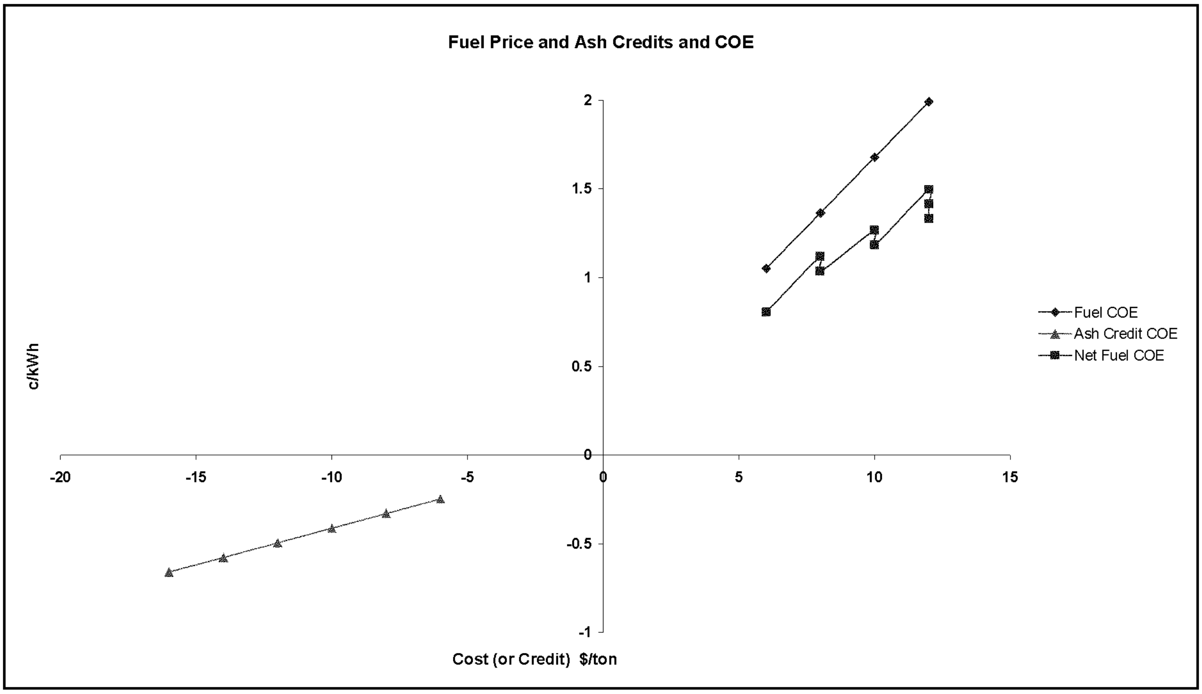


Figure 4-1 COE Sensitivity to Fuel Price and Ash Credit

4.2 Monticello Unit 1 Case

4.2.1 Capital and O&M Cost Estimate

As in the case of Reid plant, Primenergy developed capital cost for the gasification plant and supporting equipment required for the gasifier. Nexant developed detailed concept for the fuel receiving, storage and transport to the gasifier. Cost of these systems was estimated by contacting vendors and requesting written quotes. Installation cost was established based on bulk material estimates and vendor input.

Table 4-7 Capital Cost Estimates for Fuel Storage and Conveying

Material Handling Cost Estimate	Mechanical System
Major Equipment	$ 672,800
Bulk Material	$ 269,200
Direct Sub Contract	$ 438,300
Direct Labor	$ 287,200
Sales Tax @8% Freight @3%	$ 103,600
Total Direct Costs	$ 1,771,100
Field Indirect @100% Labor	$ 287,200
Total Field Cost	$ 2,058,300
Home Office Cost @ 12%	$ 247,000
Escalation (none assumed)	$ -
Total Mat. Handling Cost w/o Escalation	**$ 2,305,300**
Contingency @10%	$ 230,530
Total Estimate	**$ 2,535,830**

The following is the total capital cost for the entire system, including boiler modification and on site construction management for the TXU Monticello case. The Monticello case was analyzed as a commercial unit.

Table 4-8 Total Capital Cost for the Monticello Plant

Item	$ Cost Estimate
Primenergy Equipment	$ 11,000,000
Material Handling Equipment	$ 2,535,830
Boiler Penetrations/ Other Eng.	$ 400,000
Contingency @ 5% of above	$ 696,792
TXU Construction Management (16 week Construction Phase)	$ 250,000
Total Capital Cost	**$ 14,882,622**

Table 4-9 provides an estimate for the fuel and O&M cost for the gasifier system.

As in the WKE case, the delivered litter cost was developed by contacting local farmers and also requesting written quotes from local haulers who traditionally haul litter for the farmers. The maintenance cost was based on EPRI guideline for typical power plant with 5 mills per kWh produced. To minimize operating cost of the gasifier, the controls are to be integrated with the existing control room. Thus the plant operating personnel can operate the gasifier from the control room with no additional personnel. The total burden on the plant operation, including material handling for the poultry litter and ash removal was estimated at 21/2 men equivalent.

Two separate estimates were developed. It is assumed that during the first two years of operation, no market for the gasifier ash is available. Thus $2/ton of disposal cost was assigned to the electricity production cost. Since, the ash is a valuable P&K source, it can be sold to local farmers as an supplemental fertilizer. Nominal revenue of $6/ton was assigned for year 3 analyses.

As shown in the table 4-9 below, the fuel and O&M cost for the first two years of operation is calculated at 3.1c/kWh and for subsequent years it is 2.8c/kWh. This cost can be considerably reduced, if the litter can be procured at lower or negative price and higher price can be commended for the ash. A sensitivity analyses based on these and other financial factors is provided in the Appendix B TXU Case.

Table 4-9 Operation, Maintenance and Fuel Cost Estimate - Monticello Case

Item		Units	Cost	Basis
Gasifier Fuel and Ash				
Poultry Litter	14.53 (16.00)	t/h (tons/hr)	$7.26 ($8.00)	$/t ($/ton)
Heating Value (LHV)	9,768 (4,200)	kJ/kg (Btu/lb)	$0.74 ($0.95)	$/GJ ($/MMBtu)
Natural Gas	0 (0)	kg/h (lbs/hr)		
Heating Value (LHV)	50,007 (21,502)	kJ/kg (Btu/lb)	$5.68 ($6.00)	$/GJ ($/MMBtu)
Nominal Ash in Litter	18~23	%		
Ash Produced (@23% Level)	3.34 (3.68)	t/h (tons/hr)	$1.82 ($2.00)	$/t ($/ton)
Credit for sale of ash (year 3+)			($5.45) (($6.00))	$/t ($/ton)
Boiler Availability Factor	80%	%/year	(assumed)	
Gasifier Capacity Factor	90%	%/year		
Total Poultry Litter Usage	91,631 (100,915)	tpy (tons/yr)	$807,322	/year
Total NG Usage	0 (0)	kg/y (lbs/y)	$0	/year
Total Ash Produced	21,075 (23,210)	tpy (tons/yr)	**$46,421**	/year (year 1,2)
Ash Credits (year 3+)			($139,263)	/year (year 3+)
Total Gasifier Output Eq. kWe	**12,782.7**	kWe		
Total Power Produced	**80,622,887**	kWh/y		
Fuel Cost (year 1,2)	**$ 0.011**		**$853,743**	**/year (year 1,2)**
Fuel Cost (year 3+)	**$ 0.008**		**$668,059**	**/year (year 3+)**
Operation				
Operation Manpower	3.00	man-year	$20.00	/hr
OH Multiplier	1.50		$30.00	/hr
Operation Payroll Cost	**$ 0.002**	**$/kWh**	**$187,200**	**/year**
Utility				
Water	3.41 (54.02)	l/s (gpm)	$0.53 ($2.00)	$/kl ($/1000 gal)
Air (Accounted as Aux Load)				
Electricity (-do-)				
Utility Cost	**$ 0.001**	**$/kWh**	**$40,885**	**/year**
Annual Maintenance	**$ 0.005**	**$/kWh**	**$403,114**	**/year**
Total O&M Cost	**$ 0.008**	**$/kWh**	**$631,199**	**/year**
Operating Cost of Power				
Fuel & O&M Cost (year 1,2)	**$ 0.018**	**$/kWh**	**$1,484,942**	**/year**
Fuel & O&M Cost (year 3+)	**$ 0.016**	**$/kWh**	**$1,299,258**	**/year**

4.2.2 Financial Pro Forma

Table 4-10 Levelized Cost of Electricity for Monticello Case

Economic Summary (Costs are in thousands of mid-2002 dollars)	
Item	**$ Cost**
Total plant cost (TPC)	14,883
Cost of land	0
Organizational and startup expenses	355
Working capital	263
AFUDC	384
Fuel cost, $/MM Btu	0.95
Allocation of TPC over design/const. years	
Year	
1	0.12
2	0.88
3	0.00
Annual fixed O&M costs	587
Annual variable O&M costs @100% CF	14
Power output (kWe) @ design capacity	12,783
Heat rate, kJ/kWh (Btu/kWh)	11,101 (10,514)
Constant dollars levelized Cost of Electricity (COE), mills/kWh	
Capital	19.8
O&M	7.4
Fuel	7.2
COE $/kWh (mills/kWh)	**0.0345 (34.5)**

4.2.3 Sensitivity Analysis for Monticello Case

As mentioned in the Reid plant case, the price of electricity produced from the biomass gasifier is dependent upon capital cost, fuel cost and fixed O&M cost for the gasification operation. Table 4-11 below provides sensitivity analysis for changes in some of these parameters for the Monticello case.

Table 4-11 COE Sensitivity Analyses for Monticello Case

Case	Litter Cost $/ton	Ash Credits $/Ton	Capital Cost (TXU Cost)	Interest %	Period Years	Fuel c/kWh	O&M c/kWh	Capital c/kWh	Total c/kWh
Base Case	8	0	$14,882,622	7.5%	10	1.00	0.78	2.69	4.47
2	8	(6)	$ 4,882,622	7.5%	10	0.83	0.78	2.69	4.30
3	8	0	$14,882,622	7.5%	10	1.00	0.78	1.34	3.13
4	6	(6)	$14,882,622	7.5%	10	0.58	0.78	2.69	4.05
5	6	(6)	$14,882,622	7.5%	10	0.58	0.78	1.34	2.71
6	4	0	$14,882,622	7.5%	10	0.50	0.78	2.69	3.97
7	4	0	$14,882,622	7.5%	10	0.50	0.78	1.34	2.63
8	0	(6)	$14,882,622	7.5%	10	-0.17	0.78	2.69	3.30

The effect of changes in the litter price and credit for the ash sales will be same for the Monticello plant as in the Reid case.

5 Results and Discussion

Key issues affecting the economics of Biomass gasification cofiring include the capital cost of the gasification island, the costs of retrofitting the utility boiler, any potential boiler derating or loss of capacity as a result of the retrofit, the cost and reliability of the feedstock, and the opportunity costs associated with alternate fuels such as switching to natural gas. The costs of operating a relatively new technology such as the gasifier under cofiring arrangement may be influenced by potentially unforeseen maintenance or component replacement as well as the usual up-keep of such a plant. Similar uncertainties may be associated with the costs of maintaining the retrofitted boiler now being operated in a co-fired mode. With cofiring, there will be the need to integrate the controls for the gasification plant with those of the boiler operation in order to assure good performance and reliable operation from the gasifier and boiler integration. Unforeseen controls issues may also affect the operation of the combined plant and hence the costs of power production.

The broader market for commercializing this gasification technology includes other sites in the US, which have utility boilers and large concentrations of poultry litter production near by. These sites must be numerous enough to attract the industrial investment needed for a profitable business in this technology. The type of business model, varying from direct equipment sales to owning and operating the gasification plant [i.e., selling hardware versus selling product gas] will influence how attractive this market is to the industry. The prospect of more stringent environmental controls coupled with more complete deregulation of the utilities will also impact the economic benefits associated with the co-firing market since more or less utilities will consider converting their boilers to this mode of operation. Finally, the relative flexibility of this gasification approach will impact the extent to which other biomass feedstocks can be gasified in the same manner as poultry litter; the extent to which the gasifier and feedstock handling equipment need to be modified; the change in equipment capital and operating costs associated with such modifications; and the resulting shift in market opportunities associated with these issues.

5.1 Infrastructure/Fuel Supply and Alternative Fuels

Gasification has been applied to a wide variety of biomass materials including charcoal wood and wood waste, spent pulping liquor, pulp mill sludge, biosolids (wastewater treatment plant sludge), waste paper, rice hulls, rice straw, switchgrass, sugar cane, bagasse, poultry litter, and other animal wastes. Historically it has been used in close-coupled combustion applications to make steam, and in generation of electrical power largely through firing in internal combustion engines. In recent years efforts also have been made to couple biomass gasification to combustion turbines in integrated gasification-combined cycle (IGCC) applications.

A key feature of the fuel infrastructure is proximity of the biomass fuel source to the co-firing facility. This helps to reduce the costs of gathering and transporting the biomass fuel to its point of use. In other cases, where the fuel supplier is ready to pay for the haulage costs to avoid related processing and environmental problems, there may even be a financial credit associated with the use of the biomass. Depending on the nature of the feedstock, on-site storage and mass handling of the raw biomass feedstock also require attention in the facility design and maintenance considerations to avoid potential groundwater contamination and stream run-off, as well as odor and pest control.

Other fuel infrastructure problems include consistency of the feedstock properties and rate of delivery. Large fluctuations in either of these factors will require a more flexible design of the gasifier and co-firing features of the boiler with potential escalations in capital and operating costs.

5.2 Merits of the Project

Gasification-based co-firing has numerous inherent advantages. It increases the market potential of biomass co-firing. Not only is it applicable to both PC and cyclone boilers, but it is also applicable to many natural gas-fired boilers. If used in conjunction with duct burners between combustion turbine and a heat recovery steam generator (HRSG) it is applicable to combined cycle technology as well. The concept of gasification-based co-firing has the potential to accomplish the following objectives for boiler co-firing:

5.2.1 Energy Benefits and Impacts

- Maintain the ability to increase boiler capacity when firing wet coal by adding more Btu's to the primary furnace
- Minimizes the particle size reduction requirement for the biomass as gasifiers typically are capable of using 20 mm (¾”) minus size particles rather than the 6 mm (¼”) minus size particles associated with co-firing
- Minimize efficiency losses in the boiler by taking those moisture-related losses in the gasifier

5.2.2 Environmental Benefits and Impacts

- The gasification approach broadens the range of biomass that can be successfully co-fired with coal or with natural gas, including the use of zero cost and negative cost fuels (for example reduction in the size of biomass is not as stringent for gasification as it is for direct co-firing)

- Permits deployment with natural gas-fired reburn systems for possible NOx reductions when combusting the producer gas from the gasifier. The over fire reburn system in PC boilers has shown reduction in the NOx from the boiler.

- Continuing the reduction of emissions by reducing the sulfur content of the fuel in the high sulfur coal burning plants.

- Modifying the operating combustion mechanism with gas firing for NOx control, and reducing the particulate loading on existing boiler.

- Biomass co-firing reduces the amount of coal or other fossil fuel used and thereby reduces the net amount of CO_2 emission to the atmosphere since the use of biomass is considered to have zero impact on the CO_2 atmospheric budget (i.e. plant feed for poultry with subsequent production of poultry litter implies that the CO_2 absorbed by the plants is transmitted in part to the litter and in part to the production of meat – consequently more CO_2 is absorbed than is released from the biomass during gasification and combustion). This can be considered a CO_2 *credit* under this form of accounting).

5.2.3 Economic Benefits and Impacts

The potential hurdles to economic acceptance of the proposed technology include a capital cost commitment to the biomass gasification co-firing technology, uncertainties of the maintenance and operations cost in this application, and the degree to which the reliability and consistency of the feedstock can be assured. The following items represent economic benefits that can potentially offset some of these cost hurdles:

- Keeping the biomass ash separate from the coal ash by gasifier design protects the ability for the plant operator to make ash sales as potential fertilizer.

- The zero or negative cost of biomass (including the benefits of tipping fee avoidance) may lower the cost of plant operation, off-setting to some degree overall cost of electricity (COE) from the biomass gasification plant.

- An actual demonstration of this technology in the future will provide necessary capital and operating cost data to support an accelerated commercialization of the proposed biomass gasification co-firing technology for utility boilers

5.2.4 Infrastructure/Fuel Supply Benefits and Impacts

Biomass gasification projects depend upon availability of cheap fuels. Biomass by itself is a cheap source of fuel and it is generated on year round basis. Therefore supply of biomass is normally not a problem. However, logistics and associated cost of gathering such biomass and delivery to a central location for gasification is the challenge and normally a high cost item. With the low Btu value of the biomass transportation costs can quickly escalate to become a major cost factor.

The WKE application provides a good resolution to all of the infrastructure/fuel supply issues. The Reid plant is ideally located from the fuel supply perspective because of its proximity to large-scale chicken processing plants and the existence of an infrastructure to deliver chickens from area farmers to a central location for processing. Preliminary estimates from the processing plants put the poultry litter in the 50 miles radius of the Reid plant at 180 000 to over 200 000 tons per year. Further, there is a high degree of consistency and rate of delivery of the litter because of the mass production farming features and growth uniformity of chickens farmed in this manner.

The disposal of the poultry litter has been a significant problem for the local farmers and they have been requesting a regulatory relief from US EPA and US Department of Agriculture. At present the farmers do a partial clean up of the bedding material every 16~18 weeks and go through a springtime cleanup, whereby they completely remove the litter and dispose of it as landfill. If these farmers can find alternatives to land-based disposal, it may be possible to set up long-term fuel supply contracts at low or no cost to the Reid plant. The benefit to the local farmers will be an outlet for their poultry waste as well as more flexibility in scheduling clean-up and removal of the bedding material from their farms.

5.3 Project Sustainability and Opportunities for Replication

The chicken processing and other food processing industries are recession proof activities. Hence the supply of poultry litter is assured for the Reid plant as long as nearby chicken processing plants stay in operation. Alternatively, Primenergy gasifiers have been successfully tested with variety of other biomass fuels, such as sawdust pulp mill sludge, rice hulls, biosolids, etc. This flexibility allows the gasifier operators to secure and switch to alternative bio-fuels if poultry litter supply problems develop.

The operation of the co-firing project at the Reid Plant also meets a primary requirement of sustainability; that is WKE already has established a maintenance organization for its switchgrass biomass power plant and plans to generalize their services to include the proposed gasification facility at their Reid plant.

This project also addresses problems faced by local poultry farmers. The increasing appetite for poultry in North America has increased the concentration of poultry farms and associated litter. Poultry litter has become a disposal problem and runoffs from the fields over-fertilized with litter may carry excessive nutrients to nearby waterways potentially hurting water quality and aquatic life. The proposed gasification system at WKE's Reid Plant will reduce the litter volume while supplying biomass-based energy to the boiler. The greatly reduced volume of ash from the poultry litter will be more economical to transport and sell as high quality fertilizer. Thus the proposed gasification plant will turn a liability into a potential profit center.

This project can also demonstrate excellent replication opportunity throughout the country. The food industries in general and perishable food processors in particular are widely distributed due to the market they serve. The processors have well-established supply and delivery systems for their products as well as for the waste they generate. With these premises, it is safe to assume that there are many other utility power plants that can serve as hosts to gasification systems. With Federal Tax credit under Section 29 for renewable energy, which includes poultry litter, we believe that many utilities will be interested in setting up cooperative agreements with the poultry processors/poultry farmers and in evaluating gasification-based co-firing of biomass.

As a result of these potential benefits we believe that the technology and siting approach proposed here can lead to commercialization of this particular application of biomass co-firing in the future compared to other concepts currently being considered for biomass. However, at present, the economic evaluation based on current price of coal does not lead to commercialization of this technology in North America.

6 Conclusions

This project was proposed to demonstrate technical and economical feasibility of integrated biomass gasification and co-firing applications. The primary focus for the project was to utilize poultry waste as cofiring fuel, although any other biomass that is readily available can be used. Two sites – WKE's Reid plant and TXU's Monticello plants were selected for the feasibility studies. Primary objectives of the Phase I of the study were:

- To foster commercialization of a biomass co-firing technology that utilizes biomass, agricultural waste and farm animal wastes in an environmentally benign, technically practical in an economical application.
- To conduct an evaluation of the technical, regulatory, environmental and economic impacts of gasification based co- firing on existing fossil fuel fired boilers located in the vicinity of significant sources of animal waste and agricultural biomass.
- To identify the potential modifications, if any, required in the proposed gasification, boiler or other integral ancillary systems, to enable effective utilization of the biomass fuels considered.
- To evaluate these factors specifically for the TXU Energy in order to develop engineering cost and schedule estimates for implementing such biomass facilities.
- To implement such a facility at a later date, if the cost estimates and economic evaluations indicate that a useful demonstration of the proposed biomass gasification and co-firing technology can be carried out and replicated at multiple facilities.

The technical evaluations showed the following potential project benefits:

- Environmentally more acceptable renewable and premium power
- Reduced landfill and runoff into waterways
- Potential for reduced fuel cost
- Potential for fertilizer from ash (P/K)
- Gasification external to the boiler offer flexibility in biomass fuels

Gasification-based co-firing has numerous inherent advantages and merits of the proposed projects can be outlined as follows.

- It increases the market potential of biomass co-firing by creating a more attractive gaseous fuel
- The low Btu gas can be used in various types of boilers including HRSG
- A wide range of different fuels can be gasified
- Biomass co-firing substitutes for coal or other fossil fuels and thereby reduces the net amount of CO2 emissions to the atmosphere.

However, even though advantages of biomass gasification process is well recognized, and gasification based cofiring does offer a low cost alternative to a stand alone gasification plant, the current economic model is not attractive enough for utilities to consider this option. The primary hurdle in this process is required initial capital cost. From power generator's perspective, new capital investment does not offer any additional kW. Although, gasification based cofiring provides least intrusive alternate fuel for the existing boiler, it does not add to net generation from the plant, and probably may reduce the net efficiency slightly.

For the two cases examined here, the following observations can be made.

In case of WKE, it was more attractive and least cost option to install natural gas fired burners to the existing boiler that provided alternate fuel. The cleaner natural gas offered flexibility in operation during NOx mitigation season from May through October, and lowered overall plant NOx and SO2, and particulate emissions on annual basis. Although, biomass cofiring also offered year round reduction in NOx, SO2, and particulate emissions, the reductions that would have been achieved could not be documented as substantial. This is due to low level of cofiring, i.e. 5-10% of boiler heat input v/s up to 100% natural gas firing is feasible. The fuel price advantage of biomass fuel over natural gas was mitigated by procuring natural gas at low price during low demand period – the summer months – which also offered most environmental benefits during high NOx season. The other advantage that biomass gasification offered – a renewable resource with no net emissions of green house gases – would be a compelling advantage, provided there was a penalty in the form of carbon tax for utilities relying on fossil fuels.

In case of TXU, there are no plans for fuel substitution in the form of natural gas. With the size of the unit – over 500 MW, natural gas firing will be difficult to justify on cost basis. This also played against the cofiring, as heat input from biomass was insignificant, less than 1%. This also negated any environmental benefits from cofiring, as it would be insignificant and cannot be quantified accurately. The other factors outlined for WKE's case were also applicable to TXU case.

In conclusion, gasification based cofiring is practical and technically feasible, but under the present economic model cannot be justified. If there are economic incentives, i.e., substantial government participation in the project, carbon tax consequences, or tax incentives for green and renewable power, utilities and power producers will look into gasification based cofiring with more interest in the future. If there is carbon tax for utilities burning fossil fuels for power generation then the biomass based fuel will have some appeal, and biomass cofiring can become an option for further considerations.

7 References & Bibliography

7.1 References

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List of Acronyms and Abbreviations

°C	Degrees Celsius
Btu	British thermal unit
CO_2	Carbon Dioxide
COE	Cost of Electricity
deg F °F	Degrees Fahrenheit
gr/dscf	grains per dry standard cubic feet
HRSG	Heat Recovery Boiler
LLC	Limited Liability Company
MWe	Mega Watt Electrical
NOx	Compounds of Nitrous Oxides
O&M	Operation and Maintenance
P&K	Phosphorus and Potassium based fertilizer
PC	Pulverized Coal
ppbv(d)	parts per billion on volume basis (dry basis)
ppmv(d)	parts per million on volume basis (dry basis)
psi	pounds per sq. inch
scf	Standard cubic feet
SO_2	Sulfur Dioxide
SOx	SO_2/SO_3 Oxides of sulfur
TXU	Texas Utility Corporation
WKE	Western Kentucky Energy Corporation