Gasification Based Biomass Co-Firing
Phase I

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DISCLAIMER

ABSTRACT

Biomass gasification offers a practical way to use this locally available fuel source for co-firing traditional large utility boilers. The gasification process converts biomass into a low Btu producer gas that can be fed directly into the boiler. This strategy of co-firing is compatible with variety of conventional boilers including natural gas fired boilers as well as pulverized coal fired 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 reduction in the primary fossil fuel consumption in the boiler and thereby reducing the greenhouse gas emissions to the atmosphere.

Nexant Inc., with its team partners, Primenergy LLC, and Western Kentucky Energy Corp., 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. The Reid Plant was selected as a potential site for the biomass co-firing demonstration project. The engineering design for gasification and the economic analysis provided for the Reid plant in this study can be adapted to other utility boilers with minor modification and by incorporating site-specific parameters

The Reid plant located about 30km (20 miles) from Henderson in southwest Kentucky is maintained and operated by Western Kentucky Energy Corp., a subsidiary of LG&E Energy Corp., under a 25-year lease with Big Rivers Electric Corporation. The plant, a 63 MW pulverized coal-fired unit built in 1964, uses Kentucky coal as a fuel. The Reid plant is an ideal candidate for a biomass co-firing demonstration. Within a 80 km (50-mile) radius of the Reid plant there are large-scale poultry farms that generate over 68,000 metric tons/year (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 farm spread as fertilizer.

The preliminary findings of this study are that the project can be economically viable, provided that the litter can be delivered at the Reid plant site at cost of $6/ ton and the ash produced from the litter gasification can be marketed for P and K based fertilizer at a price that can offset the cost of the litter. Based on the project finances developed using price of litter and the current cost of coal at the Reid plant, WKE has decided not to pursue the Phase II – demonstration of the gasification based cofiring. Alternately, the project is pursuing other sites and other potential utilities as well as different biomass fuel sources.

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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 determine the technical and economical feasibility of biomass gasification and co-firing in an existing pulverized coal fired utility boiler. For plant specific technical and economical evaluation, the Reid plant located in Henderson County and operated by Western Kentucky Energy Corporation was selected. However, the findings are also general in nature and can be applied to any other fossil fueled power plant. The primary focus is to use poultry litter as a fuel for the gasification process, but 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 commercialize a biomass co-firing technology that utilizes biomass, agricultural waste and/or farm animal wastes in an environmentally benign, technically practical, and economical applications.
- 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 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 Reid Plant operated by Western Kentucky Energy Corp. and to develop preliminary design and cost estimates as it applies to the Reid Plant.

Fuel Supply

The USDA National Agricultural Statistical Service estimates that US produces nearly 7.5 million metric tons (8.25 MM tons- year 2000 estimate) of litter a year. Poultry litter analyzed from various sources for this study and from the literature survey has determined an average heating value (HHV) of about 10,470 ~14,420 kJ/kg (4,500 ~6,200 Btu/lb) on dry basis. Even if only 10% of this renewable resource is utilized, there is potential for generating about 480 million kWh or electricity every year from poultry litter. However, the power generation is dependent upon reliable supply at economically attractive price to justify electricity production from renewable resources.

The Reid plant initially selected for this study is one such plant located adjacent to a large poultry processing facility and with over 500 poultry farmers within a 80 km (50-mile) radius and estimated litter supply of over 60,000 metric tons (66,000 tons) per year.

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/h of steam at 513°C and 9,060 kPa (690,000 lbs/hr at 1300 psig and 955°F) 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 the operator flexibility of switching to natural gas firing during the NOx mitigation season, normally from May through September.

Proposed Gasifier
The proposed gasifier for the Reid plant setup is a Primenergy KC-18 system consisting of fuel feed system, one gasifier, hot gas filtration system and a two staged after burner combustion system. The KC-18 can handle 7,620 kg/h (8.4 tons/hr.) of poultry litter. The KC Reactor/Gasifier is a fixed bed, air blown, updraft, near atmospheric pressure gasifier.

The use of mechanical bed agitation, precise gasification air control and zoning produces a clean, combustible gas with heating value of about 4,102 kJ/m^3 (110 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 gasifier retains phosphorous and potassium present in the poultry litter while the fuel bound nitrogen is lost with the gasification products. The ash has potential value as P-K fertilizer. Project developed estimates of potential market price for the P-K fertilizer derived from gasifier ash. Based on the current 20-10-10 N-P-K fertilizers prices, the ash from the litter can be marketed at $30/ metric tons on P-K constituent basis, excluding transportation cost.

Boiler Gasifier Integration
The low Btu gas from the gasifier (producer gas) is at 840°C and has a calorific value of about 4,102 kJ/m3 (1550°F, 110 Btu/std. cu. ft.) The gas is burned in a two-stage combustion process, which raises the temperature of the gas to about 1,316°C (2400°F). The gas can be fed into any existing boiler at a suitable location as additional heat input to the boiler.

For the Reid plant case analyzed here, the cleaned hot gases are to be fed just below the existing coal burners, allowing the reduction of the primary fossil fuel to the boiler. It is estimated that about 8~10% of heat input can be provided from the producer gases, which can allow Reid operators to reduce proportionate amount of coal.

Conclusions
Poultry litter is a renewable energy resource. Due to low sulfur content in the poultry litter, and gasification with two staged combustion process, addition of the

gasifier can reduce the SO_2 and NOx by over 5% from the existing boiler while burning eastern coal. With the hot gas filtration system, gases from the gasifier can be cleaned and fed into the existing boiler. This can also reduce particulate loading on the electrostatic precipitator (ESP). However, no estimates of reduction in particulate loading are made in this study.

The study shows that the Reid plant or similar fossil fuel boiler can reduce their primary fuel consumption by 8~10%, achieve some reduction in SOx and NOx pollutants and can claim a reduction in greenhouse emissions (CO_2) from the boiler.

1 Introduction

This project was undertaken to determine technical and economical feasibility of integrated biomass gasification and co-firing in an existing utility boiler. The specific case for the gasification based biomass cofiring was developed for the Reid plant operated by Western Kentucky Energy and utilizing poultry litter as biomass fuel for gasification. However, these findings can be applied to other sites and other biomass materials with site-specific variations in engineering design and economic parameters for the biomass fuels with minimal effort. Specific objectives of this project are:

- To commercialize a biomass co-firing technology that utilizes biomass, agricultural waste, farm animal wastes or other readily available biomass in an environmentally benign, technically practical, and economic application
- To evaluate the technical and economic impact of gasification based co-firing on the existing class of fossil fuel fired boilers currently within range of biomass sources of reliable consistency and delivery rates needed for economic operation in a commercial market environment
- To determine possible modifications, if any, required in either the proposed gasification or boiler technology, for effective integration of gasification based co-firing
- To evaluate these factors specifically for the Reid Plant operated by Western Kentucky Energy Corp. and to develop preliminary design and cost estimates as it applies to the Reid Plant

The proposed concept of gasification based co-firing is shown in Figure 1.

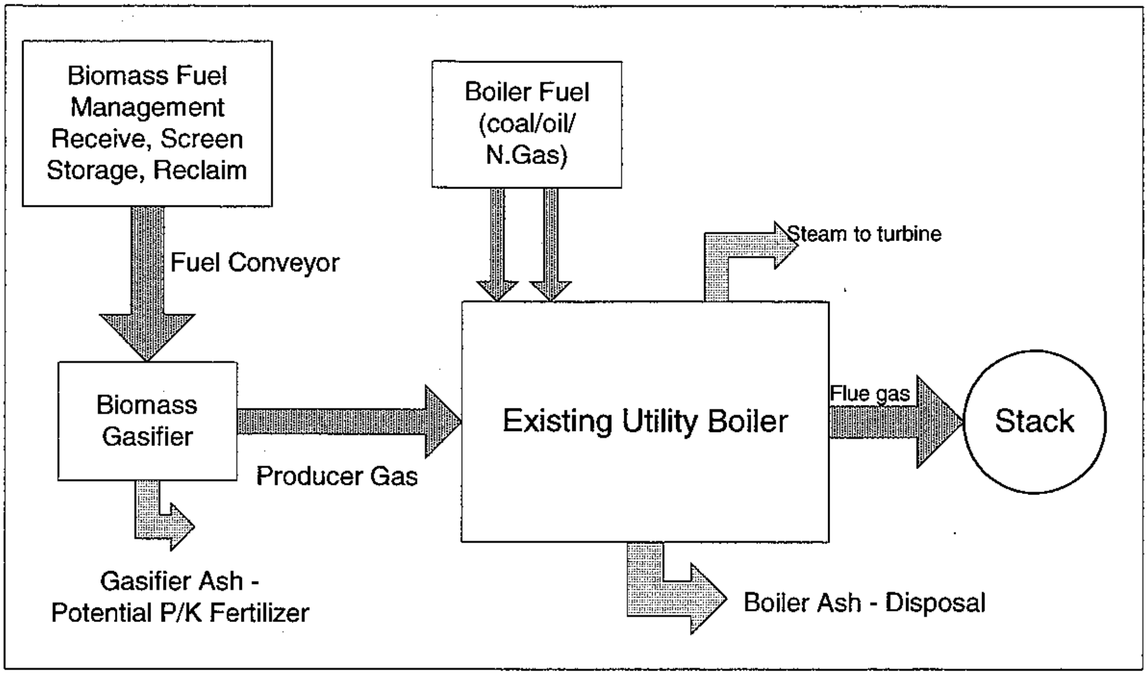

Figure 1 Gasification Based Biomass Co-firing System Concept Diagram

The feasibility study was undertaken for possible future demonstration phase of the project at WKE's Reid plant located in Henderson County, KY. Primenergy, LLC, gasifier is selected for the engineering design basis for this study. Detailed information on the Reid plant PC boiler and Primenergy's fixed bed updraft gasifier is provided here. Nexant, Primenergy and Western Kentucky Energy (WKE) evaluated a gasification system to be located in the vicinity of the existing boiler and provide producer gas to the Reid plant boiler and to displace a portion of the current coal and / or future natural gas fuel consumption in the boiler.

1.1 PHASE I Organization

The gasification based biomass co-firing project has reviewed and evaluated technical feasibility and economical viability of building and operating a poultry litter gasifier at WKE's Reid plant near Henderson, KY. The project reviewed the existing plant design and operation; evaluated available poultry litter supply, and prepared detailed cost estimates, as it would apply to the Reid plant for the Phase II of the project. Preliminary engineering design, equipment specifications and plant layout, estimate of emissions under co-firing for the Reid plant have been provided in the report.

The project has two phases. Phase I addresses technical feasibility and economic evaluation. Under Phase II actual demonstration of the technology can be undertaken. Project Organization chart for Phase I is shown here.

Gasification Based Cofiring Project
Phase I

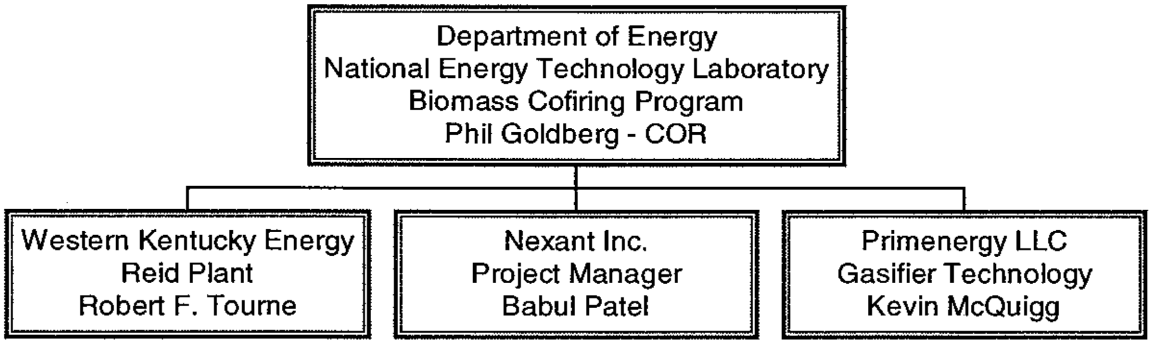

Figure 2 Project Organization Chart Phase I

The project team has undertaken a detailed feasibility study of integrating the Reid plant with Primenergy's gasifier unit utilizing poultry litter as primary feedstock. The tasks that were performed under this study are:

- Conceptual engineering of the gasification facility, including the fuel handling aspects of that facility.
- 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 and price range for the poultry litter. This effort is concentrated on locally available poultry litter, but other biomass in the area can be substituted pending assessment of price and availability.
- Economic assessment of gasification-based co-firing based on the fuel cost implications, including sensitivity analysis based on variation of fuel price and potential after market for the ash from gasification as potential fertilizer.
- Modeling of the boiler to determine suitable boiler penetrations and overall impact on boiler performance based on cofiring.
- Estimate of environmental benefits from reduction in green house gases.

1.2 Phase I Tasks and Schedule

A detailed work plan by major tasks for Phase I is provided here. Figure 3 illustrates the logical flow of work carried out in this program. At each of these stages, criteria for proceeding to the next stage were established. Figure 4 provides a revised project schedule and additional tasks the project is undertaking to enhance the technical knowledge and future market potential for similar projects at other sites. The project addressed each of these tasks listed here and a description of evaluation of these tasks is included in this report.

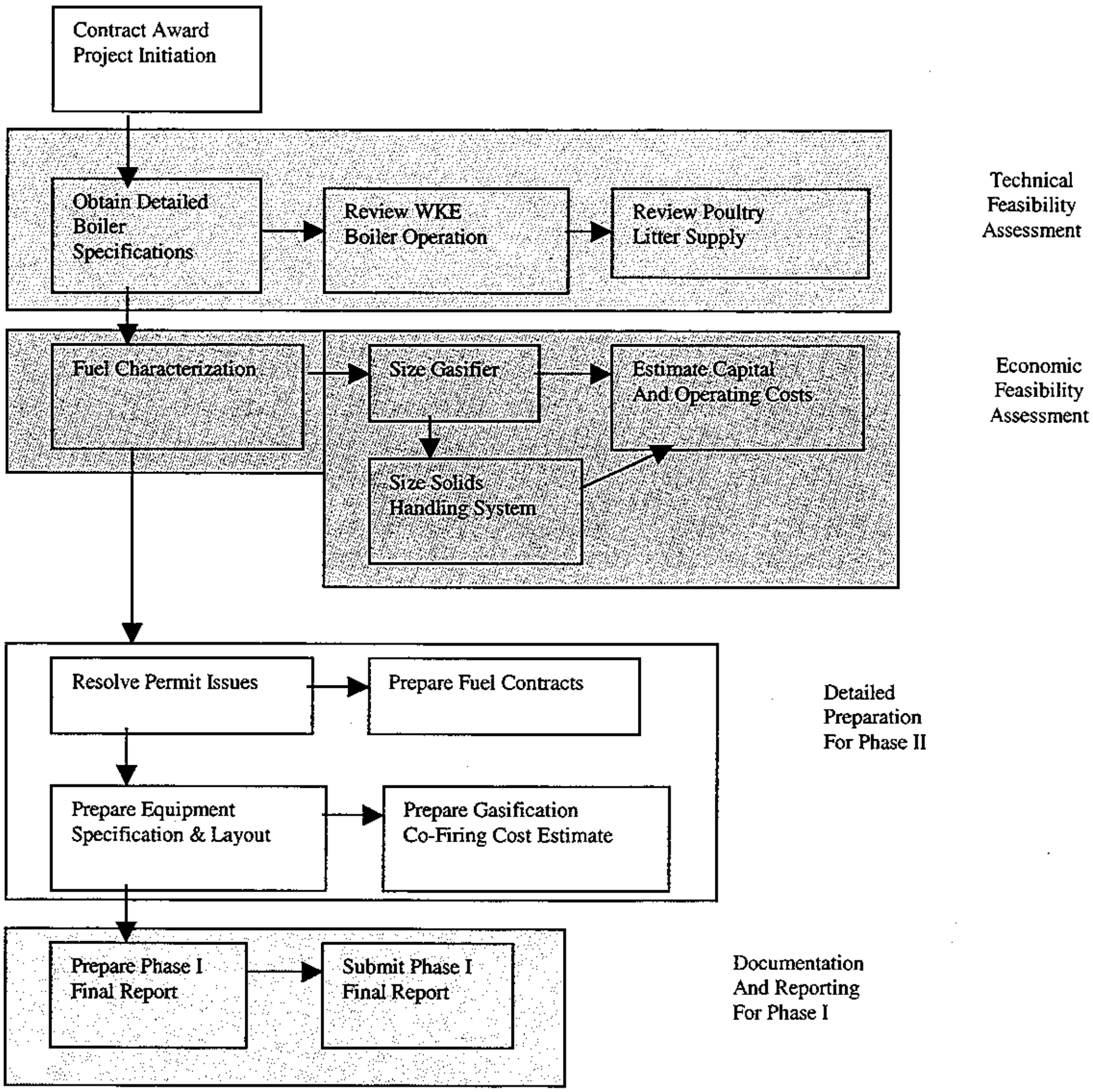

Figure 3 Interrelationships of Tasks in Phase I

The revised schedule with additional tasks is shown in Figure 4

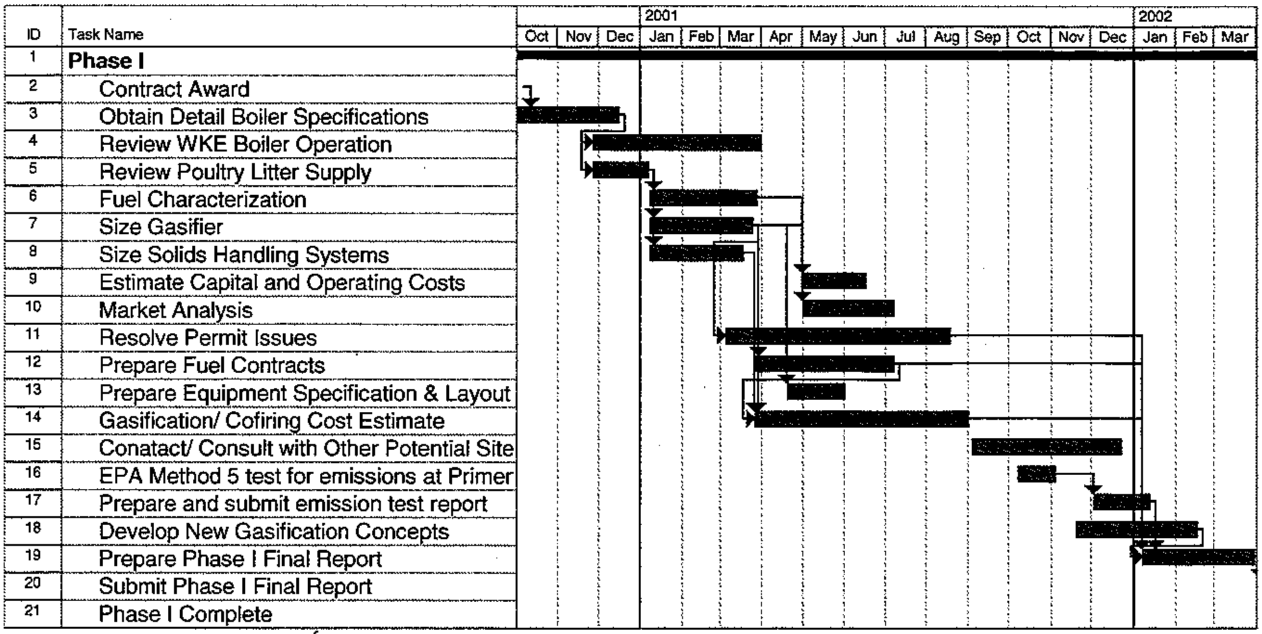

Figure 4 Project Milestone Schedule (Revised)

2 Experimental

2.1 Reid Plant Boiler Specifications

The WKE's Reid plant is located near Henderson, Kentucky. It is a 63 MW unit with a pulverized coal-fired Riley Stoker boiler. The boiler uses Western Kentucky coal. The boiler has maximum continuous capacity of 313,000 kg/h of steam at 513°C and 9,060 kPa (690,000 lbs./hr of steam, 1300 psig and 955 °F).

Detailed Specifications of the boiler vendor and a boiler schematic (Figure 5) are provided here.

Reid Plant Boiler Specifications (MCR)

Location	Henderson Co. KY
WKE and RILEY Stocker Boiler Contract	B2502
RILEY Boiler Serial No	3456
Year Built	1964
Rating based on burning specification coal	
Maximum Continuous Steam Capacity (690,000 lbs./hr)	313,000 kg/h
Peak Steam Capacity, (for four hrs. 760,000 lbs./hr)	345,000 kg/h
Type of Furnace Operation	Pressurized
Drum Design Pressure (1475 psig)	10,266 kPa
Economizer design Pressure (1525 psig)	10,610 kPa
Operating Pressure at Super heater Outlet (1300 psig)	9,060 kPa
Steam, Temperature at Superheater Outlet (955°F)	513°C
Furnace Volume (50,250 cuft)	14,239 m^3
Heat Release (at MCR 16,600 Btu/cuft/hr)	618.9 MJ/ m^3/h
Heat Release (at peak capacity, 19,400 Btu/cuft/hr) (For four hrs when burning coal.)	723.3 MJ/m^3/h
Heating Surfaces (Per Manufacturer's Stamping Sheet)	
Boiler (4,020 sq. ft)	373.5 m^2
Water Walls (2,100 sq. ft)	195.0 m^2
Superheater (2, 330 sq. ft)	216.5 m^2
Economizer (4,200 sq. ft)	390.2 m^2
Air Heater (82,400 sq. ft)	7,655 m^2
Water Capacity To Normal Water Level (~500, 788 lbs.)	227,358 kg
Water Capacity For Hydrostatic Test (~827,253 lbs.)	375,573 kg

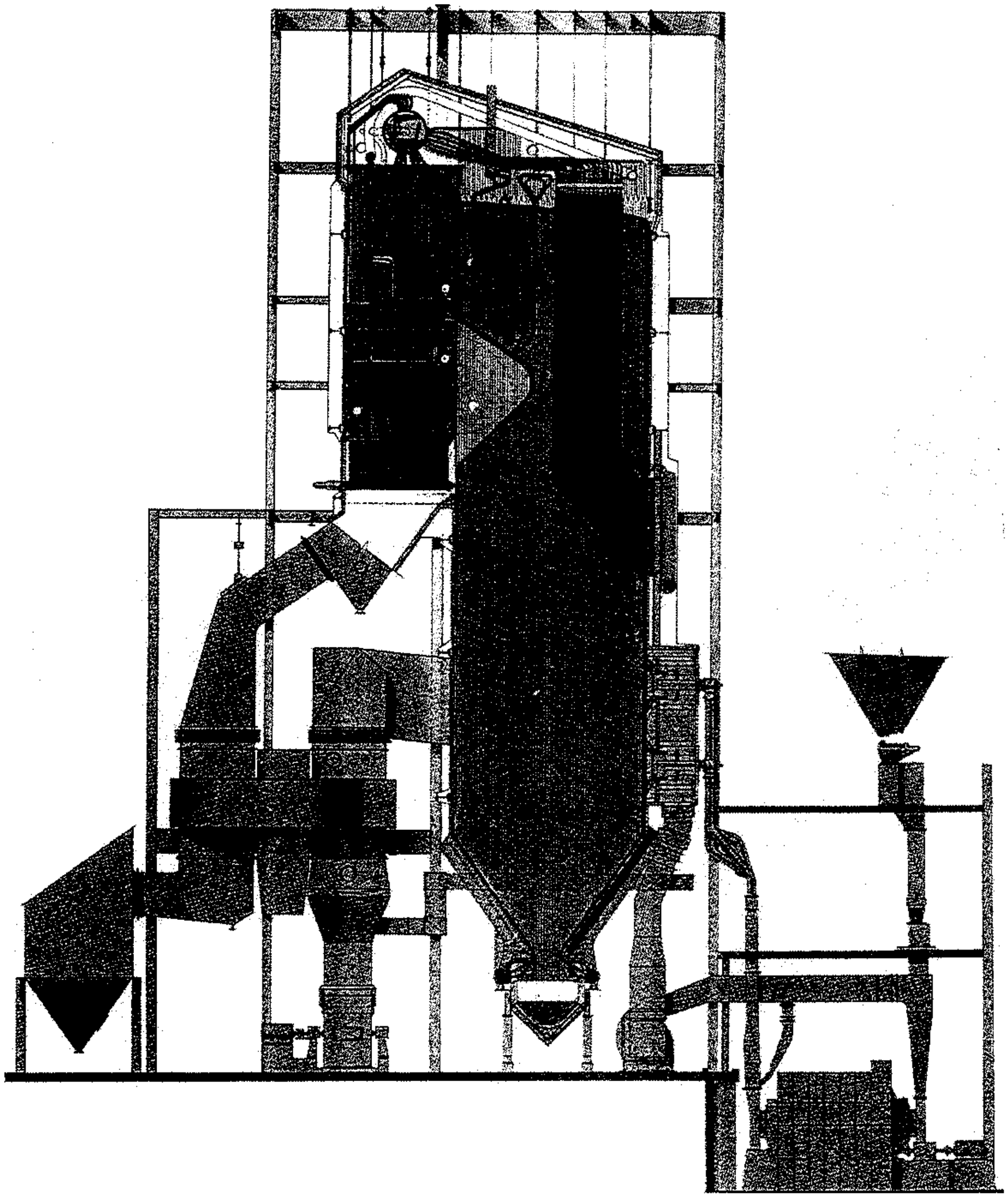

Figure 5 Reid Plant Boiler Schematic

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

2.2 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. Following Table list the summary of the boiler operating data.

Table 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

Reid Plant Coal Analysis

Analysis of coal burned at the Reid plant was obtained from the plant. Following is the reported as received compliance coal used in the boiler for the year 2000.

Table 2 As Burned Coal Analysis at the Reid Plant

Coal	Units	Average	Minimum	Maximum	Source
As Burned Coal (LHV)	kJ/kg (Btu/lb)	27,880 (11,986)	26,560 (11,422)	28,600 (12,296)	Reid Plant Data (WKE)
Moisture	%	8.6	7.5	10.8	(Y 2000)
Ash	%	10.6	8.6	12.2	↓
S	%	2.6	2.3	2.8	

2.3 Review of Poultry Litter Supply

The Reid plant 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 68,000 tons per year (75,000 tpy).

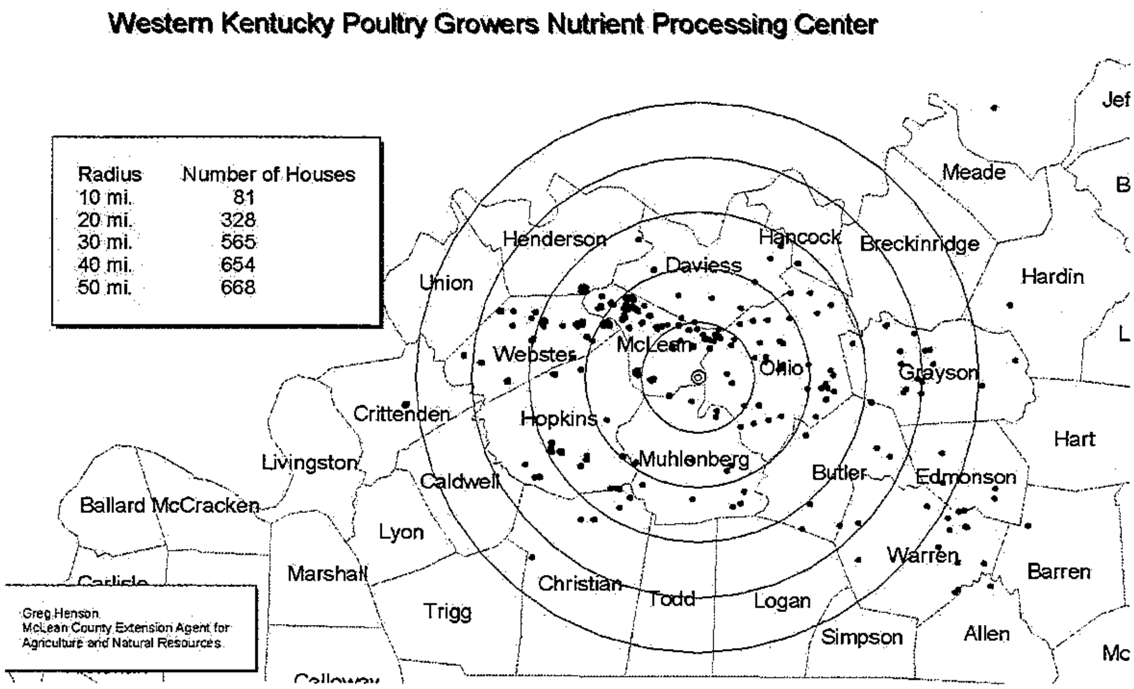

Figure 6 Poultry Supply in Vicinity of Reid Plant, Henderson, KY [1]

The map in Figure 6 is drawn with center in McLean County, about 30 km from the Reid plant. The map shows that within 80 km 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 110 km (65 miles) due southeast from the Reid Plant. Poultry farmers associated with Purdue Farms may overlap in the above map.

2.4 Fuel Characterization

Some of the area farmers were contacted to obtain poultry litter samples for analysis. The following two tables provide average proximate and ultimate analysis of the poultry litter samples and ash characteristics.

Table 3 Fuel Characterizations - Poultry Litter Analysis

Sample Analysis	As Received	Dry Basis
Proximate (%)		
Moisture	32.47	0.00
Ash	19.12	28.57
Volatile	40.57	59.95
Fixed C	7.84	11.48
Total	**100**	**100**
Sulfur	0.43	0.64
KJ/kg (Btu/lb) - HHV	9,551 (4,111)	14,100 (6,069)
Ultimate (%)		
Moisture	32.47	-
Carbon	24.60	36.37
Hydrogen	2.74	4.01
Nitrogen	2.52	3.75
Sulfur	0.43	0.64
Ash	19.12	28.57
Oxygen (by difference)	18.12	26.66
Total	**100**	**100**
Chlorine** (separate analysis)	0.99	1.52

The above results compare well with published literature and samples collected and analyzed by Primenergy from various sources from other parts of the country. A summary of the analytical results from Primenergy samples is provided in Table 4 for comparison.

Table 4 Poultry litter sample analysis by Primenergy [1]

	Moisture	Proximate Analysis (% dry)			Sulfur	Higher Heating Value kJ/kg (Btu/lb.)	
	(Percent)	Ash	Volatiles	Fixed C	(% Dry)	Dry	As Received
Avg.	27.01	25.15	61.49	13.36	0.79	14,672 (6,315)	10,706 (4,608)
Min.	17.00	16.49	53.22	9.94	0.59	12,330 (5,307)	8,800 (3,788)
Max.	39.34	36.84	67.38	16.54	0.95	16,826 (7,242)	12,436 (5,353)

The ash from the poultry litter combustion was analyzed for the elemental constituents. The following table proved the results of the ash analysis.

Table 5 Poultry Litter Ash Characterization [2]

Elemental Analysis of Ash %	Litter samples from local farmers %	Primenergy samples %
SiO2	20.20	43.15
Al2O3	14.25	6.95
TiO2	0.24	0.27
Fe2O3	1.49	1.3
CaO	14.17	9.98
MgO	4.59	3.72
Na2O	8.45	2.64
K2O	10.86	10.61
P2O5	15.09	13.78
SO3	3.94	4.53
Cl	6.52	3.07
CO2	0.20	--
Total	100	100
Ash Fusion Temperature	**Reducing**	**Oxidizing**
	Deg C (Deg F)	**Deg C (Deg F)**
Initial Deformation	1,239 (2,262)	1,238 (2,261)
Softening (H=W)	1,288 (2,315)	1,256 (2,293)
Hemispherical (H=W/2)	1,287 (2,349)	1,277 (2,331)
Fluid	1,311 (2,391)	1,303 (2,377)

The above values show ash as an excellent source for potassium (as 10% K2O) and phosphorus (as 15% P2O), two major constituent of N-P-K fertilizer. Bound nitrogen in the litter is released as volatile ammonia, amines, and urea during the gasification process and is not present in the ash in measurable quantities.

2.5 Gasifier Sizing

2.5.1 Primenergy Gasifier

The Primenergy gasifier is a fixed-bed updraft system. Because this gasifier is 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 gases while reducing the long chain and cyclical condensable hydrocarbons to fragments.
Figure 7 is a schematic of the gasifier.

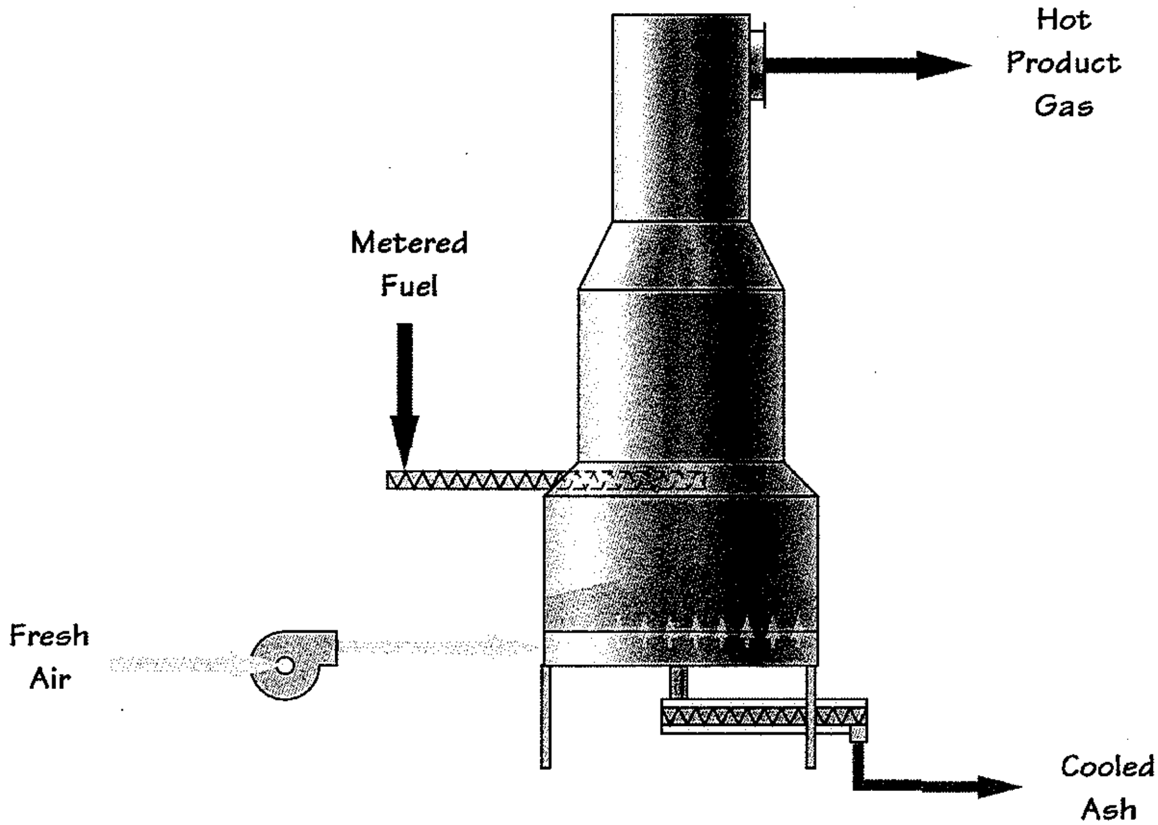

Figure 7 Primenergy Gasifier – simplified sketch

2.5.2 Gasifier Material and Energy Balance [3]

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 provides material and energy balance for specific streams. Refer to the stream number in the process flow diagram provided in the Appendix.

Table 6 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 (3617)	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 (13,661)
Hydrogen				185 (408)	185 (408)	185 (408)	88 (193)
Water (v)		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 (l)	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 7 Energy 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
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)	9,551 (4,110)			2,219 (955)	2,161 (930)	2,161 (930)	532 (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.

2.5.3 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 to flow the producer gas from the gasifier into the furnace.
- 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 [4]. Following is the brief description 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 1320°C (2400 °F).
- 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 45.7 m/s (150 ft/sec)
- Four penetrations of 0.5 m (20 inch) inside diameter will meet the total flow cross sectional area requirements of 0.7 m2 (8.8 ft2).
- 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 budget 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.

2.6 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 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 575.5 kg/ 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 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 energy 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 the table under economic analysis section. The layout plans with the proposed mechanical and pneumatic conveying are provided in the Appendix.

2.7 Permit Issues

NOx Emissions: Due to bound nitrogen in the poultry litter (urea/ ammonia), straight combustion of litter with excess air at high temperature would produce 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 and amine and urea 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 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. This can be considered as 8~10% of the fuel input to the boiler going through an equivalent low NOx burner.

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. 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, of the 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.

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

2.8 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.

2.9 Equipment Specifications

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.

Table 8 Gasifier Island Equipment List

Equipment	Quantity
Fuel Feed Rotary Valve	1
Fuel Infeed Auger	1
KC-18 Gasifier	1
Agitator	1
Ash Discharge Auger #1	1
Ash Discharge Auger #2	1
Ash Cooling Auger	1
Ash Silo	1
Underfire Air Fan	1
Cooling Water Pump	2
Hot Gas Filter	1
Fly Ash Discharge Valve	2
Final Ash Conveyor	1
ID Fan	1
Overfire Combustion Chamber	1
Overfire Air Fan	1
Air Compressor	1
Ash Silo	1
Combustion Air Heater	1
Refractory Lined Piping	As Req'd.
Expansion Joints for boiler Penetrations	4
Pipe Supports	As Req'd
MCC Unit	1
DCS Unit	1
Operator Consoles	2

Table 9 Material Handling System Equipment List

Equipment	Quantity
Fuel Storage Silos	2
Vibrating Screen/ Grizzly	1
Fuel Unloading Pit	1
Screw Conveyor	1
Bucket elevator	1
Fuel Diverter	1
Fuel Storage Building	1
Fuel Storage Bldg. Ventilation System	1
Fan Blower for Fuel Conveyor	1
Rotary Valve	2
Fuel Day Silo	1
Cyclone Separator	1
Separation Screen	1
Hammer mill	1
Hammer mill Air System	1
Silo Unloader	1
Silo Discharge Conveyor	1
Metering Bin Discharge Screw	1
Bucket Elevator	1

2.10 Equipment Layout

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

3 Results and Discussion

Reid Plant Specific Case:

3.1 Gasifier Sizing

Assuming annual litter production per poultry house of approximately 135 metric tons (150 tons) and based on the over 500 poultry houses in the 80 km radius of the plant, annual litter supply will be about 70,000 metric tons (80,000 tons). After review of the local poultry litter supply, one KC-18 gasifier was selected for this project. The KC-18 has a capacity of 7.5 tph (8.4 TPH.) At 80% capacity factor this will require 52,280 tons of litter per year (58,867 tons/year). The local supply will be sufficient to meet the gasifier fuel demand.

The 7.5 tph of litter will generate about 72.85 GJ/h (69 MMBtu/hr) of heat at HHV of 9,550 kJ/kg (4,110 Btu/lb) in the poultry litter. With gasifier efficiency of 82%, about 60 GJ/h of heat will be available to the boiler. This is about 8-9% of the existing boiler input. Thus integrating the gasifier with the existing boiler, 8% of the energy input will come from the renewable resource – poultry litter. This will also displace about 2.7 t/h (3 tons/hr) of coal presently burned in the boiler on annual basis, or about 1,900 tons of coal (2,100 tons) can be replaced by renewable resources.

3.2 Gasifier Plant Layout

Reid Plant is located at Sebree complex. The Sebree site has two Green River coal fired units, the Reid plant and two City of Henderson coal fired units and a 45 MW GE frame 7 gas turbine as a peaking unit. WKE operates all of the plant on lease basis from their respective Owners – Big River Energy Corp. and City of Henderson.

Due to existing facility, on site coal storage area, switchyard and other infrastructure, it was necessary to obtain input from the plant staff and WKE management on the litter storage area and gasifier location. After site survey and review of the existing facility plot plans with the plant operating staff, it was decided that the gasifier could be situated adjacent to the Reid plant existing boiler. The ideal place to locate the gasifier island was west side of the boiler, underneath the coal conveyor and between the boiler house and warehouse. The plant layout drawings provide location of the gasifier with respect to the Reid plant.

3.3 Litter Storage and Handling

Coal is delivered at the Reid plant via truck and is stored outdoor and reclaimed for the boiler as required. However, storing poultry litter on site will require special considerations. Poultry litter has a strong urea based odor. Hence, odor control necessitates enclosed storage. Litter will be brought to the site in covered trucks. Project is evaluating the three different schemes to store litter on site and transport it to the gasifier.

A. row storage and belt conveying
B. silo storage and pneumatic conveying
C. silo storage and belt conveying

The following is a brief description of the major system and equipment associated with the biomass receiving, storage and transport to the gasifier.

- **Truck Unloading**: The truck unloading facility will consist of an enclosed building with single bay for unloading one truck. The bay will feature a hinged lid that will swing down to open for a bottom dump or back dump trucks. The bunker is equipped with a moveable floor an hydraulic pump and motor and controls system. The litter falls onto the moveable floor.

- **Feed System Screening and Processing**: The push floor pulls the litter to a horizontal belt conveyor. This conveyor carries the litter through the bunker wall to an enclosed sandwich conveyor to lift the load to the screen and hammer mill shed located above grade. Alternatively, a drag chain conveyor may be used. Air is drawn from the bunker through the trench and conveyor enclosure to the screen and hammer mill shed by the under fire air fan

- **Oversize Material Reduction and Reclamation System**: Within the size reduction and reclamation system, there will be a size-screen, which will permit only 6 mm (¼") material to pass through. Larger material will vibrate down the upper surface of the sloping screens and be conveyed into a hammer mill or a tub grinder feeder. The hammer mill will reduce the size of this material to 6 mm (¼") or smaller. The milled material will be conveyed back to the feed port of the size-screen. The size reduction is required for gasification and flowability. Over-size material that can not be milled such as metal pieces and rocks will be collected in the hammer mill for disposal. Through material from the screen will be transferred to the long term storage building by an enclosed sandwich conveyor. The screen and hammer mill shed will be maintained under slight negative pressure established by the suction of the under fire air fan.

- **Long Term Storage**: The 6 mm (¼") poultry litter from the screen and hammer mill shed transfers to a distributor conveyor for conveying to the long term storage building or storage silo.

  - The long term storage building is a single level building 40 m W x 45 m L x 5 m H (130' x 140' x 16'). The litter on the distributor conveyor is diverted to a cross-distributor conveyor via a scraper for even storage pile in the long term storage building.

- Alternately, if silos are used for long term storage, it will be two silos, each 10 m diameter and 24 m H (30'diax70' H). If the silos are used, bucket elevator with a cross distributor conveyor is used to fill the silo with the litter.
- The long term storage building or the storage silos are under a slight negative pressure due to air suction from the under fire air fan.

o **Long Term Storage to Day Storage**: Litter from the long term storage can be transported to the day storage area with belt conveyor or with pneumatic conveyor. For the Reid plant case, the enclosed belt conveyor can be mounted underneath the existing coal conveyor or transported through the underground trench. Alternatively, the litter can be conveyed through pneumatic conveying in two 150 mm (6" diameter) pipes located underneath the existing conveyor belt.

o **Day Storage**: There will be one enclosed, ventilated storage building or storage silo. For mechanical conveying the storage building capacity will be up to 8-12 hours of inventory of poultry litter. For pneumatic conveying, the storage silo will be sized for 4 hour of storage.

o **Airlock System**: Litter from Day storage is continuously transferred to an enclosed conveyor in order to be lifted to the top of an enclosed chute feeding an airlock. The airlock vessel is required to maintain the slightly negative pressure in the solids handling system.

o **Under Fire Air Fan System**: The gasifier requires about 25,000 kg/h (~40,000 lbs/h) of air for the gasifier, and for the after burn in the second stage combustion. This amount of air translates to 1.4 air changes per hour for the enclosures of the solids handling system. This air change is sufficient to maintain a slight negative pressure throughout the solids handling system and contain odor associated with the litter.

o **Miscellaneous**: Civil site preparation and finished paving for rerouted utilities, pavements, etc. are determined from the layout of the new equipment. No major system or existing equipment will have to be relocated in order to make room for the solids handling system.

The concepts presented above and shown in the layout drawings in the Appendix for the poultry litter storage and conveying has not been field tested. Some of the issues for the project to address and evaluate are:

- Wide variation in the litter quality –e.g. moisture content from 20% to as high as 40%
- Compacting and bridging over of the litter when stored in the silo

- Flowability of the litter

Project is planning to address and evaluate these factors further.

3.4 Boiler- Gasifier Integration

The existing Reid plant boiler is a stand alone unit. Boiler master control provides all necessary trip functions for the safe operation of the plant. When an external gasifier is integrated with the boiler, review of the boiler safety functions is required. The controls of gasifier will be integrated with the boiler controls for safe boiler operation. Boiler master will be able to override the gasifier operation and isolate the existing boiler from the gasifier. The gasifier controls will be modified to trip and purge the gasifier unit on a trip of the boiler. The fuel feed will be cut off, the gasifier purge valve will be opened and the under fire air blower will be tripped. Similarly, on a gasifier trip, the gasifier will be isolated from the boiler.

3.5 Gasifier Ash Disposal

One of the advantages of gasification based cofiring is that the boiler ash and gasifier ash are kept separate. The ash removed from the gasifier is rich in nutrients such as potassium and phosphorus. The ash is sanitized at 800°C (1500°F) in the gasifier and hence does not contain any biological pathogens, and is safe to handle. The ash has market potential as a fertilizer as well as food supplement additive for the animal feed. Project is evaluating economic end use of the ash.

3.6 Environmental

3.6.1 Environmental Emissions

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 10 for evaluation. The test was conducted on the stack after burning the producer gas from the gasifier in the heat recovery steam generator. A stack testing third party working independently for Primenergy, LLC, collected this proprietary data.

Table 10 Unabated Emissions Data for Poultry Litter Test Gasification Run [4]

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

The greenhouse gases, primarily carbon dioxide, (CO_2), Methane (CH_4), and Nitrous Oxide (NOx) are associated with the industrial and agricultural activities. One way to reduce these green house gases is to displace some of the carbon dioxide that is now emitted to the atmosphere from the combustion of fossil fuels with carbon derived from renewable resources. At Reid plant about 90-100 kg/GJ (220~250 lbs/MMBtu) of CO_2 is generated on heat input basis into the boiler. With the biomass-based fuel, this CO_2 from fossil fuel is replaced by the renewable fuels. It is estimated that one gasifier can replace ~7.3 t/h (~8 tons/hr) of CO_2 from the Reid boiler.

3.6.2 Comparison of Coal Combustion v/s Litter Gasification

Table 11 Reid Plant fuel and emissions: coal v/s local litter samples

	Coal	Coal	Litter	Litter		Coal	Litter
Constituents	Per kg (or lb)	kg/GJ (lbs/ MMBtu)	Per kg (or lb)	kg/GJ (lbs/ MMBtu)	Emissions	kg/GJ (lbs/ MMBtu	kg/GJ (lbs/ MMBtu)**
KJ (Btu)	25,315 (11,200)	-	9,493 (4,200)			-	
S	0.025	1.0 (2.23)	0.005	0.53 (1.07)	SOx	2 (4.46)	1.06 (2.14)
C	0.635	25 (56.72)	0.246	25.9 (58.57)	CO2	92 (208.)	95 (214.76)
H	0.045	1.8 (4.02)	0.027	2.84 (6.52)	H2O	16.2 (36.2)	25.6 (58.7)
N	0.015	0.59 (1.290)	0.025	2.6 (5.95)	NOx	0.37* (0.78*)	0.17~0.2 (0.36~0.4)
Ash	0.119	4.7 (10.63)	0.192	20.2 (45.71)	Ash	10.63	20.2 (45.71)

Note: * as reported by WKE, ** estimates from Primenergy

Discussion on environmental impact of poultry litter cofiring:

- S in coal is elemental S and ends up as SOx. S in the litter is compound S and as such, some of it remains in the ash as Alkaline sulfates. Hence, the calculated 1.06 kg/GJ (2.14 lbs/MMBtu) SOx is the high end estimate when gasifying litter. It is expected that over 50% of S will remain in the ash, as evident from elemental analysis of ash indicating 4% SO_3 in the ash. Thus, litter gasification will reduce SO_2 emissions from the Reid plant.
- On GJ (MMBtu) basis, carbon is about the same in litter and coal, and hence CO2 emissions from litter or coal are a wash. However, from life cycle perspective, CO_2/ Carbon is closed loop when gasifying the litter, and hence no new net CO_2 is introduced in to atmosphere from the chicken/ litter cycle.
- Nitrogen (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 and under direct combustion of litter will result in very high NOx emissions. However, when the litter is gasifed, the bound nitrogen is released as ammonia, amines, amino compounds, urea, etc. Again, if these gases from the gasifier are 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, amino compounds, urea, etc. are broken down into elemental N and water/CO2. Primenergy expects NOx from gasifer to be less than 0.2 kg/GJ (0.40 lbs/MMBtu).
- Gasifier will generate about 4 times the ash on GJ (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. The project is investigating after market for the ash to offset the cost of acquiring the litter.
- The current price of P-K fertilizer without nitrogen is estimated to be about \$25~\$30/ton. With 15% P2O and 10 % K2O in the ash, the current price of P-K fertilizer can be realized offsetting the price of litter. However, no credit is taken in the financial pro-forma cost analysis.
- Litter does not have any detectable level of heavy metals, such as Hg, As, Pb, etc. Hence, there will not be any detectable level of these heavy metals in the gasifier syn gas, nor in the ash.

3.7 Economic Analysis

Key issues affecting the economics of Biomass gasification cofiring include the capital cost of the gasification and material handling systems, the costs of retrofitting the utility boiler, any potential boiler derating or loss of capacity as a result of the retrofit and cofiring, the cost and reliability of the feedstock, and the opportunity costs associated with alternate fuels such as switching to natural gas. The cost of operating a relatively new technology such as the gasifier is 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. 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 from the combination. Unforeseen controls issues may also affect the operation of the combined plant and hence the costs of power production from it.

The following is a detailed capital cost estimate for the WKE's Reid plant case. Two cases are examined, Mechanical conveying and pneumatic conveying. The cost of long term storage in either case, a storage building or two large silos are assumed to be similar.

Table 12 Capital Cost Estimates

Item	Cost $	Cost $
	Mechanical Conveying	**Pneumatic Conveying**
Primenergy Equipment	$ 6,951,847	$ 6,951,847
Material Handling Equipment	$ 1,673,414	$ 1,175,000
Boiler Penetrations/ Other Eng.	$ 250,000	$ 250,000
Contingency	$ 443,763	$ 418,842
WKE Construction Management (12 week Construction Phase)	$ 144,000	$ 144,000
Total Capital Cost	**$ 9,463,024**	**$ 8,939,689**
DOE Cost Share	$ 4,731,512	$ 4,469,845
WKE Cost	**$ 4,731,512**	**$ 4,469,845**
Interest Rate (Cost of Money)	7.50%	7.50%
No. of Years	10	10
Annualized Value (of WKE Share)	**$ (689,315)**	**$ (651,193)**

Table 13 provides an annualized cost of electricity production from the poultry litter gasification. Since, WKE is operating Reid plant as a merchant plant, it is normally dispatched during high demand period. Per WKE operating scenario, the Reid plant will be operated at 70% capacity factor. For the economic analysis, the Project assumed that the gasifier plant will be operated in tandem with the Reid plant, however, gasifier availability is assumed at 90%. Thus the gasifier plant capacity factor in conjunction with the Reid boiler is 90x70 = 63%. Based on material and energy balance, the total energy input from the gasifier is about 8.6% at 65.33 MW plant output. This will generate 28,912,496 kWh of electricity. Table 13 provides detailed cost of electricity production based on fuel cost, O&M cost and annualized capital cost.

The cost developed here does not include cost of land or existing infrastructure available to support the gasifier plant installation.

Table 13 Cost Summary for the energy production from poultry litter

Item	Value	Units	Cost	Basis
Poultry Litter	8.20	t/h	$ 12.00	per ton
Heating Value (LHV)	4,200	Btu/lb	$ 1.43	/MMBtu
Natural Gas	46	lbs/h		
Heating Value (LHV)	21,502	Btu/lb	$ 6.00	/MMBtu
Ash Produced	2.16	t/h	$ 2.00	/ton (year 1,2)
			$ (6.00)	/ton (year 3+)
			Alternate	Check
Total Boiler Heat Input @ 65.8 MW	663.3	MMBtu/hr	543,500.0	lbs/hr Steam
Heat Input to Boiler - Gasifier	56.9	MMBtu/hr	46,623.2	lbs/hr due-Gasifier
Boiler Efficiency (from BBPower)	86.90	%		
% Input from Gasifier	8.6%	%		
T/G Output (design)	65,851	kWe		
Turbine Heat Rate (@ design pt.)	8,863	Btu/kWe	8.42	lbs steam/kW e
T/G Output Due to Gasifier	5,648.9	kWe	5,534.5	2% (diff.)
Less Aux Load for Gasifier	410.0	kWe	410.0	
Total Gasifier Output Eq. kW	**5,238.9**	kWe	**5,124.5**	2% (diff.)
Boiler Availability Factor	70%	%/year	(Assumed)	Per WKE
Gasifier Capacity Factor	90%	%/year	(When boiler is available)	
Total Poultry Litter Usage	45,254	tpy	$ 543,050.	/year Litter Cost
Total NG Usage	253,865	lbs/y	$ 32,752.	/year NG Cost
Total Ash Produced	11,910	tpy	$ 23,819.	/year (Year 1,2)
Ash Credits (year 3+)			$ (71,457)	/year (yr 3+ credit)
Total Power Produced	**28,912,496**	kWh/y	(from gasifier energy)	
Cost of Power				
Fuel Cost (year 1,2)	2.07	c/kWh	$ 599,621.	year 1,2
Fuel Cost (year 3+)	1.74	c/kWh	$ 528,163.	year 3+
Other O&M Costs	0.97	c/kWh	$ 279,450.	/year
Capital Cost			**$9,463,024.**	
WKE Cost @ 50% Cost Share			**$4,731,512.**	
Cost of Money Terms				
Interest Rate	7.50%			
Term	10	years	$ 689,315	/year Present Value
Capital Cost	2.38	c/kWh		
Total Cost of Power	**5.42**	c/kWh	(year 1-2)	
	5.10	c/kWh	(year 3+)	
Annual Cost of Net Power	**$ 1,568,385**		(year 1,2)	
	$ 1,473,108		year 3+	
Notes:				
All cost are in current $ (2002).				
c/kWh is based on gasifier output =	28,912,496	kWh/y		

The above cost case was assumed as a base case. A cost sensitivity analysis was performed by varying the cost of fuel, capital cost of the project and financing terms and credit for ash generated from the gasifier. The Table 14 provides sensitivity analysis for seven cases besides the base case provided in Table 13.

Table 14 Sensitivity Analysis of Cost of Electricity

Case	Litter Cost	Ash Credits	Capital Cost	WKE Cost Share	Interest	Period	Fuel	O&M	Capital	Total
	$ /ton	$ /Ton	$	$	%	Years	¢ /kWh	¢ /kWh	¢ /kWh	¢ /kWh
Base Case	12	(6)	9,500,000	4,750,000	7.5%	10	1.74	0.97	2.39	5.10
2	8	(6)	9,500,000	4,750,000	7.5%	10	1.12	0.97	2.39	4.48
3	10	(8)	9,500,000	4,750,000	7.0%	15	1.35	0.97	1.80	4.12
4	12	(10)	9,500,000	4,750,000	7.0%	15	1.58	0.97	1.80	4.35
5	6	(12)	8,900,000	4,450,000	7.0%	15	0.56	0.97	1.69	3.21
6	8	(12)	8,900,000	4,450,000	7.5%	10	0.87	0.97	2.24	4.08
7	10	(14)	8,900,000	4,450,000	7.0%	10	1.10	0.97	2.19	4.26
8	12	(16)	8,900,000	4,450,000	7.0%	10	1.33	0.97	2.19	4.49

3.7.1 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 produced, with gasifiers typically capable of using 3/4' minus size particles, rather than the 1/4" minus size particles associated with co-firing

- Minimize efficiency losses in the boiler by taking those moisture-related losses in the gasifier

3.7.2 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 dramatic NOx reductions (e.g., >50 percent)

- Continuing the reduction of emissions by reducing the sulfur content of the fuel, modifying the operating combustion mechanism with gas firing for NOx control, and reducing the impact of co-firing on opacity

- Biomass co-firing reduces the amount of coal or other fossil fuel used, and thereby reduces the net amount of CO_2 rejected 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).

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

- ~2.7x10^12 kJ (2.60x10^6 MMBtu)
- NOx and SOx data for coal are as reported by WKE to EPA
- NOx and SOx data for litter is estimation from the expected gasifier performance

Table 15 Emission Estimate for Cofiring (1998 Data)

Fuel	Heat Input GJ (MM Btu)	NOx Emissions kg/year (lbs/year)	NOx Emissions kg/kJ (lbs/MMBtu)	SOx Emissions kg/year (lbs/year)	SOx Emissions kg/kJ (lbs/MMBtu)
Litter	497 (470,938)	85522 (188,375)	0.17 (0.40)	256,567 (565,125)	0.52 (1.20)
Coal	2,745 (2,602,000)	911,970 (2,008,744)	0.33 (0.77)	5,414,404 (11,926,000)	1.97 (4.58)
Total	3,242 (3,072,938)	997,492 (2,197,119)	0.31 (0.71)	5,670,971 (12,491,125)	1.75 (4.06)

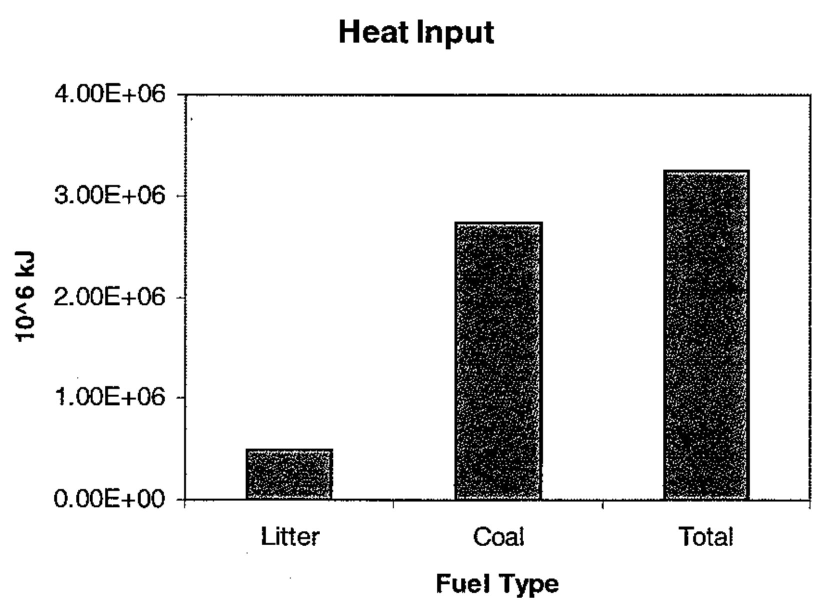

Figure 8 Heat input to the boiler with co-firing

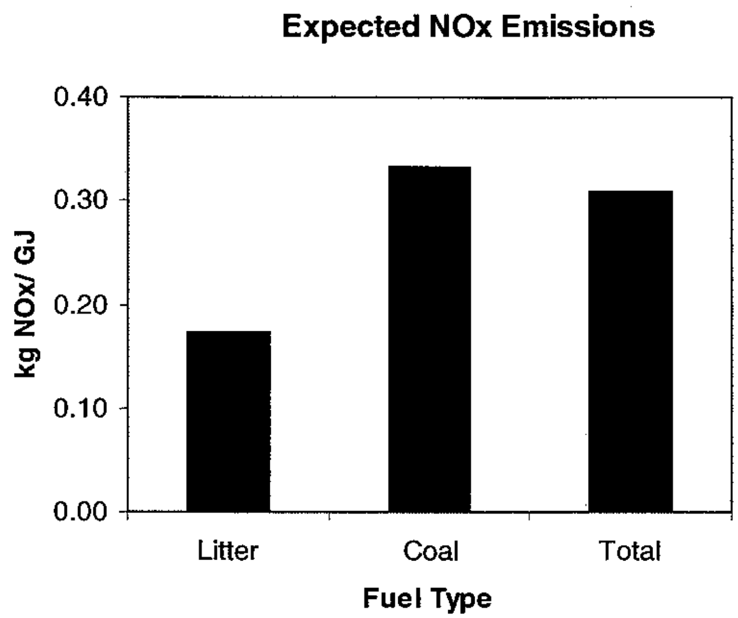

Figure 9 Expected NOx emissions with co-fifing

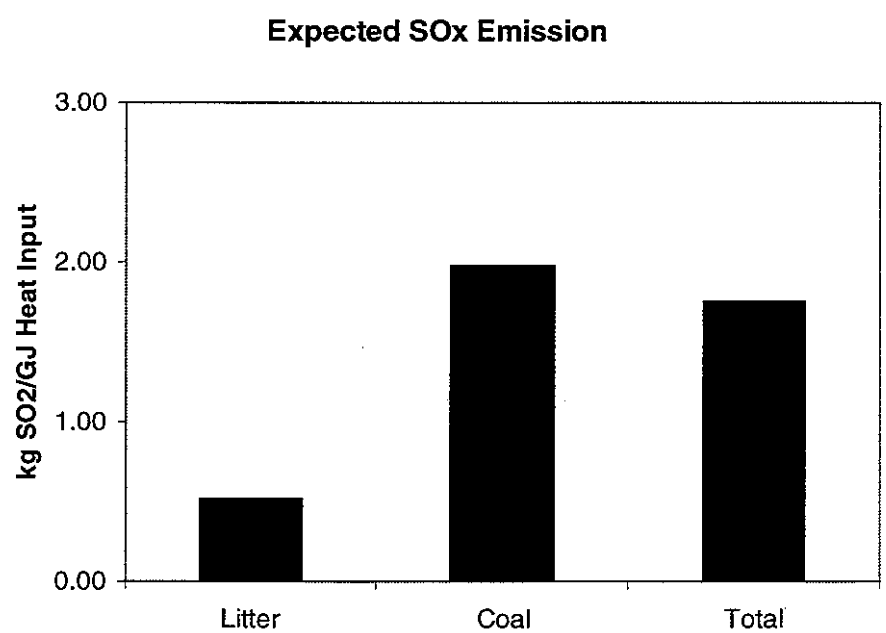

Figure 10 Expected SOx emissions with co-firing

4 Conclusions

The phase I of the project is to evaluate the technical and economical feasibility of biomass gasification and co-firing in an existing pulverized coal fired utility boiler operated by Western Kentucky Energy Corporation. The primary focus is the use of poultry litter as 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.

The Reid plant is located adjacent to a large poultry processing plant with over 500 poultry farmers within a 50-mile radius of the plant and estimated litter supply of over 75,000 tons per year. Primenergy has analyzed poultry litter samples from various sources, and have estimated an average heating value of the as received litter to be about 4,500 Btu/lb and 6,200 Btu/lb on dry basis.

The proposed gasifier is a Primenergy KC-18 system consisting of fuel feed system, one gasifier, hot gas filtration system and a two staged after burner combustion system. The KC-18 will handle 8.4 tons/hr. of poultry litter. The KC Reactor/Gasifier is a fixed bed, air blown, updraft, near atmospheric pressure gasifier.

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

The low Btu gas from the gasifier (producer gas) is at 1550°F and has a calorific value of about 110 Btu/std. cu. ft. The gas is burned in a two-stage combustor, which raises the temperature of the gas to about 2400°F. The gas can be fed into any existing boiler at a suitable location as additional heat input to the boiler. For the Reid plant, the cleaned hot gases will be fed above the existing burners, allowing the reduction of the primary fossil fuel to the boiler. It is estimated that about 8~10% of heat input will be coming from the synthesis gases, which will allow Reid operators to reduce proportionate amount of coal.

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). Poultry litter is a renewable energy resource. The Reid plant will be able to reduce their fossil fuel consumption by 8~10% and can claim a reduction in greenhouse emissions (CO_2) from their boiler.

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[2] Scott WN. Analytical Test Results of Poultry Litter Samples. Private correspondence, March 1999.

[3] Poultry Litter Sample Analysis by Hazen Research, Inc. Golden, CO. Hri – 009-464, Dated 12/8/2000 and 01/18/2001

[4] McQuigg K, Scott WN. Starved Air Gasification on Five Biomass Feedstocks. Paper presented at the BioEnergy '98 conference, Madison, WI. October 4-8, 1998.

[5] Frank Zone, Jr., Richard J. Dube, and Brian Vitalis, "Preliminary Engineering Study for Feasibility of Modular Bio-gasifier Hot Producer Gas Injection into PC Fired Flat Wall Furnace", Private Report by BBPower for Nexant, Inc., May 2001.

[6] Source: CETCON, INC. "Summary of Results: Test No. C1", Conducted at Primenergy, Tulsa, OK, September 15, 1997

List of Acronyms and Abbreviations

GJ	Giga Joules (1.E6 kJ)
Btu	British thermal unit
ACFM	Actual std. cu.ft. per min
scf	Standard cubic feet
CO2	Carbon Dioxide
SO2/SOx	Sulfur Dioxide
NOx	Compounds of Nitrous Oxides
PC	Pulverized Coal
WKE	Western Kentucky Energy Corporation
ppmv(d)	parts per million on volume basis (dry basis)
ppbv(d)	parts per billion on volume basis (dry basis)
gr/dscf	grains per dry standard cubic feet
HRSG	Heat Recovery Boiler
MW	Mega Watt (electrical)
psi	pounds per sq. inch
Pa (kPa)	Pascal (kilo Pascal)
deg F, °F	Degrees Fahrenheit
LLC	Limited Liability Company
°C	Degrees Celsius

Appendices

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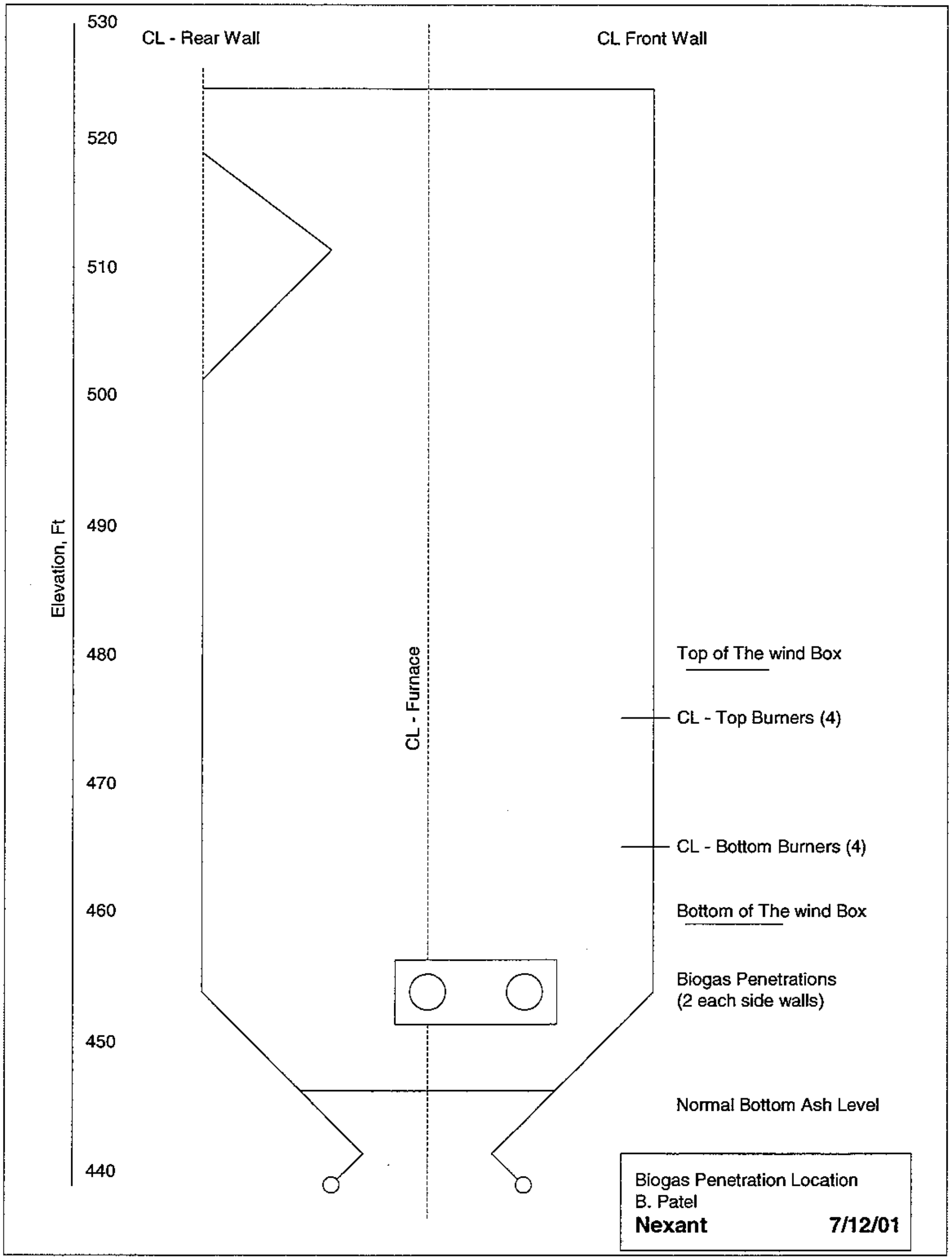


Figure 11 Schematic for Boiler Penetrations

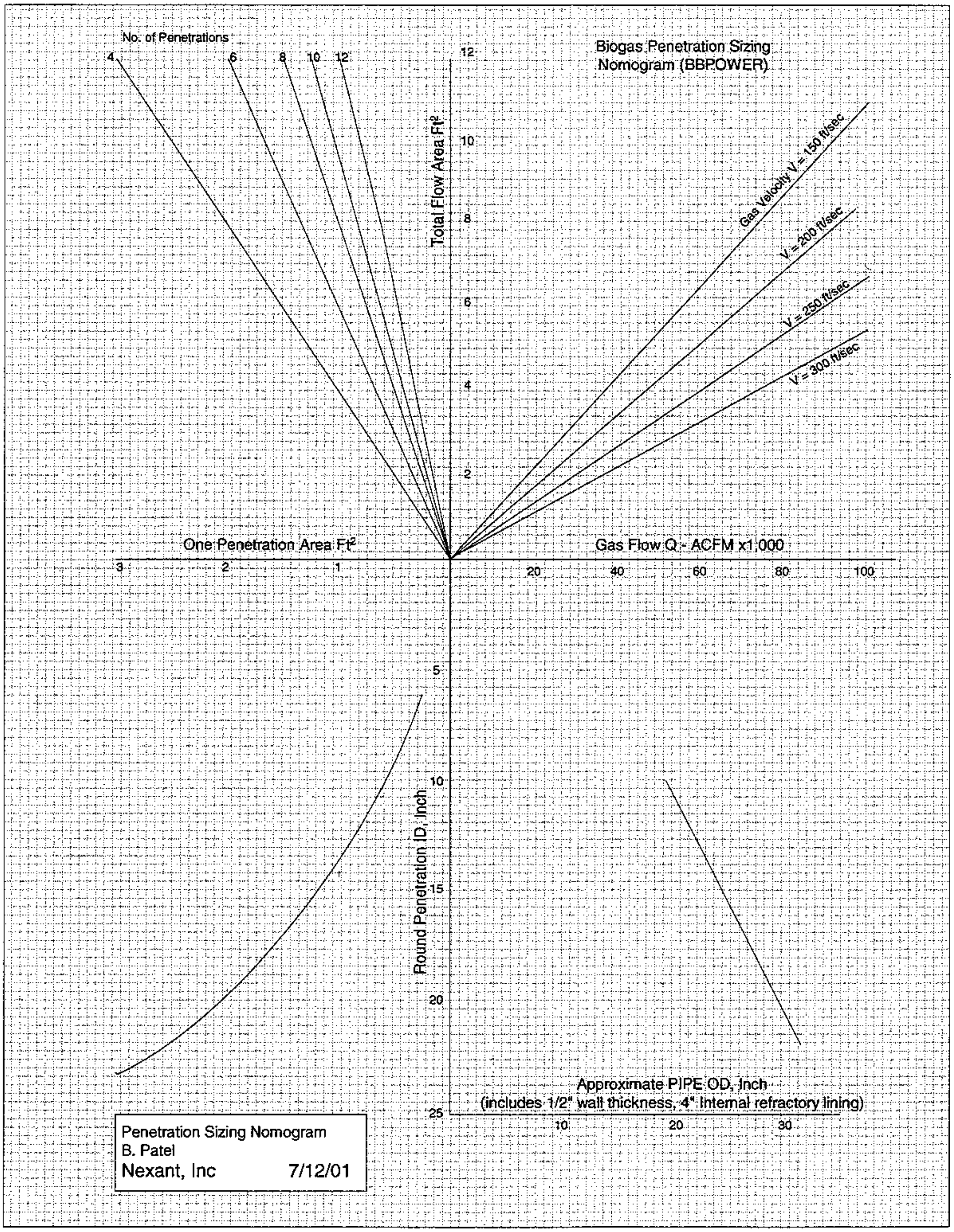


Figure 12 Boiler Penetrations Size Selection Nomogram

Table 16 Reid Plant Turbine Performance

	Flow	Temp	Press	Enthalpy	Total Energy	Turbine Output	Steam Quality
	lbs/hr	Deg F	psia	Btu/lb	Btu x 10E06		
Case Name Plate - 65.85 MW							
Steam from Boiler	543,500.0	950.0	1,264.7	1,468.2	797.9		
Steam to Turbine	542,600.0	950.0	1,264.7	1,468.2	796.6		
Steam to Ejector	900.0	950.0	1,264.7	1,468.2	1.3		
1st Stage Extraction	39,420.0	639.0	315.7	1,335.4	52.6		
2nd Stage Extraction	26,932.0	492.9	155.3	1,270.0	34.2		
3rd Stage Extraction	23,400.0	333.8	62.5	1,199.0	28.1		
4th Stage Extraction	28,510.0	250.0	29.8	1,140.3	32.5		0.98
5th Stage Extraction	35,729.0	190.8	9.5	1,061.6	37.9		0.92
Condenser	388,609.0	91.7	0.7	982.7	381.9		0.87
FW to Boiler	543,500.0	432.6	1,350.0	392.5	213.3		
Electrical Output					224.7	65,851	kW
Heat Rate						8,863	Btu/kWh
Turbine Efficiency						38.5%	

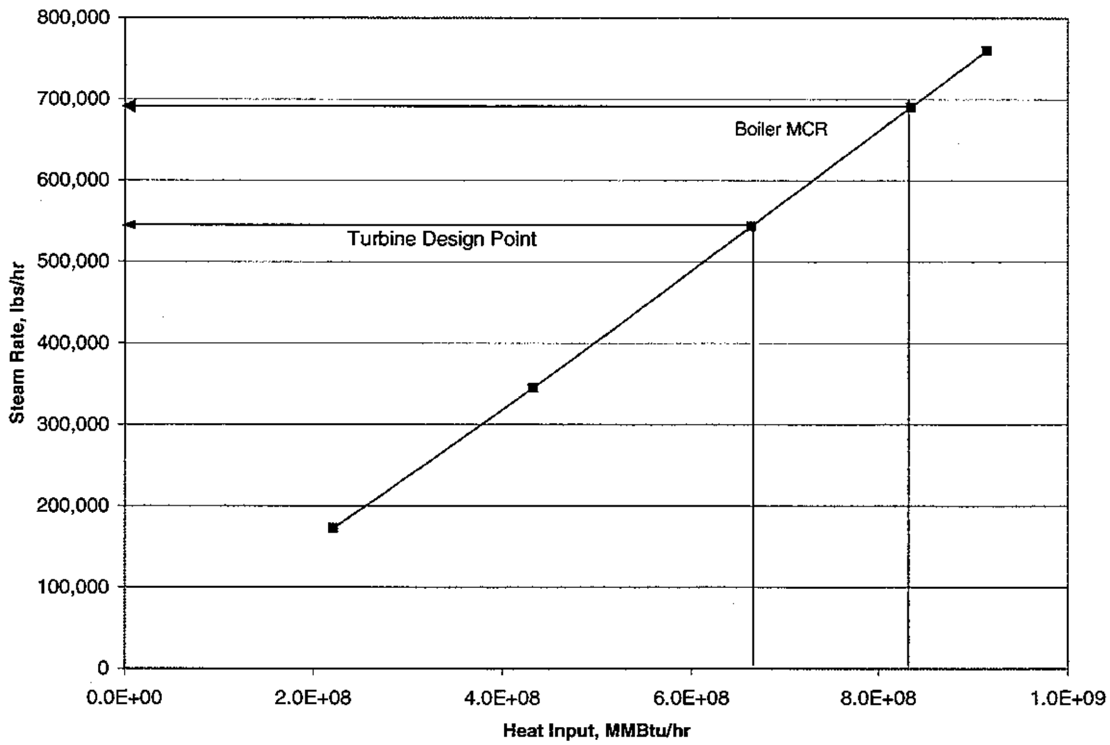


Figure 13 Boiler MCR and Turbine Nameplate Operating Points

Reid Plant Turbine Heat Rates

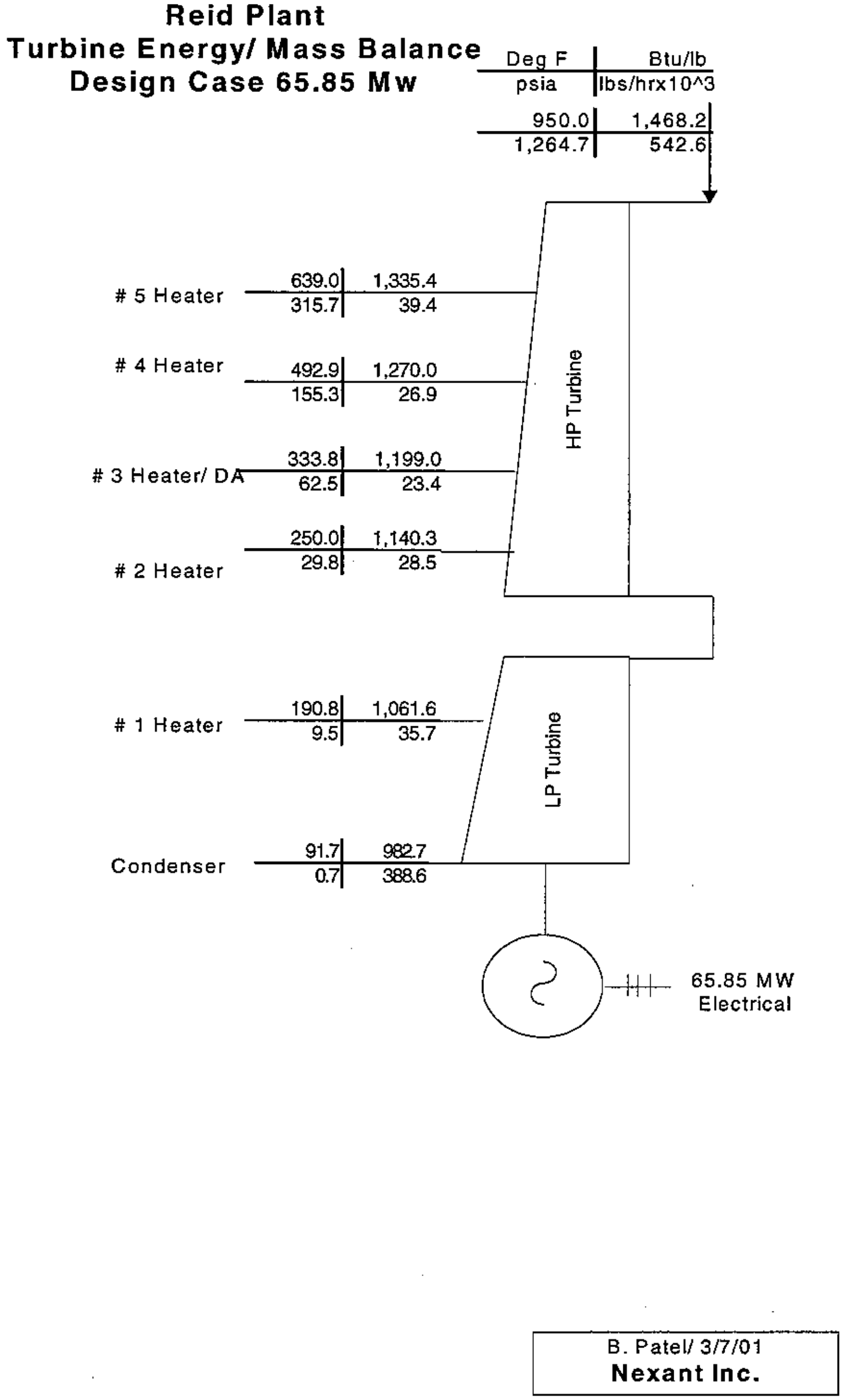


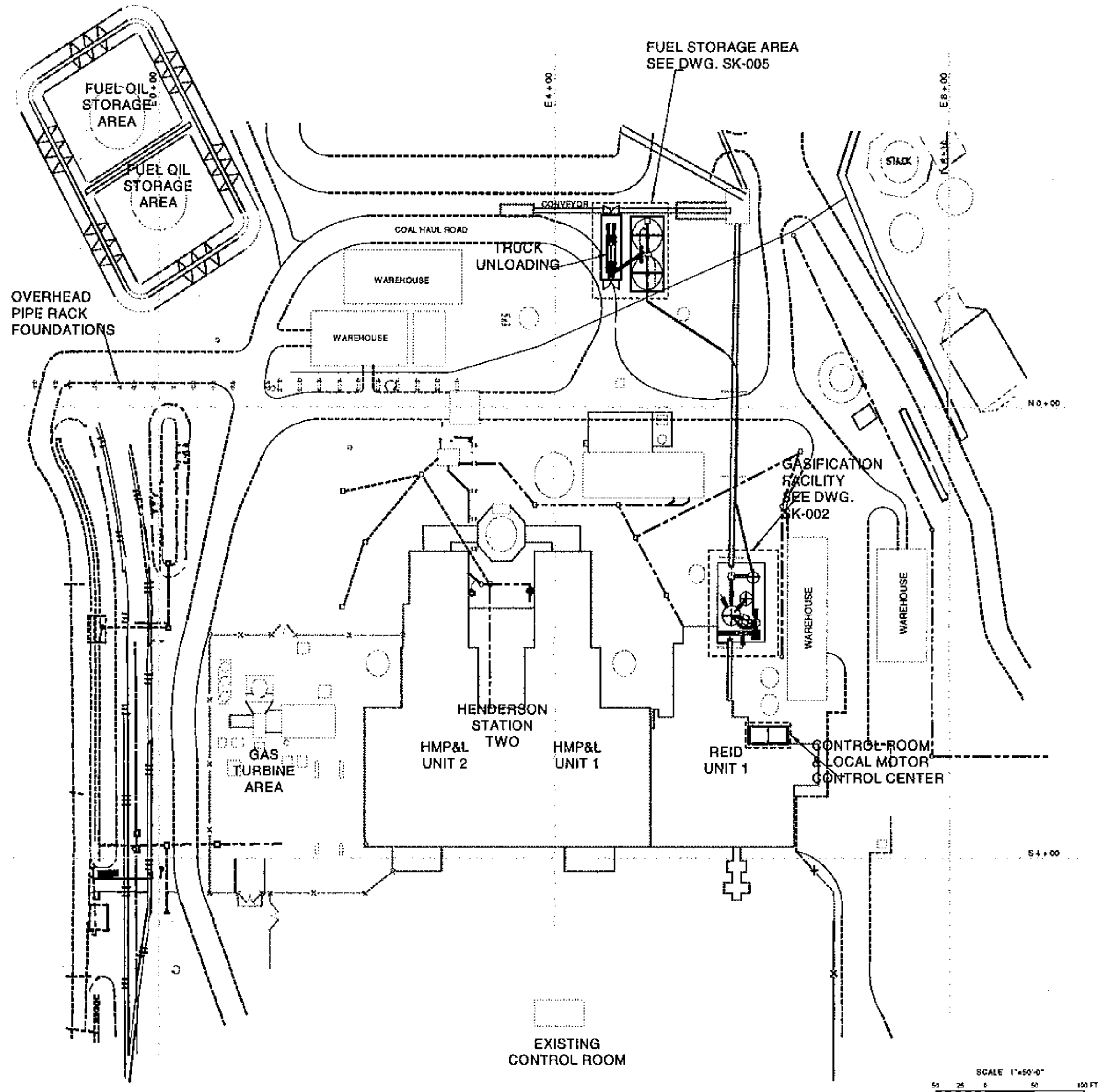
Figure 14 Turbine Heat Balance Diagram

Table 17 Capital Cost Estimates for Reid Plant Case

Item	Cost $	Cost $	
	Mechanical	Pneumatic	
Primenergy Equipment	$ 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%)	$ 443,763	$ 418,842	
WKE Construction Management	$ 144,000	$ 144,000	
(12 week Construction Phase)			
Total Capital Cost	**$ 9,463,024**	**$ 8,939,689**	
DOE Cost Share	**$ 4,731,512**	**$ 4,469,845**	
WKE Cost	**$ 4,731,512**	**$ 4,469,845**	
Interest Rate (Cost of Money)	7.50%		
No. of Years	10		
Present Value (for WKE Share)	$ (689,315)	$ (651,193)	Rate
Capital Cost of Power c/kWh	**2.38**	**2.25**	
Material Handling			
			(Alternate High estimate)
Conveying	Mechanical	Pneumatic	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 Material Handling	$ 1,673,414	$ 1,175,000	$ 2,104,762

Table 18 O&M Cost Estimates for the Reid Case

Item		Units	$ Cost	Basis
Operation				
Operation Manpower	2.50	man-year	$ 15.00	/hr
OH Multiplier	1.50		$ 22.50	/hr
Hours	2080	/man-year		
Operation Cost			$ 117,000	
Utility				
Water	54.02	gpm	$2.00	/1000 gal
Air	Provided in estimate			
Electricity	Provided in estimate			
Utility Cost			$ 17,887	
Annual Maintenance	0.50	c/Kwh	$ 144,562	
Total O&M Cost			**$ 279,450**	
Total Electricity			**28,912,496**	kWh
O&M Cost for Electricity			**0.97**	c/kWh



REFERENCE	
SK-002	REID PLANT GENERAL ARRANGEMENT GASIFICATION FACILITY PLAN
SK-005	REID PLANT GENERAL ARRANGEMENT GASIFICATION FACILITY FUEL STO. AREA PLAN

8/22/01 REISSUED FOR INFORMATION
2/01/01 ISSUED FOR INFORMATION

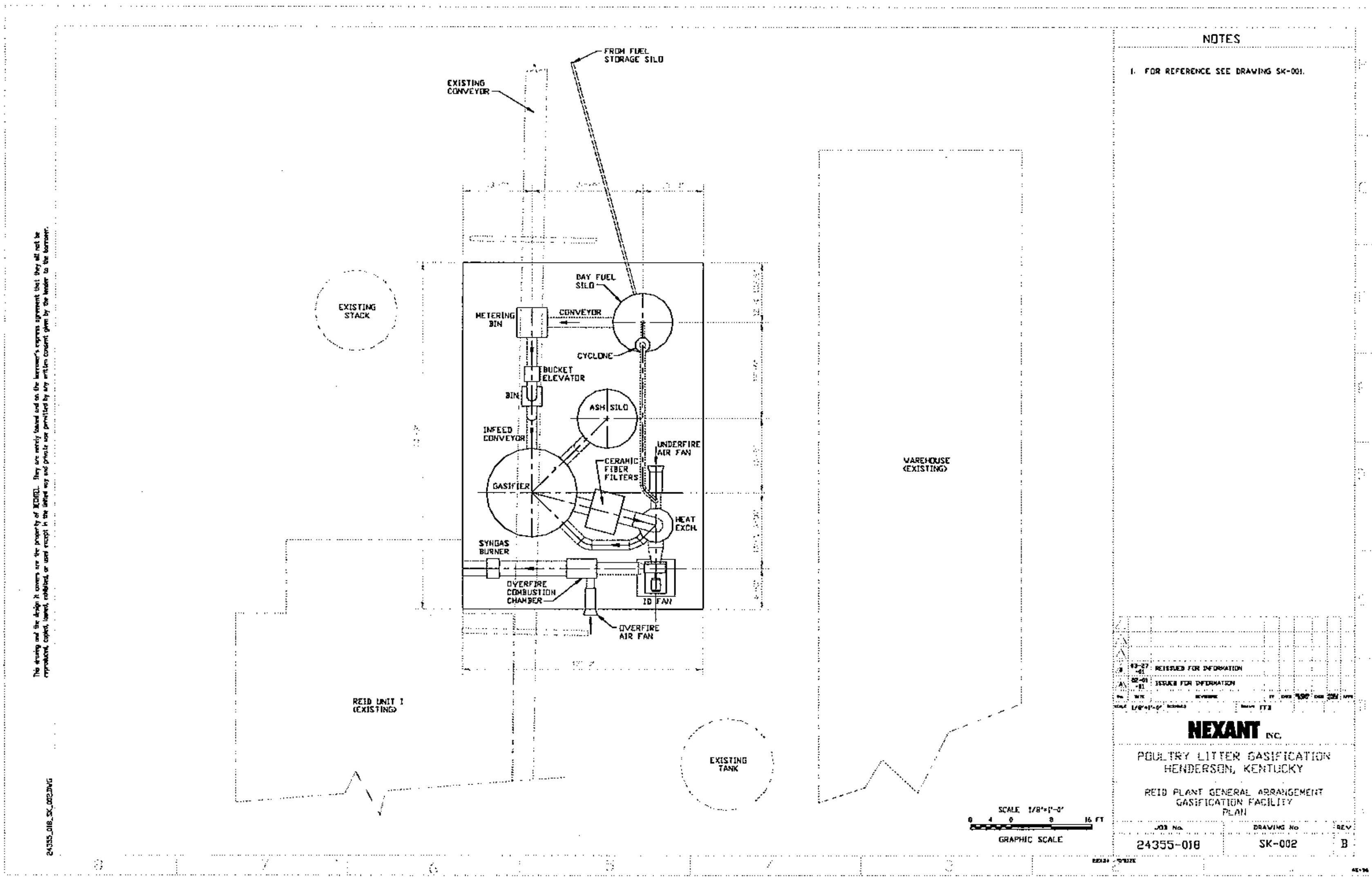
NEXANT INC.

POULTRY LITTER GASIFICATION
HENDERSON, KENTUCKY

REID PLANT SITE PLAN

JOB No	DRAWING No	REV
24355-018	SK-001	B

24355_018 SK_001.DWG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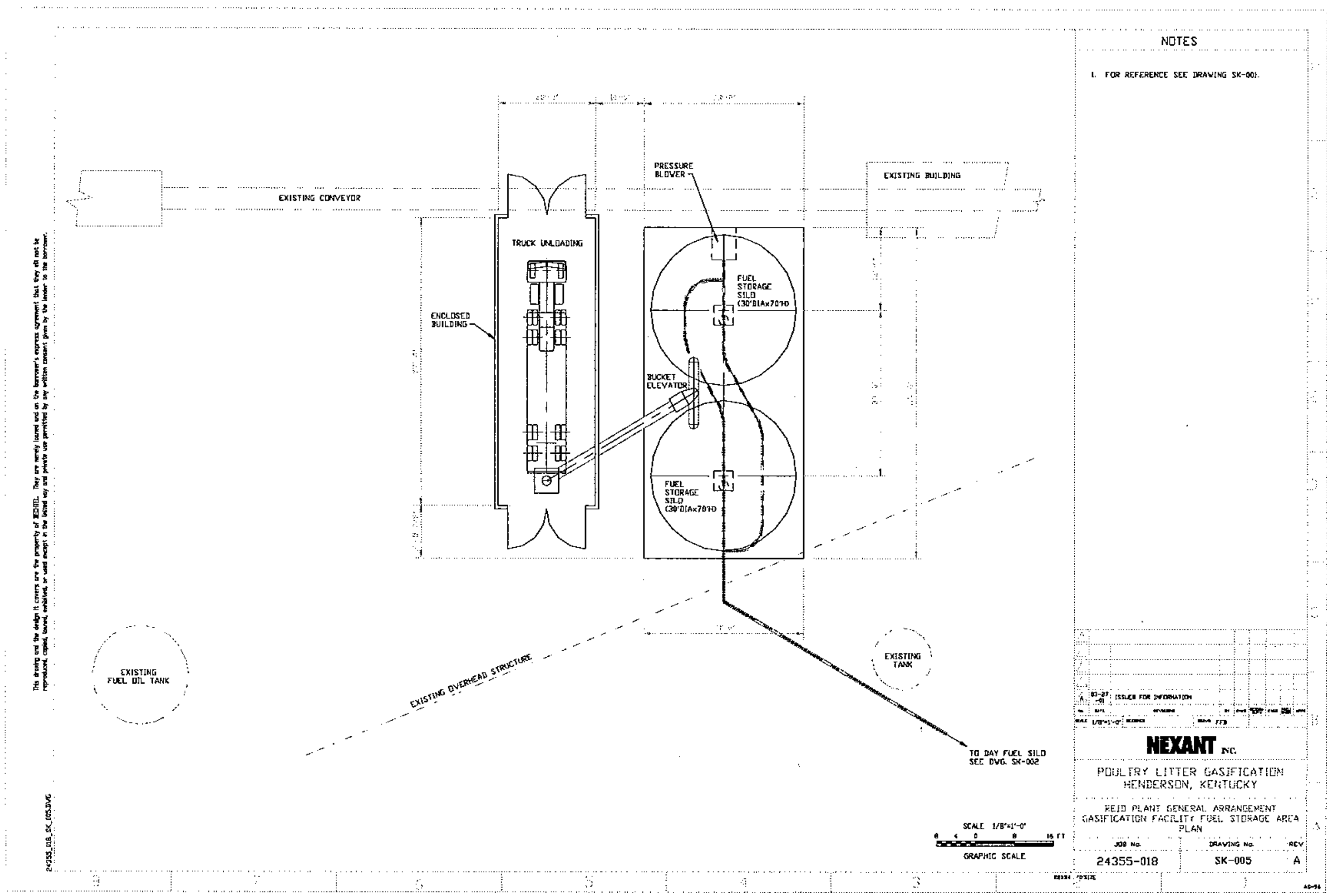
FROM FUEL STORAGE SILO
EXISTING CONVEYOR
DAY FUEL SILO
METERING BIN
CONVEYOR
CYCLONE
BUCKET ELEVATOR
BIN
ASH SILO
INFEED CONVEYOR
UNDERFIRE AIR FAN
CERAMIC FIBER FILTERS
GASIFIER
HEAT EXCH.
SYNGAS BURNER
OVERFIRE COMBUSTION CHAMBER
ID FAN
OVERFIRE AIR FAN
EXISTING STACK
REID UNIT 1 (EXISTING)
EXISTING TANK
WAREHOUSE (EXISTING)
SCALE 1/8"=1'-0"
GRAPHIC SCALE
RELEASED FOR INFORMATION
ISSUED FOR INFORMATION
NEXANT INC.
POULTRY LITTER GASIFICATION
HENDERSON, KENTUCKY
REID PLANT GENERAL ARRANGEMENT
GASIFICATION FACILITY
PLAN
JOB No.
24355-018
DRAWING No
SK-002
REV
B


NOTES
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EXISTING CONVEYOR
EXISTING BUILDING
PRESSURE BLOWER
TRUCK UNLOADING
ENCLOSED BUILDING
FUEL STORAGE SILO (30'DIAx70'H)
BUCKET ELEVATOR
FUEL STORAGE SILO (30'DIAx70'H)
EXISTING FUEL OIL TANK
EXISTING OVERHEAD STRUCTURE
EXISTING TANK
TO DAY FUEL SILO SEE DWG. SK-002
SCALE 1/8"=1'-0"
GRAPHIC SCALE
NEXANT INC.
POULTRY LITTER GASIFICATION
HENDERSON, KENTUCKY
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PLAN
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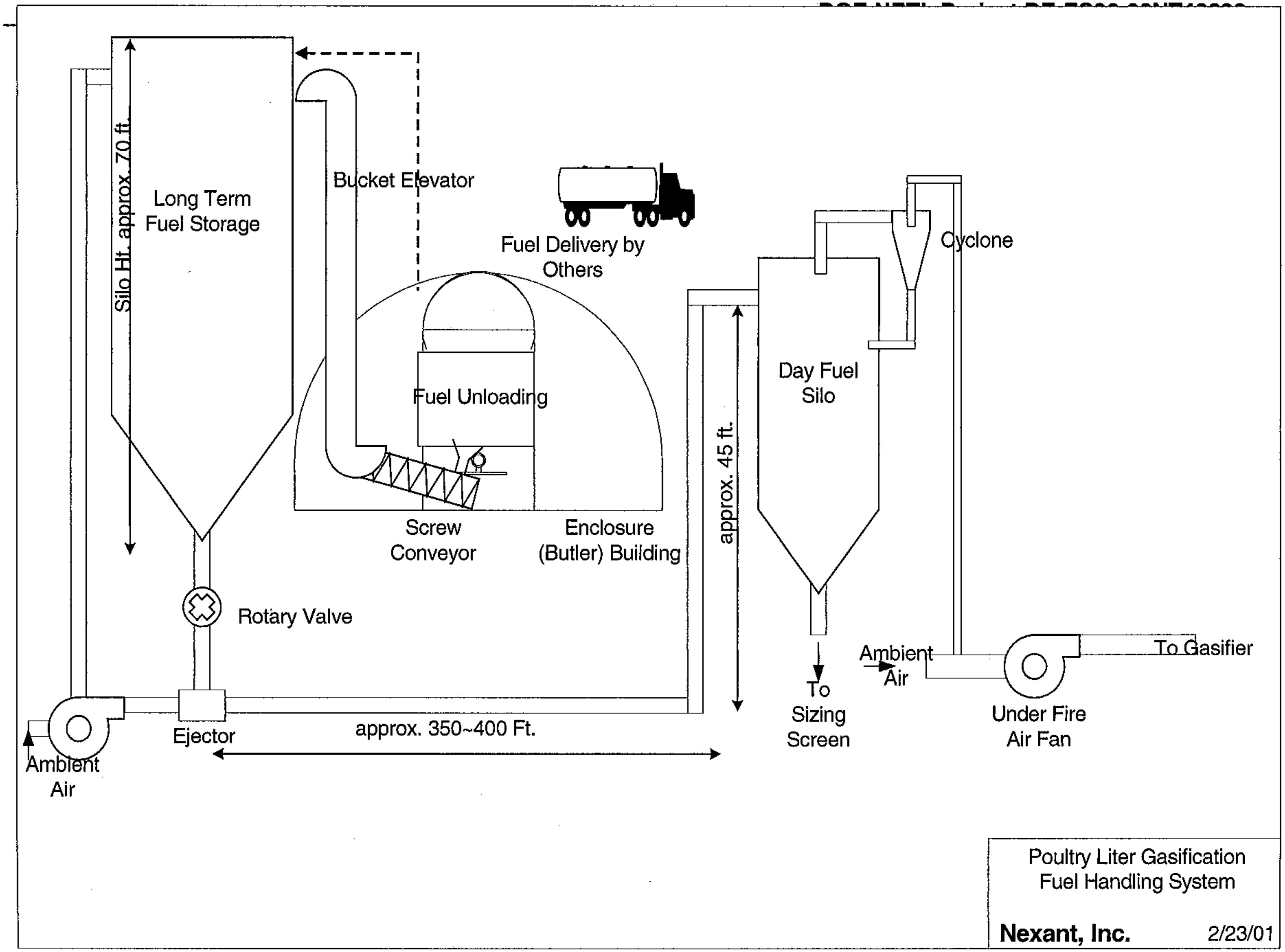
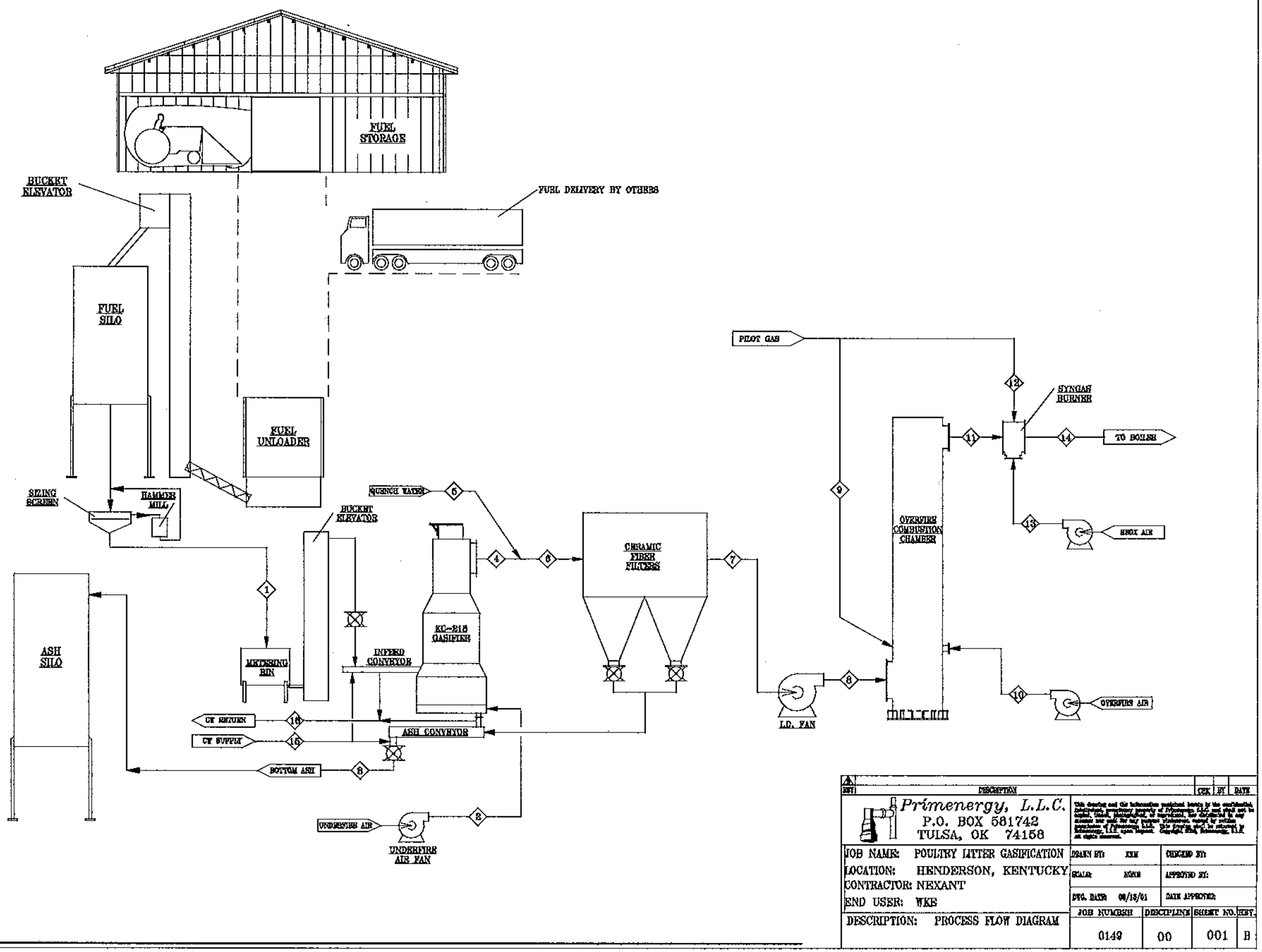
DRAWING No. SK-005
REV A


Long Term
Fuel Storage
Silo Ht. approx. 70 ft.
Bucket Elevator
Fuel Delivery by
Others
Fuel Unloading
Screw
Conveyor
Enclosure
(Butler) Building
Rotary Valve
Ejector
approx. 350~400 Ft.
Ambient
Air
approx. 45 ft.
Day Fuel
Silo
Cyclone
To
Sizing
Screen
Ambient
Air
Under Fire
Air Fan
To Gasifier
Poultry Liter Gasification
Fuel Handling System
Nexant, Inc.
2/23/01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QUENCH WATER
METERING BIN
INFEED CONVEYOR
KC-218 GASIFIER
CERAMIC FIBER FILTERS
ASH SILO
CW RETURN
CW SUPPLY
BOTTOM ASH
ASH CONVEYOR
UNDERFIRE AIR
UNDERFIRE AIR FAN
I.D. FAN
PILOT GAS
SYNGAS BURNER
TO BOILER
OVERFIRE COMBUSTION CHAMBER
OVERFIRE AIR
Primenergy, L.L.C.
P.O. BOX 581742
TULSA, OK 74158
JOB NAME: POULTRY LITTER GASIFICATION
LOCATION: HENDERSON, KENTUCKY
CONTRACTOR: NEXANT
END USER: WKE
DESCRIPTION: PROCESS FLOW DIAGRAM
JOB NUMBER
0149
00
001
B

12/20/2001

Table 19 Case I: 8.4 TPH Poultry Litter

Stream ID			1	2	3	4	5	6
Stream			GASIFIER	GASIFIER	GASIFIER	GASIFIER	QUENCH	HGF
Name			FEED	COMB	BOTTOM	SYNGAS	WATER	INLET
				AIR	ASH			SYNGAS
Pressure, psig ("w.c.g)			----	(20.0)	----	(-0.25)	50	(-0.50)
Temperature, °F			77	80	300	1550	77	1400
		lb/lbmole	---	28.68	67.17	24.95	18.02	24.69
Component	Formula	mw	lb/h	lb/h	lb/h	lb/h	lb/h	lb/h
Carbon	C	12.01	4,617		467			
Hydrogen	H	1.01	527					
Nitrogen	N	14.01	463					
Oxygen	O	16.00	3,416					
Sulfur	S	32.06	83					
Chlorine	Cl	35.45	0					
Fuel Gas	CH4	16.04						
Carbon Monoxide	CO	28.01				3,819		3,819
Carbon Dioxide	CO2	44.01				9,207		9,207
Hydrogen	H2	2.02				421		421
Water (v)	H2O (v)	18.02		267		5,412		6,576
Nitrogen	N2	28.01		20,853		21,316		21,316
Oxygen	O2	32.00		6,313				
Sulfur Dioxide	SO2	64.06				166		166
Hydrogen Chloride	HCl	36.46				0		
Ash	SiO2	60.08	3,494		3,961	70		70
Lime	CaCO3	100.09						
Water (l)	H2O (l)	18.02	4,200				1,164	
TOTAL			16,800	27,433	4,428	40,410	1,164	41,574
AVAILABLE ENERGY (LHV-Hv), Btu/lb			4,196		14,100.0	953.9		927.1
AVAILABLE ENERGY, MMBtu/h			70.50		6.6	38.5	0.0	38.5
FLOW RATE, scfm (gpm)				6,050		10,243	(2.33)	10,652
FLOW RATE, acfm				6,283		39,593		38,100
PARASITIC ELECTRICAL LOAD, kW		341						

7	8	9	10	11	12	13	14	15	16
HOT GAS	ID	PILOT	OVERFIRE	OVERFIRE	PILOT	REOX	COMB	GASIFIER	GASIFIER
FILTER	FAN	GAS	COMB	SYNGAS	GAS	COMB	PROD TO	COOLING	CW
EXHAUST	EXHAUST		AIR			AIR	BOILER	WATER	RETURN
(-10.0)	(8.0)	30	(13.0)	(7.0)	30	(13.0)	(6.0)	60	10
1382	1382	77	80	2400	scfm	80	2330	110	165
24.66	24.66	16.04	28.68	26.96	16.04	28.68	28.02	18.02	18.02
lb/h	lb/h	lb/h	lb/h	lb/h	lb/h	lb/h	lb/h	lb/h	lb/h
		23			23				
3,819	3,819			633					
9,207	9,207			14,276			15,335		
421	421			200					
6,576	6,576		157	8,756		245	10,844		
21,316	21,316		12,257	33,574		19,099	52,673		
			3,711			5,782	3,737		
166	166								
								26,738	26,738
41,505	41,505	23	16,125	57,440	23	25,125	82,588	26,738	26,738
928.7	928.7	21,502		229.0	21,502			0.0	1.0
38.5	38.5	0.5		13.2	0.5			0.0	1.5
10,644	10,644	9	3,556	13,478	9	5,541	18,642	(53.5)	(53.5)
37,701	37,701	9	3,693	74,129	8	5,754	100,031		