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.

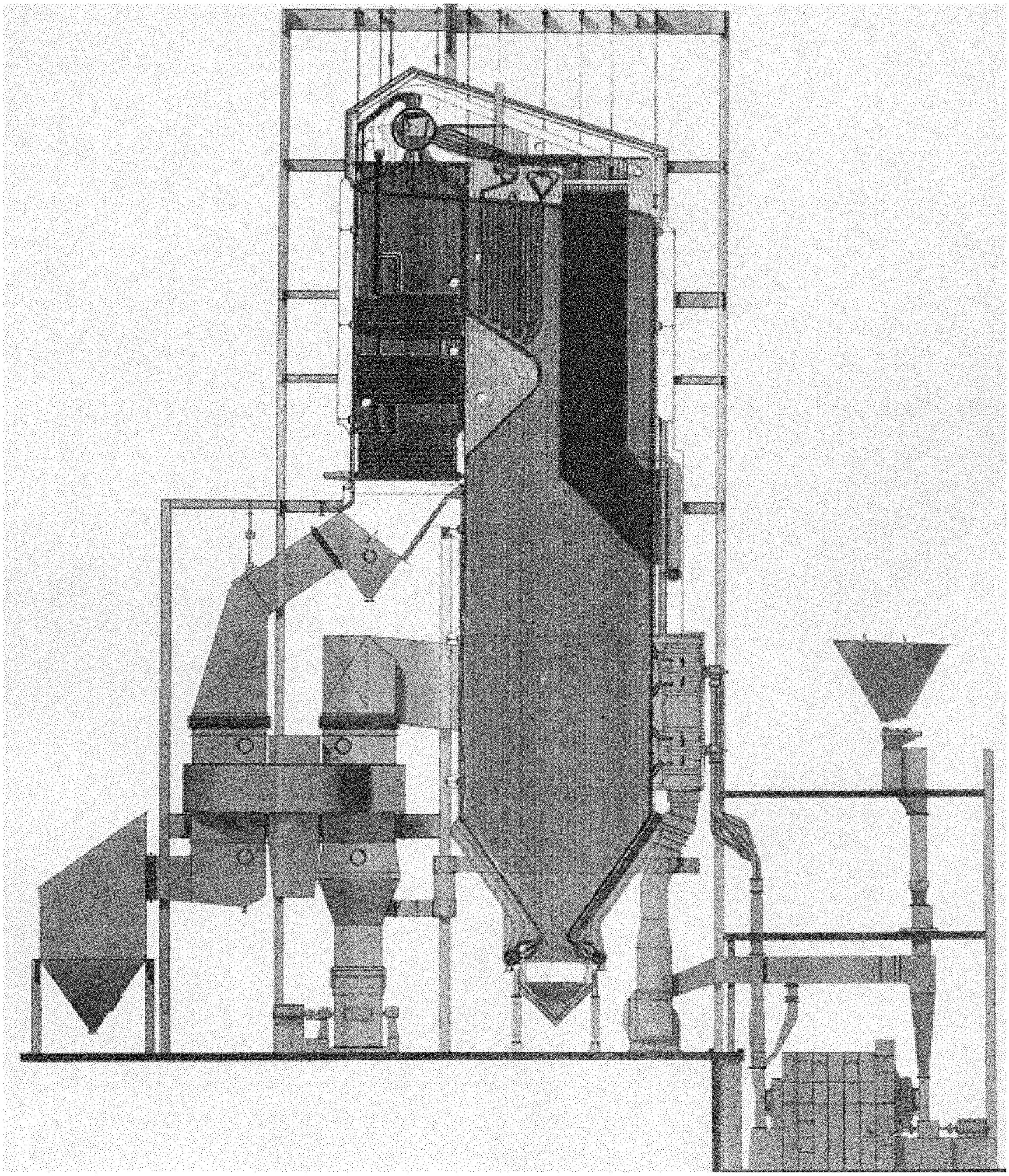

Figure 3-1 Reid Plant Boiler Schematic

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.

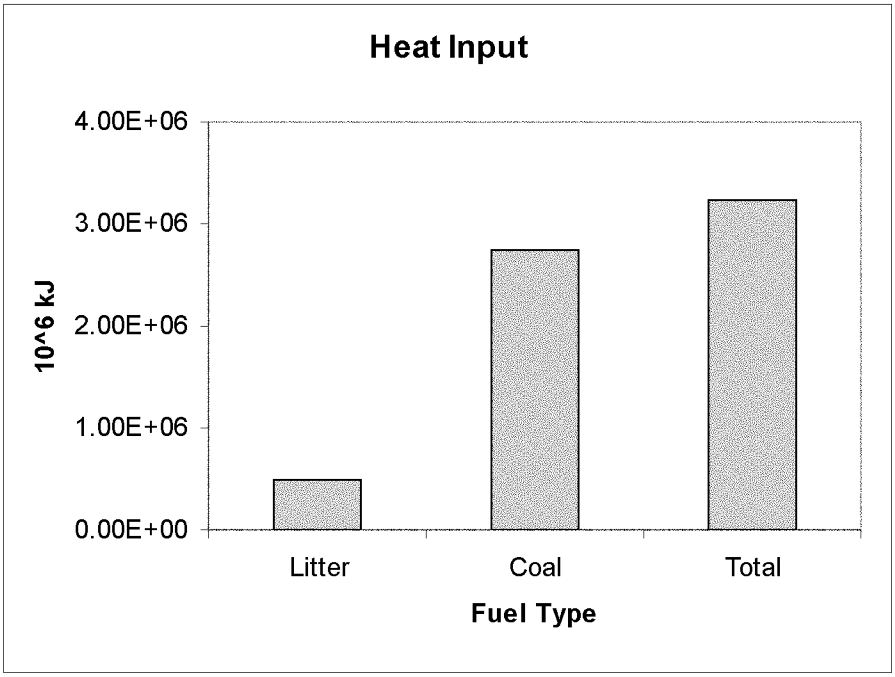

Figure 3-2 Heat input to the boiler with cofiring

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 815ºC (~1500ºF) 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.

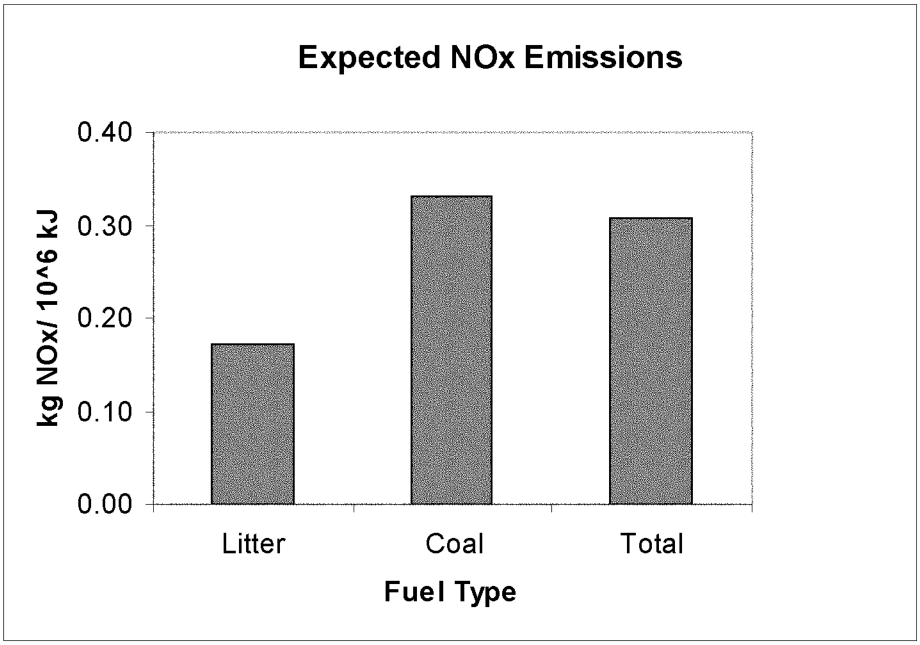

Figure 3-3 Expected NOx emissions with cofiring

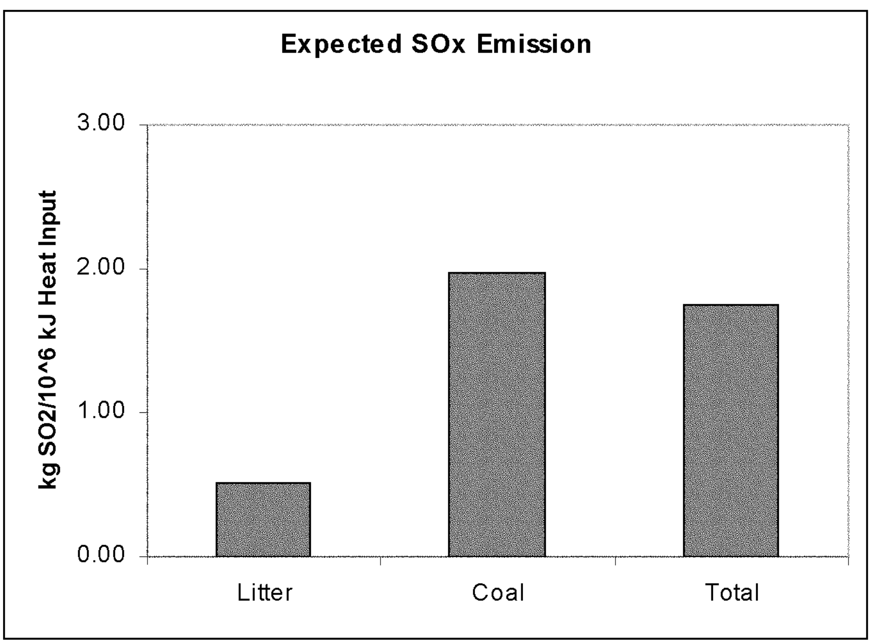

Figure 3-4 Expected SO_2 emissions with cofiring

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.

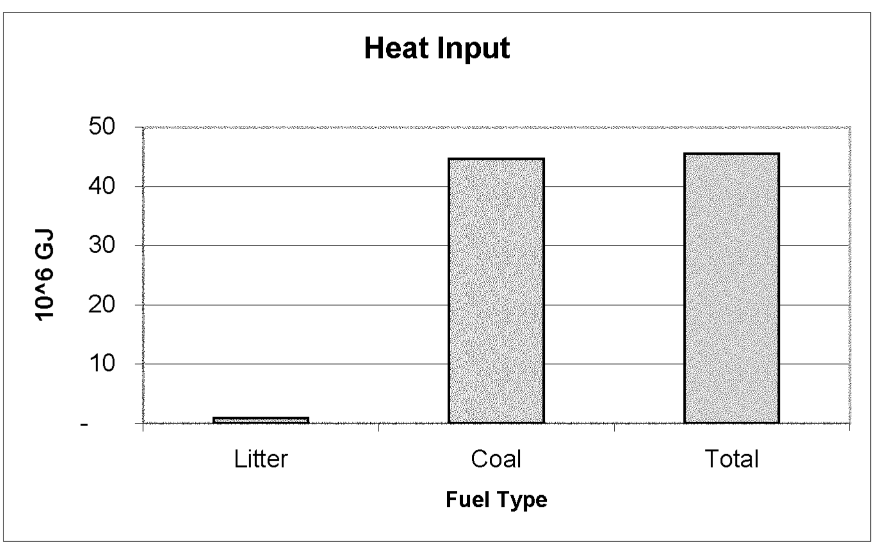

Figure 3-6 Heat input to the boiler with cofiring

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.

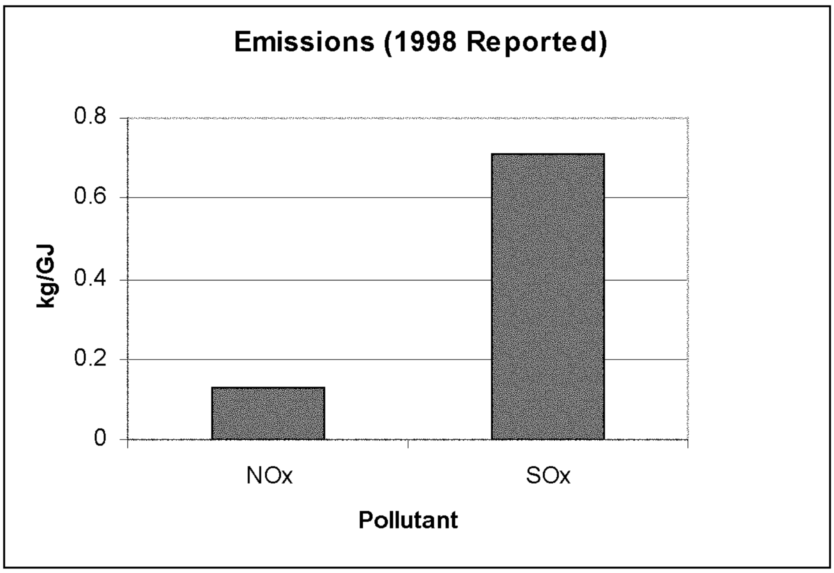

Figure 3-7 Reported NOx and SOx emissions at Monticello Plant

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.