FINAL TECHNICAL REPORT
March 1, 2006, through April 30, 2007

Project Title: FEASIBILITY OF A COMMERCIAL DEMONSTRATION PFBC COMBINED HEAT AND POWER FACILITY

ICCI Project Number: DEV05-7
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ABSTRACT

This report discusses the concept feasibility of a power plant that would supply both steam and electricity to meet the future needs of the Eastern Illinois University. The university is located in Charleston, Illinois. The proposed new plant would use an environmentally clean technology that would burn coal, or a mix of coal and out-dated dry corn as its fuel. This plant would be a first-ever plant at small scale that uses a technology already pioneered in the much larger size for commercial electric power generation.

Pressurized fluidized bed combustion (PFBC) is a solid-fueled electric power generation technology that is in commercial operation in various parts of the world. The worldwide fleet of these units have accumulated over a quarter-million operating hours, from units mostly from about 100 MWe electric output unit size up to one unit sized to provide 400 MWe. The PFBC concept unit described in this report is much smaller; 11 MW (electric equivalent), and unlike its larger cousins, is instead designed to provide both electricity and steam to the University campus in this cogeneration configuration.

The PFBC unit would use a condensing controlled-extraction-type steam turbine, which would generate more or less electricity, depending on the campus demand for steam. When steam demand is high, it frees steam for delivery to the campus, and produces less electricity; at 50,000 lb/h steam delivery to the campus it would produce 7,820 kWe of electric power for campus self-use, and for electric sales. At times of low steam demand or low electric demand, any excess electric generation would be sold to the electric spot market on the state's electric grid; at 10,000 lb/h steam delivery it would produce 10,570 kWe.

EXECUTIVE SUMMARY

Pressurized fluidized bed combustion (PFBC) is a commercial solid-fueled electric power generation technology that is in commercial operation in various parts of the world. The worldwide fleet of these units have accumulated over a quarter-million operating hours, from units mostly from about 100 MWe electric output unit size up to one unit sized to provide 400 MWe.

The PFBC concept unit described in this report is much smaller; 11 MW (electric equivalent). Unlike its larger commercial cousins, the coal-fueled PFBC unit described here is designed to provide both electricity and steam to the Eastern Illinois University campus in this cogeneration configuration. When steam demand is high, the extraction steam turbine frees steam for delivery to the campus, and produces less electricity. For example, at 50,000 lb/h steam delivery to the campus, the unit is expected to produce 7,820 kWe of electric power for campus self-use, and for electric sales. At times of low steam demand or low electric demand, any excess electric generation would be sold to the electric spot market on the state's electric grid. As another example, at a low steam demand point, with only 10,000 lb/h steam delivery needed by the campus, the unit would produce 10,570 kWe of electricity for campus use and for sale to the electric grid.

Since such a unit would be a scale-down from commercially operating equipment, the technical risk is believed small for a first-such unit.

The unit would fit into the available space at the campus, and even though it has some tall structures, it could use aesthetic treatments that would minimize its visual impact, allowing the power plant to blend into the other architectural features of the campus. The new unit would replace the existing powerhouse, but the existing boilers would be retained for back-up when the new unit is down for maintenance or for emergency backup if there should be necessity for an unplanned outage.

The PFBC technology is a clean coal technology, with low environmental emissions.
This cogenerating PFBC plant has an estimated total plant cost of about $75,741,000. The net operating cost of this new facility is estimated to be about $3,517,000 per year, which includes operating and administrative labor, fuel and consumables, and maintenance (levelized labor and materials). This capital cost must be amortized over the book life of the plant. This yields an estimated total annual payment (first year, no escalation for fuel, labor, etc.) of about $9 million per year.

OBJECTIVES

This report discusses the concept feasibility of a power plant that would supply both steam and electricity to meet the future needs of the Eastern Illinois University. The university is located in Charleston, Illinois. The proposed new plant would use an environmentally clean technology that would burn coal, or a mix of coal and out-dated dry corn as its fuel. This plant would be a first-ever plant at small scale that uses a technology already pioneered in the much larger size for commercial electric power generation.

In larger size, pressurized fluidized bed combustion (PFBC) has proven itself as a clean solid-fueled electric power generation technology. These larger units in commercial operation in various parts of the world, Exhibit 1, have accumulated over a quarter-million operating hours, from units mostly from about 100 MWe electric output unit size up to one unit sized to provide 400 MWe. The PFBC concept unit described in this report is much smaller; 11 MW (electric equivalent), and unlike its larger cousins, is instead designed to provide both electricity and steam to the University campus in this cogeneration configuration.

Exhibit 1 - Commercial PFBC Installations

Source: Burkett [1]

PFBC has a number of interesting technical features that encouraged the United States Department of Energy's National Energy Technology Laboratory (NETL) to investigate whether there is merit to applying this combustion-based technology to this smaller scale, and to see if it makes sense to apply PFBC technology for industrial-sized applications.

NETL felt there may well be a market for developing smaller-scale PFBC units that are suited for industrial co-generation applications, where combined heat and power might be supplied by the smaller-sized units. NETL thus launched this concept feasibility investigation in partnership with the Illinois Department of Commerce and Economic Opportunity Office of Coal Development to see if it would prove feasible to apply PFBC technology into an 11-MWe-output co-generating PFBC unit that could produce up to 80,000 lb/hr of steam for campus heating.

The objective of this study was to assess the technical merit of applying PFBC in smaller scale, to see if this clean coal application would afford benefit to university campus application, which also would provide use suited to a wide range of small industrial applications needing both steam and power.

The study objective was to provide a report that provides the following information, all of which were accomplished:

- The report provides preliminary assessment of the concept feasibility for such a small-scale PFBC power plant.
- The report identifies:
  - the technologies needed;
  - the state of development of these technology elements;
  - establishes the manufacturing base that might be used to produce such a plant;
- The report identifies many of the technical risks expected for the first-ever application of this technology at this size;
- The report provides preliminary estimates of the performance, cost, and environmental characteristics anticipated for such a plant.

Sufficient information is provided to allow an informed judgment of the economics and feasibility of such a project. If the economic incentives are judged appropriate, and the technical risks of a first-of-a-kind unit are felt acceptable, then the report describes a project that could result in a concept for the first such cogenerating PFBC unit built at the University site.

INTRODUCTION AND BACKGROUND

Why Clean Coal? Modern coal plants, such as the cogenerating PFBC described here, are very clean environmentally. Their advantage is low fuel costs, since inexpensive domestic coal is used, which is abundant locally, and low in price compared to natural gas or oil. For this project to make sense, the savings from low production costs and the income from electric sales must more than offset the expense of buying and operating the cogenerating PFBC equipment.

What Is Pressurized Fluidized Bed Combustion (PFBC)? PFBC is one of the ways that clean and efficient gas turbine combined cycle technology can be applied for use for electric power generation. It is a type of combined cycle, where a gas turbine and a steam turbine are used to maximize the recovery of heat from the power cycle. The gas turbine compressor supplies air to a pressurized combustor that burns solid fuel in a sorbent bed (the sorbent removes sulfur). The hot combustion gases are cleaned of dust, and the hot combustion products expanded in the gas turbine to generate part of the plant’s power. The pressurized fluidized bed operates at a very even and relatively low temperature so the production of NOx is low, the sorbent in the bed effectively removes sulfur, while the dust control equipment removes most all of the particulate matter. In this co-generating application, a variable extraction steam turbine is used to allow the export of steam for campus heating that is easily adjusted to the varying steam demand throughout the year. Whenever steam is not needed for the campus, it is instead diverted to generate more electricity. Excess electricity is exported to the electric grid for sale as added revenue.

Why PFBC? While the economic feasibility and application of cogenerating PFBC in the 11 MWe size range has yet to be demonstrated, its technical advantages would be similar to those features that make commercial PFBC attractive, namely:

- PFBC technology for power generation is in its 17th year of operation.
- Six plants in 5 countries have accumulated ¼ million operating hours.
- No operating PFBC plant has an availability below 83%, while the best are operating at over 87% availability [1].
- The larger size plants are offered with full commercial guarantees.
- PFBC fits in a more compact plant footprint than does an atmospheric-pressure unit of similar capacity.
- All fluidized beds, whether atmospheric or pressurized, have an advantage: with the staged combustion they can extend the range of acceptable fuels:
  - To lower heating values;
  - To higher content of fines;
  - Including wet or dry fuel feed; and,
  - If provision is made during initial design, PFBC can fire lower cost “opportunity fuels” such as outdated or moldy dry seed corn, or other biomass feed supplements.

TECHNICAL APPROACH

This conceptual design was developed to provide a preliminary assessment of the feasibility of a small university-campus-sized PFBC power house.

The investigators toured the campus, and established current and expected steam and electric demand profiles for the University, and reviewed potential site locations for the future power house. The University provided analysis and potential sources of fuel, and sorbents needed for PFBC operations.

Since PFBC technology is commercial in 200 MWe output size, this application would be a scale-down from commercial application. The investigators prepared preliminary heat and material balances for the steam and electric output using ASPEN-PLUS system models for the plant performance and thermodynamics. The investigators are experienced in coal-fueled plant design, and estimated the plant auxiliary loads based on scale from previous design projects.

Equipment was then sized based on the results of the heat and mass balance flows and temperature conditions and an equipment list prepared. As power plant designers, these preliminary estimates allowed the sizing of equipment, and layout on the plant site was developed consistent with this sizing.

The investigators design many coal-fueled power and steam facilities, and at this depth of detail, used scaling from similar pieces of equipment and recent cost information from other projects to estimate the plant costs. Since some elements of the design are not yet detailed at this preliminary level of study, and since some equipment has not yet been commercially demonstrated, both project and process contingency amounts were added to each cost account to reflect the actual costs expected for the total plant.

Economics were then evaluated using the expected value of steam and electricity, and the monthly variation for demand of each. Any electricity generated in excess of campus demand (or that needed to be purchased during plant maintenance outages) were presumed to have a sale price/cost consistent with current prevailing rates at the University.

RESULTS AND DISCUSSION

This report summarizes the details of this project's evaluation. Readers interested in the evaluation details will find them in Appendix A [2], provided as a separate document, which provides s significantly more information describing the evaluation.

This industrial-sized cogenerating PFBC concept would be designed to provide the campus steam demand for the Eastern Illinois University while cogenerating electricity to meet the campus electric load. The PFBC unit would use a condensing controlled-extraction-type steam turbine, which would generate more or less electricity, depending on the campus demand for steam. The two graphs below present campus steam demand on a monthly basis over a typical year (first graph), and power generation (second graph) over the same time span. The power graph shows the campus load and the excess power generated, which can produce revenue for the university.

Exhibit 2 - Campus Steam Demand

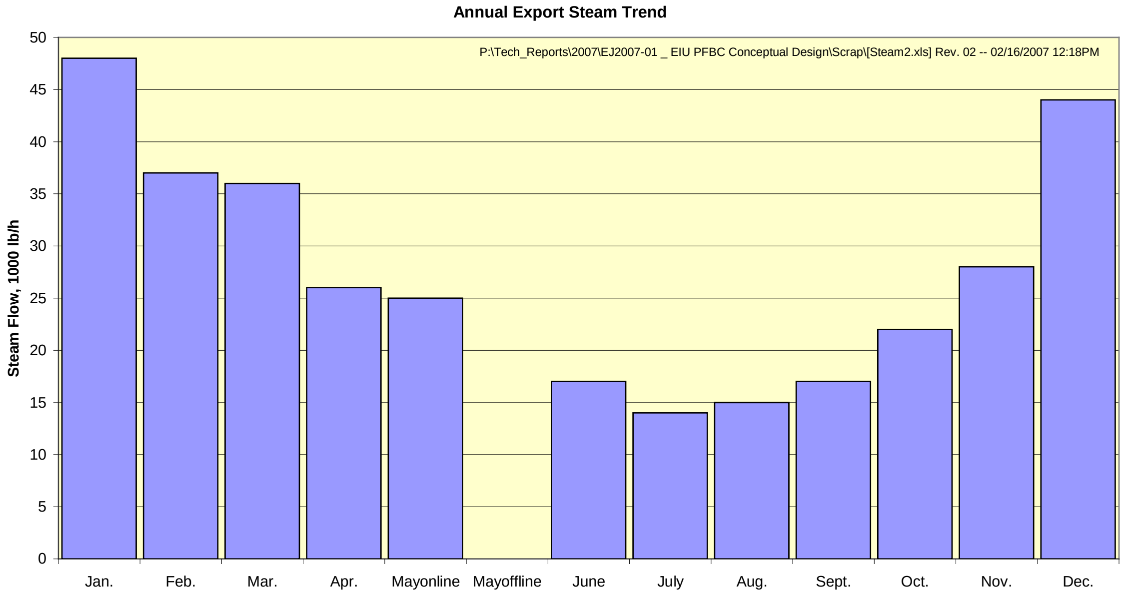
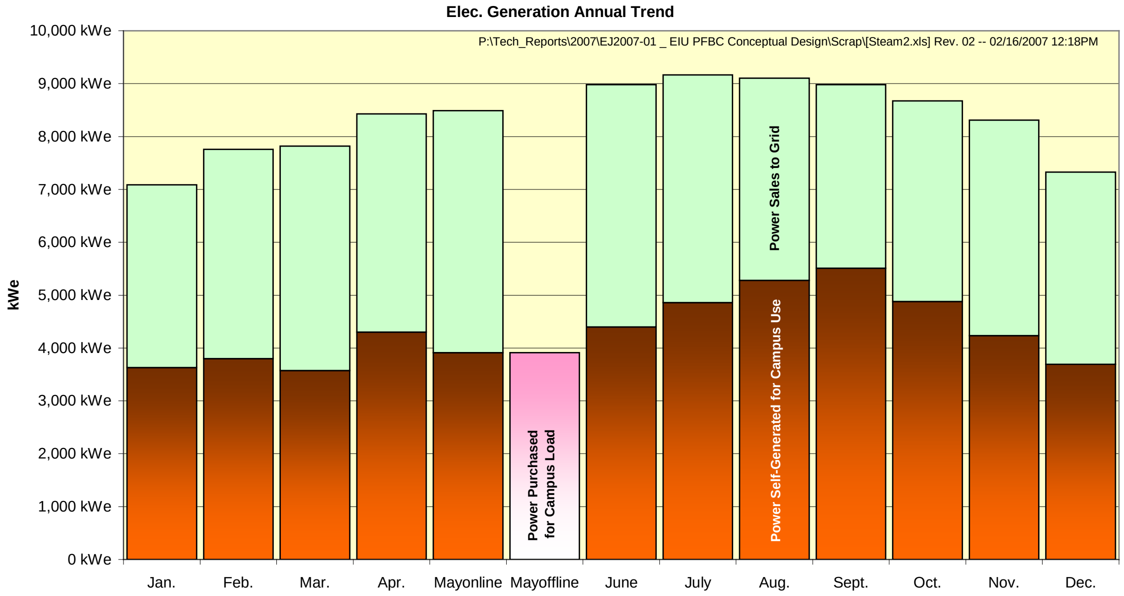


Exhibit 3 - Electric for Campus Use, with the Excess Sold for Revenue to offset Operating Costs



An 11,000 kWe cogenerating PFBC is of a convenient size. Many other university campuses and industrial manufacturing sites could use similar PFBC equipment if the technology proved technically and economically feasible.

Viewing these potential advantages, NETL launched this project, providing a body of work that is included in this report, while encouraging the Illinois Department of Commerce and Economic Opportunity Office of Coal Development to fund this study to establish the feasibility of such a cogenerating PFBC concept at this size.

Project Summary for the Cogenerating PFBC Power Plant

The plant would be located at the southwest corner of the campus, in the area illustrated by the yellow block in Exhibit 4, in the grassy area just east of the Greek Court. This location has sufficient room for the plant, and for easy transport of fuel and removal of ash from the facility. A steam pipeline would need to be constructed from this site to join the existing steam lines near Thomas Hall. A relatively short series of electric power poles would be needed to connect the generators to the power lines and switchyard on the Ameren right-of-way.

Exhibit 4 - Arial Photo of Proposed Location for the Cogenerating PFBC Power Plant

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The cogenerating PFBC plant features an automatic extraction steam turbine that adjusts the amount of steam extracted to meet campus steam demand variations, while producing electricity with the remainder of the energy. A gas turbine is used to pressurize ambient air for delivery to the PFBC combustor. The combustor burns coal or other opportunity fuels, such as out-dated corn and after filtration supplies its pressurized combustion products to expand through the gas turbine, producing a portion of the plant's electricity. Heat recovered from the PFBC and gas turbine generate steam for an extraction steam turbine that generates the bulk of the electric production. At full firing, the extraction from this steam turbine could supply up to 80,000 lb/h of steam to meet the campus steam demand. The steam extraction automatically adjusts to changes in campus steam demand. When less steam is extracted, more electricity is generated, for use by the campus, or for electric sales. At minimum steam extraction of 10,000 lb/h, at full firing the plant would then generate 10,570 kWe.

Performance Implications

The PFBC unit is a steam plant that provides and follows campus steam demand. It is a cogenerating system, so the plant also provides electricity as a byproduct for self-use to supply the campus electric needs, or for electric sales.

Exhibit 5 summarizes the expected performance at full firing with nominal winter and summer steam extraction to feed the campus steam lines.

Exhibit 5 - Summary of Performance at Full-Firing, but Different Steam Extraction Levels

	Winter Steam Export Condition	Summer Steam Export Condition
STEAM CYCLE		
Throttle Pressure, psig	450	450
Throttle Temperature, °F	750	750
Throttle Flow, lb/h	90,181	88,810
Automatic Extraction Pressure, psig	125	125
Automatic Extraction Temperature, °F	400	400
Automatic Extraction Flow, lb/h (to campus header)	50,000	10,000
Condensing Flow, lb/h	40,181	78,810
ELECTRIC POWER, kWe (at generator terminals)		
Gas turbine power	2,800	2,800
Steam turbine power	5,670	8,250
Subtotal, gross power before losses	8,470	11,050
TOTAL AUXILIARIES, kWe	-350	-440
Transformer Loss	-30	-40
Total Net Power, kWe	7,820	10,570
CONSUMABLES		
As-Received Coal Feed, lb/h	13,742	13,742
Sorbent, lb/h	3,270	3,270

Environmental Implications

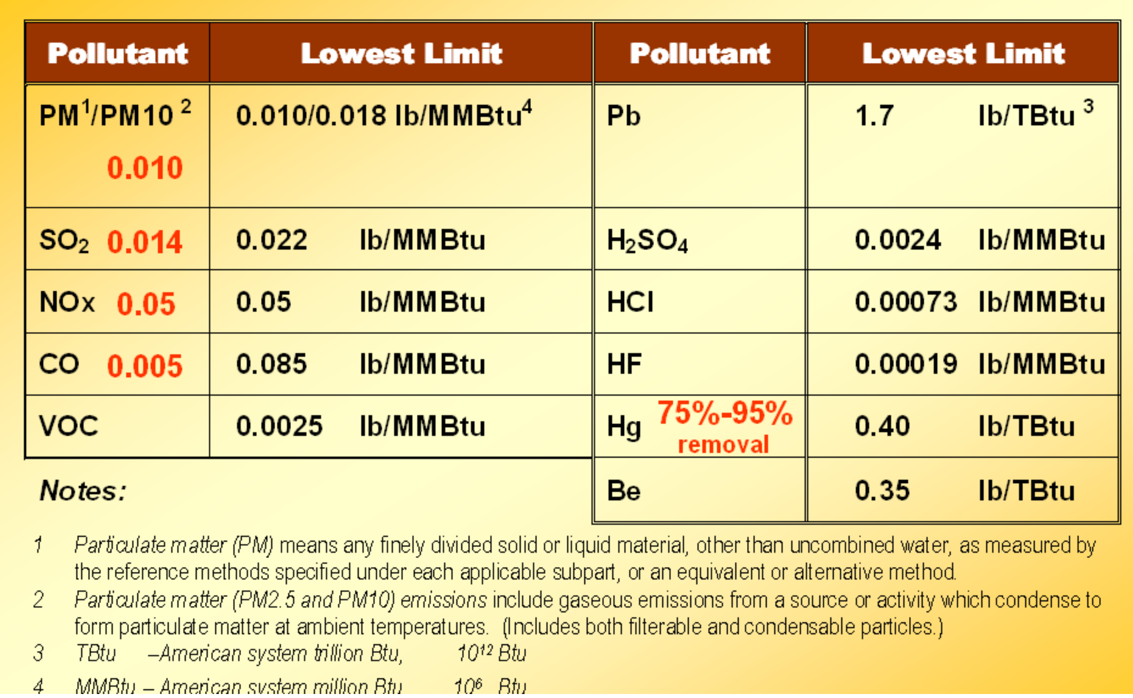
Modern coal plants are very clean environmentally. PFBC has the following environmental advantages:

- High volume bed creates large thermal reservoir, this provides a constant bed combustion temperature (even with low quality, wet, or variable fuel mix).
- The beds are very even in temperature, with no hot spots. Bed temperature is low, below threshold of production of thermal NOx.

- Limestone is injected in the bed to capture sulfur. Optimal conditions for low sorbent consumption allow use of even high sulfur-content fuels.
- Demonstrated environmental emissions from commercial PFBC plants already meet Energy Policy Act of 2005 year 2020 emissions requirements.
- Because of the long residence times, PFBCs demonstrate high combustion efficiency, high carbon conversion, thus low CO.
- High partial pressure of CO_2 eliminates free lime (CaO) formation.
- PFBC uncouples CO-NOx linkage seen in atmospheric fluidized bed boilers.
- PFBC ash is benign and cementicious. It forms low leaching mass.
- Mercury reacts with and is captured with PFBC solids.

The environmental emissions expected for this plant are listed later, in Exhibit 17, found on page 24. This expectation is reasonable, since commercial PFBC plants have demonstrated the following emission characteristics, shown in Exhibit 6:

Exhibit 6 - Environmental Emissions Measured in Commercial PFBC Power Plants



Pollutant	Lowest Limit	Pollutant	Lowest Limit
PM^1/PM10^2 0.010	0.010/0.018 lb/MMBtu^4	Pb	1.7 lb/TBtu^3
SO_2 0.014	0.022 lb/MMBtu	H_2SO_4	0.0024 lb/MMBtu
NOx 0.05	0.05 lb/MMBtu	HCl	0.00073 lb/MMBtu
CO 0.005	0.085 lb/MMBtu	HF	0.00019 lb/MMBtu
VOC	0.0025 lb/MMBtu	Hg 75%-95% removal	0.40 lb/TBtu
		Be	0.35 lb/TBtu

Notes:

1 *Particulate matter (PM)* means any finely divided solid or liquid material, other than uncombined water, as measured by the reference methods specified under each applicable subpart, or an equivalent or alternative method.

2 *Particulate matter (PM2.5 and PM10) emissions* include gaseous emissions from a source or activity which condense to form particulate matter at ambient temperatures. (Includes both filterable and condensable particles.)

3 *TBtu –American system trillion Btu, 10^{12} Btu*

4 *MMBtu – American system million Btu 10^6 Btu*

Source: Burkett

Investment and Economics Implications

This cogenerating PFBC plant has an estimated total plant cost of about $75,741,000. The net operating cost of this new facility is estimated to be about $3,517,000 per year, which includes operating and administrative labor, fuel and consumables, and maintenance (levelized labor and materials).

This $76 million capital cost must be amortized over the book life of the plant. Based on an estimate of 5% for interest (assuming the issuance of State-backed municipal type bonds), an annual capital recovery payment of about $5 million is estimated. This includes the up-front costs of financing. Additional fixed costs associated with this facility would be insurance and taxes. If the facility is exempt from local property taxes, insurance can be in the range of just under 1% of the capital cost. This yields a total annual payment (first year, no escalation for fuel, labor, etc.) of about $9 million per year.

This total of operating and capital expenditures may be subject to some degree of reduction, if Federal and/or State monies are available to directly or indirectly provide assistance to the University in constructing this type of facility. Appendix A provides the equipment lists, and the capital and operating cost detail that led to these estimates.

Site Description and Design Basis

This combined heat and power facility is located on the campus of Eastern Illinois University, Charleston, IL. There is an existing steam plant providing steam production to the campus users. The new power house is on the eastern end of the campus on a 30 acre site, which is flat and open. The ambient conditions and site characteristics as presented in Exhibit 7 and Exhibit 8.

The proposed site for the construction of the new power plant is in the available area south of Elton Road at the Southeast corner of the campus. Ample space appears to be available for construction laydown and parking at this location. Road access is available from Elton Rd or from Route 130.

Exhibit 7 - Site Design Reference Ambient Conditions

Elevation, ft	720 ft
Barometric Pressure	14.225 psia
Design Ambient Temperature, Dry Bulb	+ 60 ºF
Design Ambient Temperature, Wet Bulb, °F	+ 52.2 ºF
Design Ambient Relative Humidity, %	60 %

Exhibit 8 - Site Characteristics

Location	Eastern Illinois University, Charleston, Illinois
Topography	Level
Size, acres	30
Transportation	Truck
Ash Disposal	Off Site
Water	Municipal
Access	Having access interstate highway, city highway and campus street

Primary Fuel Coal

This 11 MWe/60 Hz PFBC unit is designed based on Illinois #6 coal as the performance fuel, with nominal properties as presented in Exhibit 9, and detailed in Appendix A. This fuel would be run-of-mine coal, which means there is likely to be a wide variation of fuel properties, ash, and moisture percentage throughout the plant life. If the design is to proceed these variations need to be investigated.

Exhibit 9 - Design Coal: Illinois #6, as received

Proximate Analysis	Pct by wt
Moisture	12.25
Volatile Matter	35.30
Fixed Carbon (by difference)	41.48
Ash	10.97
total	100.00%
Inherent moisture	
Surface moisture	
Total moisture	12.25
Ultimate Analysis	Pct by wt
Sulfur	3.28
Carbon	61.00
Hydrogen	4.25
Nitrogen	1.25
Oxygen (by difference)	6.93
Chlorine	0.07
Fluorine	
Moisture	12.25
Ash	10.97
total	100.00%
HHV, Btu/lb	10,982
LHV, Btu/lb	10,584

Supplemental and Start-Up Fuel

Shelled corn is considered as a supplemental fuel. Because of fungicides and insecticides used in treating seed corn, it was agreed that seed corn would not be used by the Client. The properties of shell corn are presented in Exhibit 10. Natural gas is utilized as the start-up fuel, or for back-up.

Exhibit 10 - Dry Shelled Corn Composition

	Hybrid Seed Corn Bone Dry	Dry Hybrid Seed Corn As Received
Bulk Density		25.0 lb/ft^3
Moisture	0.00%	12.00%
Proximate Analysis		
Volatiles	75.40%	66.35%
Fixed Carbon	15.40%	13.55%
Moisture	0.00%	12.00%
Ash	9.20%	8.10%
total	100.00%	100.00%
Ultimate Analysis		
Carbon	46.14%	40.61%
Hydrogen	6.15%	5.41%
Nitrogen	1.53%	1.35%
Sulfur	0.18%	0.16%
Oxygen	44.46%	39.12%
Moisture	0.00%	12.00%
Ash	1.53%	1.35%
total	100.00%	100.00%
HHV	8,222 Btu/lb	7,235 Btu/lb

Design Sorbent Composition

Limestone will be procured from a limestone company nearby in Champaign IL. Sorbent will be delivered to plant storage by truck. The proposed limestone should contain at least 80% calcium and 8% magnesium. Limestone analysis is presented in Appendix A.

Balance of Plant

Assumed balance of plant requirements are as follows:

Fuel and Other storage	
Coal	30 days with 10-15 day hopper
Ash	30 days
	30 days
Sorbent	14 Days
Plant Distribution Voltage	
Motors below 1 hp	110/220 volt
Motors 250 hp and below	480 volt
Motors above 250 hp and below 5,000 hp	4,160 volt
Steam and Gas Turbine generators	13,800 volt
Grid Interconnection voltage	69 kV
Water and Waste Water	
Makeup Water	The EIU steam system currently returns over 90% in condensate and is of good quality. Makeup for potable and process water, and cooling tower makeup will be drawn from city water system.
Feed water	The quality of feedwater (i.e., water treatment systems) should be suitable for the new PFBC unit. The existing water treatment system will be reviewed for the possibility to supply the water to the new unit.
Process Wastewater	Water associated with the process activity and storm water that contacts equipment surfaces will be collected and piped to the existing wastewater treatment system. Most of the wastewater is to be recycled for plant needs. Blowdown will be treated for chloride and metals, and discharged.
Sanitary Waste Disposal	Sanitary waste will be discharged to the local municipal sewer system.
Solid Waste	Fly ash, bottom ash, and slag are assumed to be solid wastes that are classified as non-hazardous wastes. Offsite waste disposal sites are assumed to have the capacity to accept waste generated throughout the life of the facility. Solid wastes sent to disposal are at an assumed nominal fee per ton, even if the waste is hauled back to the mine. Solid waste generated that can be recycled or reused is assumed at a zero cost to the project.

Plant Operating Modes, Loads, Reliability, and Maintenance Outages

The plant will operate primarily supplying steam for the year-round demands in the campus. It should be designed with reliability features that would keep the unit in service with a minimal number of forced outages.

Steam Production

The new unit will have the continuous capacity to supply adequate steam production for current average demand in the campus without operating any of the existing coal-fired, or natural gas fired boilers. The detailed description in Appendix A lists the current steam demand profiles. The proposed new PFBC plant would replace the duty of the existing boilers. The existing boilers are considered for back-up and peak load units only. Based on the preliminary heat balance, the rated steam production of the new unit shall be designed as follows (nominal values).

Steam Temperature: .... 353 °F

Steam Pressure: .... 125 psig

Steam flow: .... 80,000 lb/hr, maximum

A new steam tunnel is required to connect the new plant to the existing steam distribution system. The new tunnel will extend approximately 1000 ft to the west to connect to the existing system. The tie in point is at the north of Roosevelt Ave and west of 7th Ave.

Power Generation

Current electric load in the campus is 9 to 10 MW with an average demand of 4 to 6 MW. EIU current purchases all electricity from Ameren. The maximum nominal gross output of the new unit is expected to be 11 MW (nominal value). Appendix A provides details of the current campus electric use profiles. The surplus electricity will be sold to the grid. EIU is planning a new switchyard immediately to the north of the proposed plan site.

Conceptual Design for the Cogenerating 11 MWe PFBC

This section describes a nominal 11 MWe/60 Hz of circulating pressurized fluidized-bed combustor (PFBC) cogenerating power plant that can provide between 10,000 to 80,000 lb/h of 125 psig steam. This unit is capable of burning a wide range of coals; the design case described herein reflects performance with run-of-mine Illinois #6 coal. Performance will vary (power output, heat rate) depending on the fuel used. Since the plant will use run-of-mine coal, more detailed evaluations are required of the range of variation in coal ash and moisture expected over the plant life.

This unit is based on equipment selected from the Dresser-Rand Corporation for an industrial air compressor and industrial hot gas expander product lines. A commercially available steam turbine generator set with extraction capability is also part of the power generating equipment. The PFBC portion of the plant is configured with a single vessel containing the combustor and the fluid-bed heat exchanger. The estimated performance for this plant is a net output of 10.57 MWe with 10,000 lb/hr steam extraction, or net output of 7.82 MWe with 50,000 lb/hr steam extraction. The steam extraction may be any quantity up to 80,000 lbs/h.

Preliminary Heat & Mass Balance

The unit described in this section is based on first-generation PFBC design concepts, utilizing a combined cycle for conversion of thermal energy from the fluid bed to electric power. An open Brayton cycle using air and combustion products as the working fluid is used in conjunction with a conventional steam Rankine cycle. The two cycles are coupled by generation and superheat of steam in the fluid-bed heat exchanger surfaces within the pressurized fluidized-bed combustion (PFBC) vessel, and feedwater heating in the heat recovery unit (HRU).

The turbomachine components are configured to operate as a synthetic gas turbine, which operates in an open cycle mode, driving the electric generator from one end with the steam turbine driving from the other end. The cycle is shown on Exhibit 11 and Exhibit 12, and is described below.

Inlet air passes through an inlet filter, and then passes into an axial flow low-pressure (LP) compressor. The airflow exiting the compressor flows through an intercooler (a shell and tube heat exchanger, with air on the shell side and condensate from the steam cycle on the tube side), and then into a centrifugal high-pressure (HP) compressor. A small portion of the air (1.4 percent) is boosted to a higher pressure (280 psig) for use in the lock hopper injection system for fuel and sorbent. The main air stream exiting the HP compressor is sent to the PFBC vessel to provide O_2 for combustion reactions and fluid momentum for material transport.

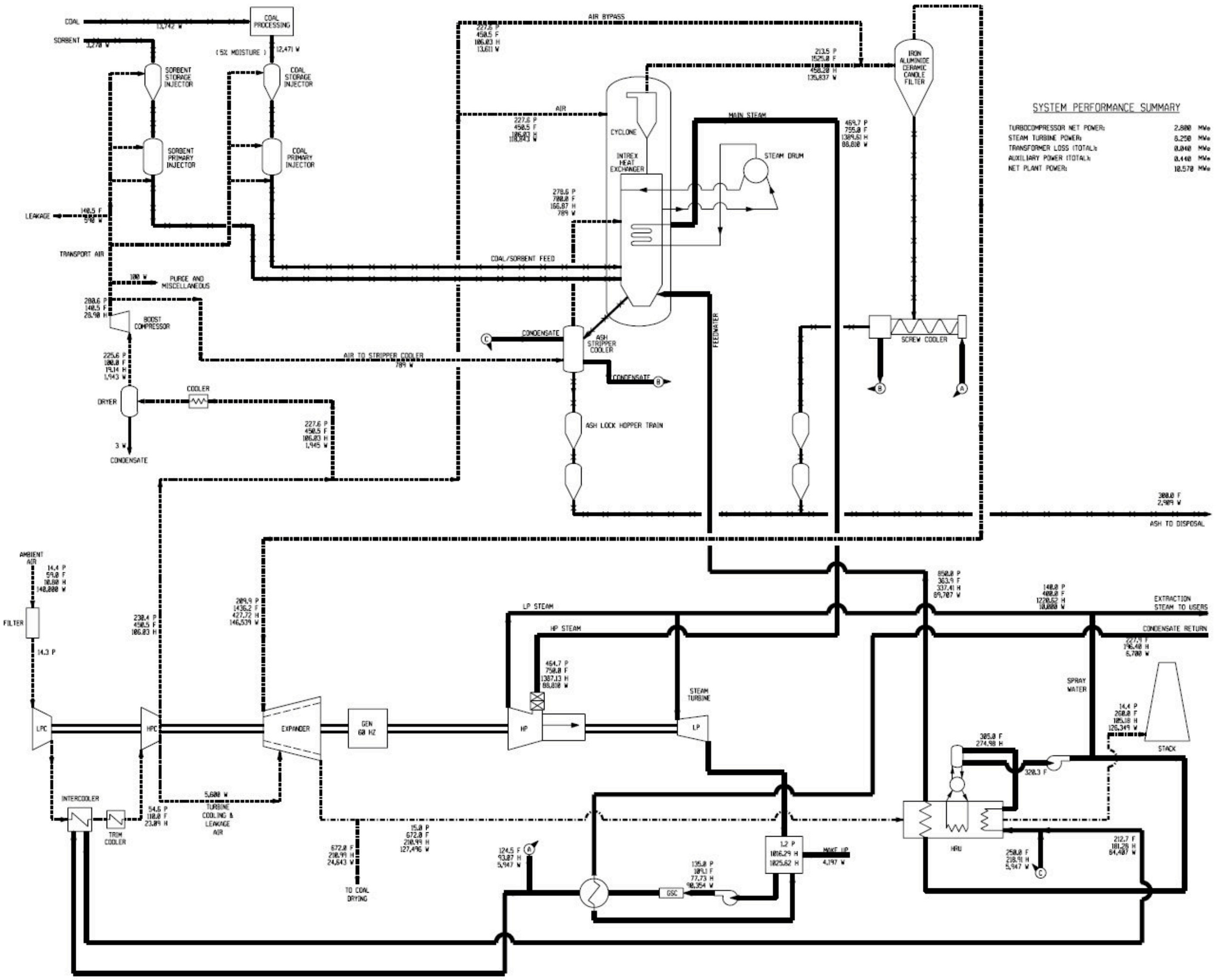
The cleaned air and gases from the PFBC are returned to the turbomachine package at a temperature of about 1436 °F. The hot gases are conveyed to the inlet of the expander section of the machine, where they enter and expand to produce power to drive the compressor and an electric generator. The expander exhaust gases are conveyed through an HRU to recover the large quantities of thermal energy that remain. The HRU exhausts to the plant stack.

The Rankine cycle used herein is based on a 450 psig/750 °F non reheat configuration with low pressure steam extracted to campus heating system. In this design an automatic extraction condensing type steam turbine is used. This machine drives one end of a 3,600 rpm totally enclosed water-cooled (TEWAC) electric generator. The gas turbomachine described above drives the opposite end. Reducing gear boxes are employed between the electric generator and both of its drivers. The steam turbine automatic extraction port exhausts to a supply line to the university steam header. The steam turbine exhausts to a single-pressure condenser operating at 2.50 inches Hga at the nominal 100 percent load summer design point.

Feedwater heating is accomplished by pumping condensate from the condenser through a regenerative heat exchanger, absorbing heat from returning condensate from the university heating system. The condensate then passes through the gas turbine compressor intercooler, and then through the low temperature economizer coil in the gas turbine heat recovery unit (HRU). The condensate then passes to the integral deaerator in the HRU, and on to the feed pump located below the HRU. The fluid (now classified as feedwater in lieu of condensate) is pumped through the high temperature heating coil of the HRU on to the PFBC.

The feedwater is heated to steaming temperature, evaporated, and superheated in the PFBC heating surfaces, and then routed to the steam turbine.

Exhibit 11 - Heat & Material Balance Diagram (Low Extraction Flow)



SYSTEM PERFORMANCE SUMMARY

TURBOCOMPRESSOR NET POWER:	2.800 MWe
STEAM TURBINE POWER:	8.250 MWe
TRANSFORMER LOSS (TOTAL):	0.040 MWe
AUXILIARY POWER (TOTAL):	0.440 MWe
NET PLANT POWER:	10.570 MWe

NOTES:

D

LEGEND

▬	CONDENSATE, FEEDWATER, OR STEAM
─┼┼─	SOLIDS
■■■■	AIR
■·■·■	COMBUSTION PRODUCTS
P	PRESSURE, PSIA
F	TEMPERATURE, °F
H	ENTHALPY, BTU/LBM
W	MASS FLOW, LBM/HR
MWe	POWER, MEGAWATTS ELECTRICAL

1. ENTHALPY REFERENCE POINT IS NATURAL STATE AT 32.018°F AND 0.08865 PSIA.
2. STEAM TURBINE LEAKAGE AND BOILER BLOWDOWN MODELED BUT NOT SHOWN.
3. 15% EXCESS AIR
4. GENERATION AT 60HZ
5. GAS TURBINE SET SHAFT LEAKAGE MODELED BUT NOT SHOWN.

848006/dvoh

REV	DATE	DESCRIPTION	DRAWN	CHECKED	LEAD DESIGNER	ENGINEER/ TECH SPEC	LEAD DISC ENGINEER	PROJ ENGR MANAGER	PROJECT MANAGER

PRELIMINARY STATUS DATE
LDE
REPRESENTS GENERAL DESIGN CONCEPTS BASED ON ASSUMPTIONS. REVIEWED NOT CHECKED.

APPROVED STATUS DATE
LDE
REPRESENTS REVIEWED AND APPROVED DESIGN. ANY PORTION MARKED "HOLD" RETAINS PRELIMINARY STATUS.

ORIGINATING PERSONNEL	PROFESSIONAL ENGINEER'S SEAL
DRAWN BY	
CHECKED BY	
LEAD DESIGNER	
ENGINEER/TECH SPECIALIST	
PROJECT ENGINEERING MANAGER	
PROJECT MANAGER	

Zero Harm
Leadership
No Incidents
Safe Behavior

ORIGINALLY PREPARED UNDER THE RESPONSIBLE SUPERVISION OF
PE: ______________ STATE: ________
LIC. NO.: ____________ DATE: ________

WorleyParsons
resources & energy

CLIENT/PROJECT TITLE
DEPARTMENT OF ENERGY STUDY
EASTERN ILLINOIS UNIVERSITY PFBC
ILLINOIS #6 COAL

HEAT & MASS BALANCE DIAGRAM
DRESSER RAND TURBOMACHINE
LOW EXTRACTION FLOW
EASTERN ILLINOIS UNIVERSITY STUDY

SCALE NONE
DRAWING SIZE ANSI D (22" x 34")
WORLEYPARSONS DWG. NO. EILU-1-DW-021-306-302
REV A

Exhibit 12 - Heat & Material Balance Diagram (High Extraction Flow)

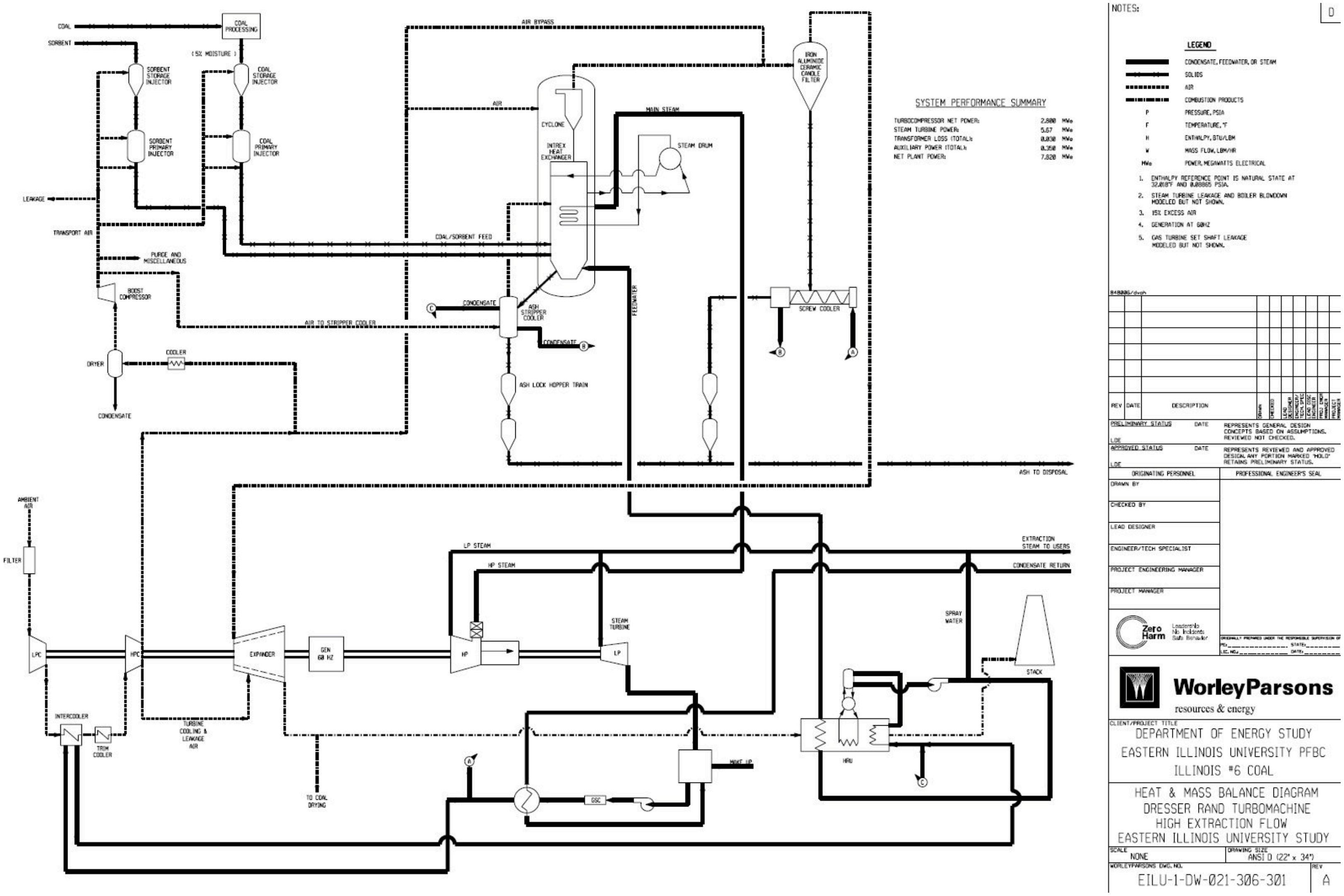


Exhibit 13 - Power Block Plan

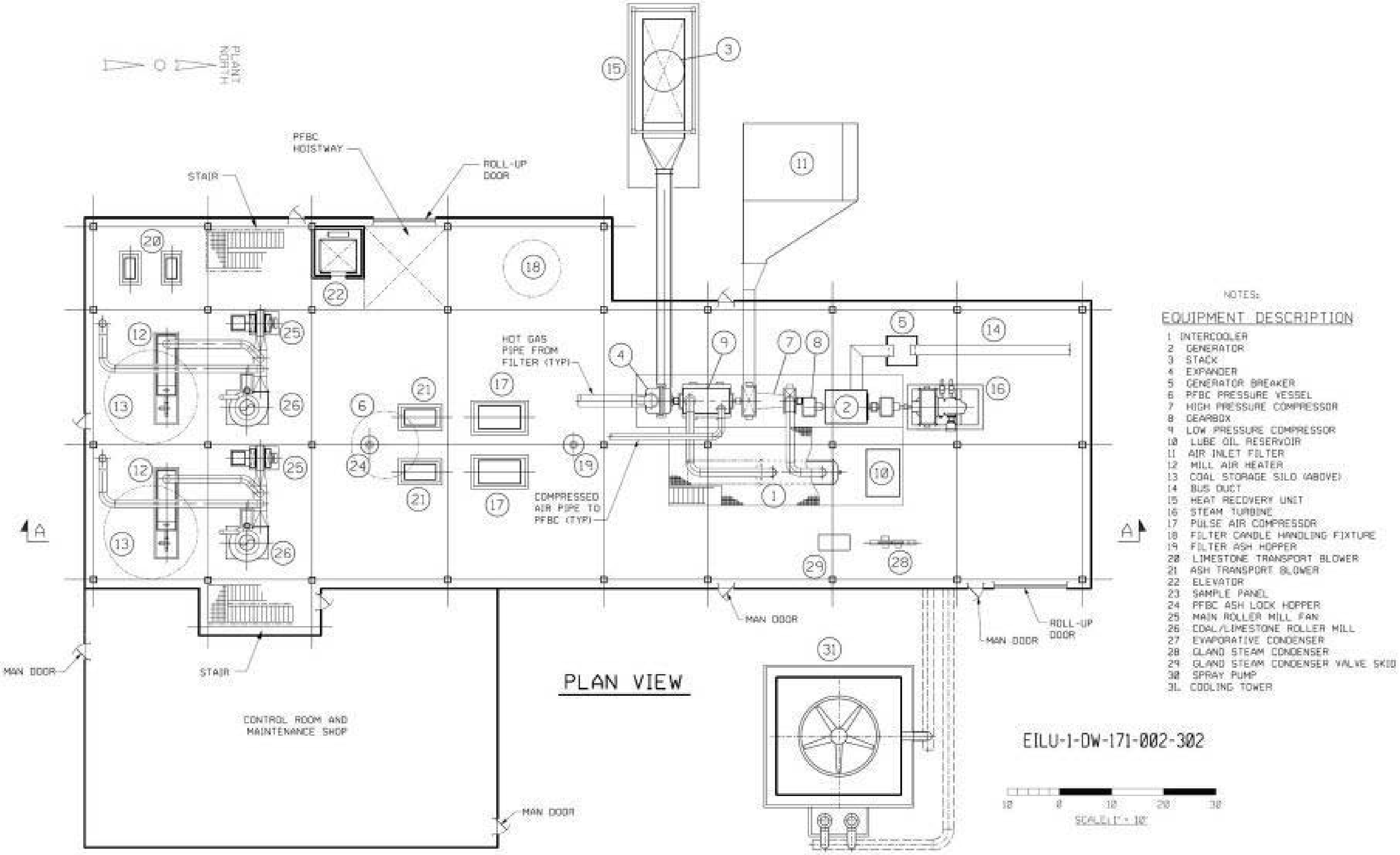
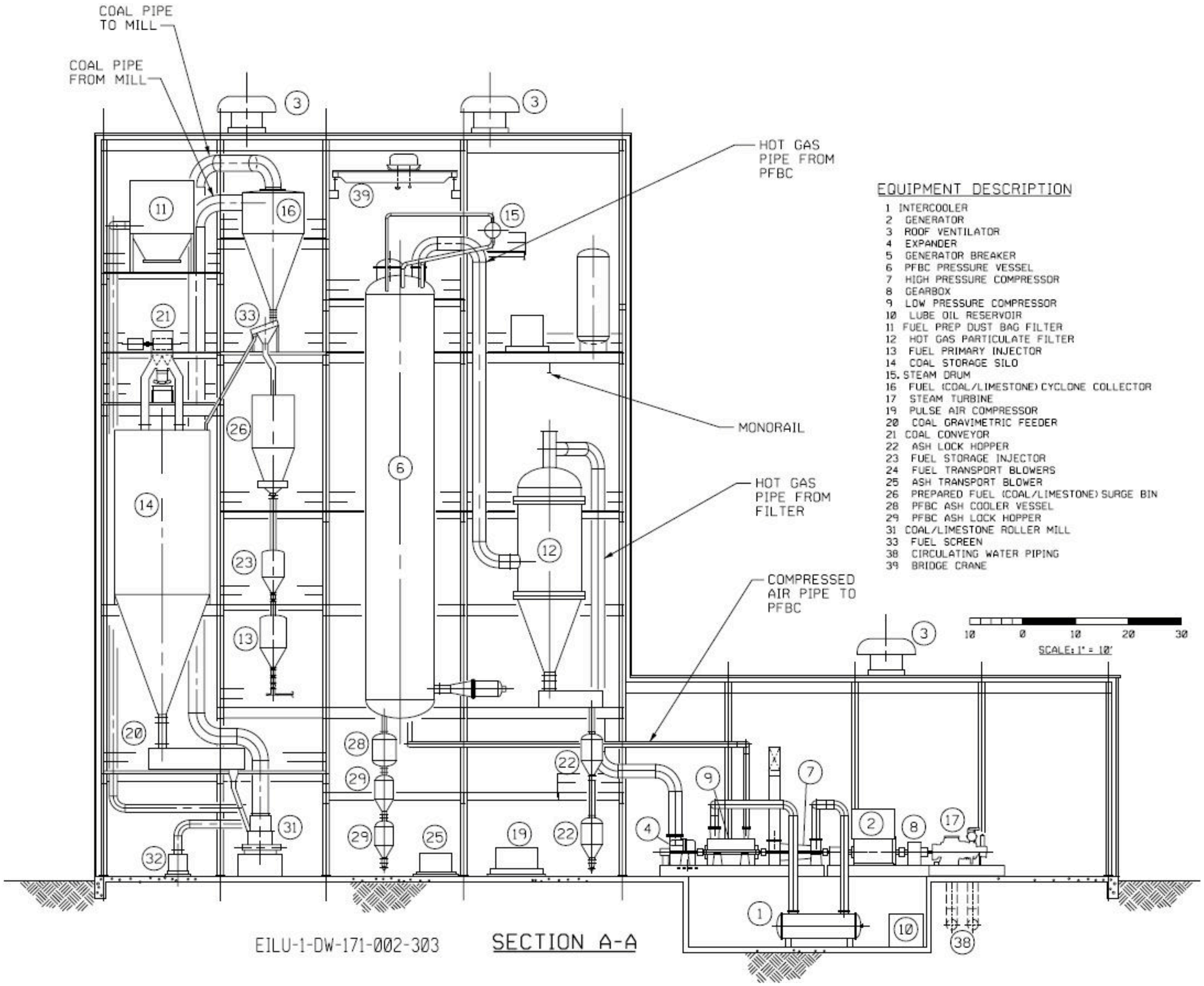


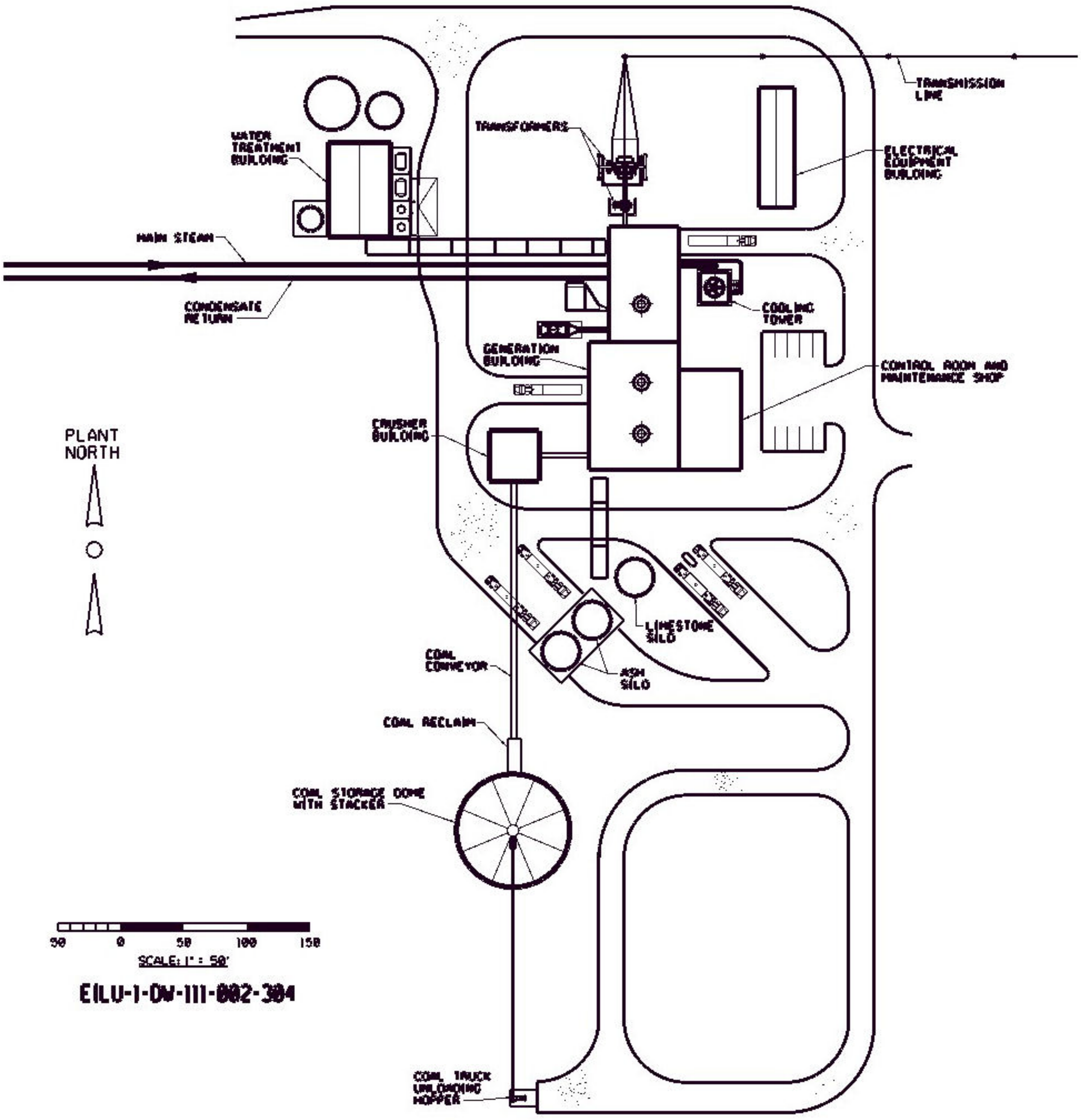
Exhibit 14 - Power Block Elevation



Plant Layout

The PFBC plant is located north of Edgar Drive, to the southwest corner of the campus, near the Greek Court, and connected to the existing main steam mains, located near Thomas Hall. Exhibit 15 provides a general arrangement plan for the PFBC system. A closer view of the power block is provided in Exhibit 13 and Exhibit 14.

Exhibit 15 - General Arrangement Site Plan



Preliminary Estimate of Performance

The new proposed Eastern Illinois University cogenerating power plant must be designed to operate in a satisfactory manner during all anticipated operating conditions, on and off peak. The selection of design points for the new facility incorporates the following considerations:

- Peak heating steam demand set at 80,000 lb/hour saturated steam at 140 psia, in winter. Nominal winter demand is set at 50,000 lbs/h.
- Minimum steam demand of 10,000 lb/hour saturated steam at 140 psia in summer.

The winter and summer design conditions are explained below.

- Winter Design Condition (high extraction steam flow to plant header) – The turbine is designed to receive steam from the PFBC steam generator at 450 psig/750 °F at 90,181 lb/hour. Electric power generation at the generator terminals is nominally 8.5 MWe, and a steam flow of 50,000 lb/hour to the plant steam header.

- Summer Design Condition (low extraction steam flow to plant header) – As steam header demand falls, steam flow through the condensing section of the turbine increases and electric power generation increases. For the purposes of this design, maximum steam flow through the turbine condensing section is set at 78,800 lb/hour. With steam turbine throttle conditions maintained at the principal design point, this corresponds to an electric power output at the generator terminals of 11 MWe, and a steam flow of 10,000 lb/hour to the plant steam header.

The steam power cycle for each of the two cases is shown schematically in the heat and mass balance diagrams, Exhibit 11 and Exhibit 12. The diagrams show state points at each of the major components. Overall performance for the entire plant is summarized in Exhibit 16, which includes auxiliary power requirements.

Exhibit 16 - Plant Performance Summary

	Winter Steam Export Design Condition	Summer Steam Export Design Condition
STEAM CYCLE		
Throttle Pressure, psig	450	450
Throttle Temperature, °F	750	750
Throttle Flow, lb/h	90,181	88,810
Automatic Extraction Pressure, psig	125	125
Automatic Extraction Temperature, °F	400	400
Automatic Extraction Flow, lb/h (to plant header)	50,000	10,000
Condensing Pressure, in. Hga	2.5	2.5
Condensing Flow, lb/h	40,181	78,810
ELECTRIC POWER, kWe (at generator terminals)		
Gas turbine power	2,800	2,800
Steam turbine power	5,670	8,250
ELECTRIC POWER, kWe (at generator terminals)	8,470	11,050
AUXILIARY LOAD SUMMARY, kWe		
Coal & Limestone Prep. & Feed	50	50
Turbocompressor Aux	10	10
Transport Booster Compressor	10	10
Condensate Pumps	20	20
Main Feed Pump	120	120
Cooling Tower Fans	30	60
Circulating Water Pumps	60	120
Miscellaneous Balance of Plant (Note 1)	50	50
TOTAL AUXILIARIES, kWe	350	440
Transformer Loss	30	40
Net Power, kWe	7,820	10,570
CONDENSER COOLING DUTY, 10^6 Btu/h	41.5	81.4
CONSUMABLES		
As-Received Coal Feed, lb/h	13,742	13,742
Sorbent, lb/h	3,270	3,270

Note 1 - Soot blowing medium is steam. Electric power consumption is negligible.
Note 2 - Includes plant control systems, lighting, HVAC, water treating, etc.

Emissions Performance

This PFBC power plant is projected to generate emissions of NOx, SO_2, and particulates as presented in Exhibit 17.

Exhibit 17 - Airborne Emissions

Fuel	Design Coal	
	lb/10^6 Btu	Tons/year
SO_2	0.3	158
NOx	0.10	53
Particulates	0.0008	<1
CO_2	205	108,000

The low level of SO_2 emissions is achieved by capture of sulfur in the bed by calcium in the limestone sorbent. The nominal design basis SO_2 removal rate is 95 percent with a Ca/S ratio of 2.4 for the PFBC bed.

The low production of NOx is achieved by staging of combustion in the PFBC bed. Limitation of bed temperature to 1600 °F or less, established to optimize sulfur capture, is a significant contributor to reducing formation of NOx in the bed, since the kinetics of NOx formation are significantly retarded at these relatively low combustion temperatures. Selective non-catalytic reduction (SNCR) is used to further reduce NOx emissions.

Particulate discharge to the atmosphere is reduced by the use of the iron aluminide candle filters, which provide a collection efficiency greater than 99.99 percent. CO_2 emissions are increased slightly, relative to simple coal combustion, by the liberation of CO_2 from the sorbent used for sulfur capture.

Emissions of SO_2 when firing a blend of coal and shelled corn are reduced proportionately to the amount of corn used. No changes are anticipated for NOx or particulates. CO_2 emissions at the stack will be reduced slightly. However, firing corn may result in a “green fuel” credit.

PFBC Systems

Appendix A provides details of the main power block equipment for the site, which includes descriptions of the following plant systems:

- PFBC Subsystem
- Gas Turbomachinery
- Heat Recovery Unit (HRU)
- Fuel Preparation and Injection System
- Sorbent Injection System
- Coal Handling System
- Limestone Handling and Preparation System
- Ash Handling
- Electrical power system
    - Motor-Generator Terminal System
    - 4,160-Volt AC Power Supply System

  - System Description
  - 480-Volt AC Power Supply Systems
  - Power House DC and Critical AC Power Supply System
  - High-Voltage Switchyard System
- Fire Protection
  - Fire Pumps and Fire Main System
  - Automatic Sprinklers
  - Carbon Dioxide
  - Fire Hose Stations and Fire Extinguishers
  - Fire Barriers
- Heating, Ventilating, and Air Conditioning (HVAC)
- Water Treatment
- Service Air and Instrument Air
- Closed-Loop Cooling Water System
- Open Cycle Cooling Water System
- Chilled Water System
- Potable Water System
- Sanitary Waste Disposal System

Steam Cycle Balance of Plant

Appendix A provides details on the following steam cycle balance-of-plant equipment:

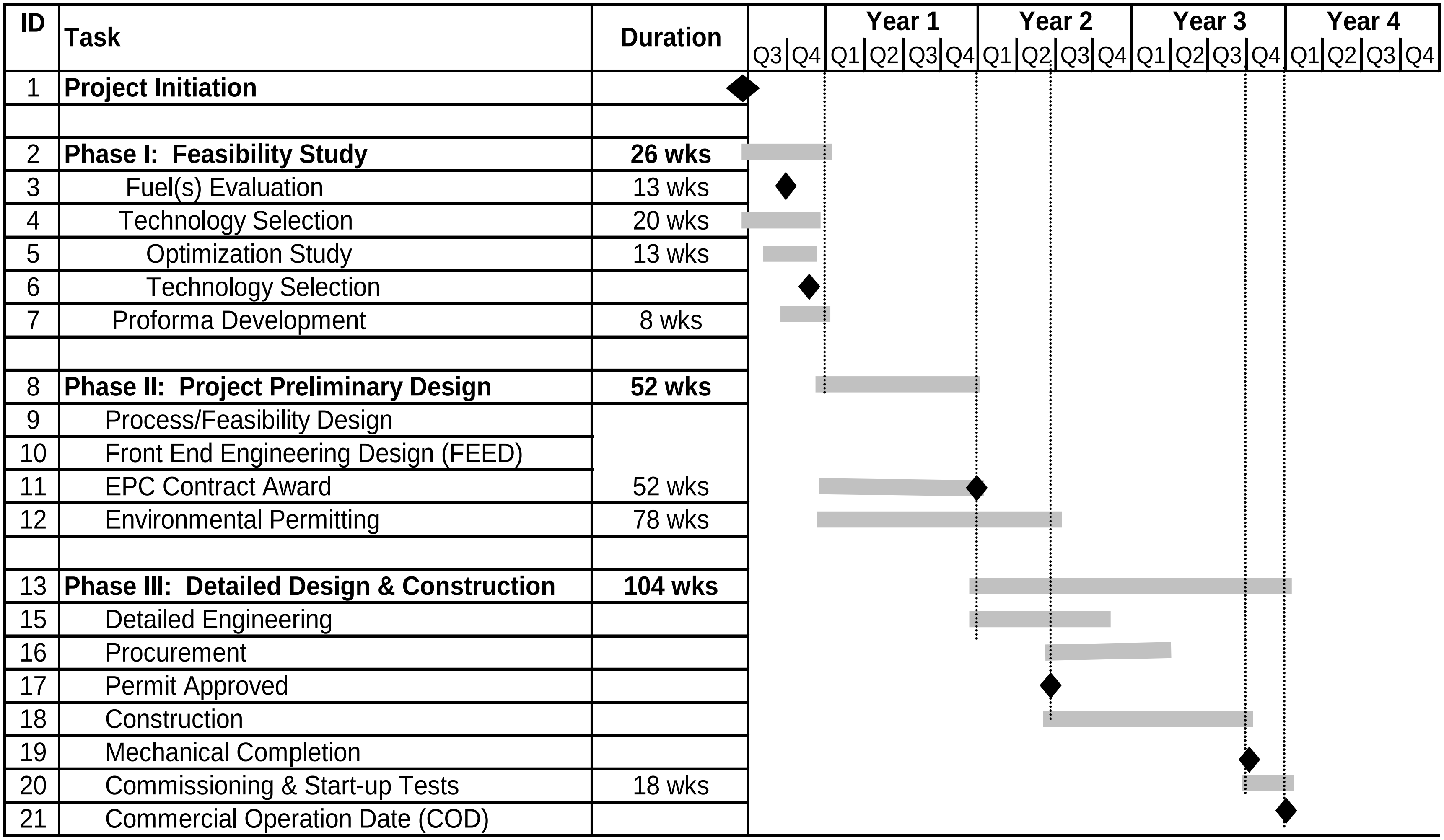
- Steam Turbine Generator
- Condensate and Feedwater Systems
- Condenser
- Circulating Water System
- Steam Cycle Piping

Construction and Tie-In

The proposed site for the construction of the new power plant is in the available area at the Southeast corner of the campus. Appendix A details some of the construction and tie-in issues for the new power house, including the following: connection to steam mains and electrical switchyard and interconnect.

The following estimated schedule shows the durations and time frame for the different phases of the project assuming no delays between phases.

Estimated Schedule



ID	Task	Duration
1	**Project Initiation**	
2	**Phase I: Feasibility Study**	**26 wks**
3	Fuel(s) Evaluation	13 wks
4	Technology Selection	20 wks
5	Optimization Study	13 wks
6	Technology Selection	
7	Proforma Development	8 wks
8	**Phase II: Project Preliminary Design**	**52 wks**
9	Process/Feasibility Design	
10	Front End Engineering Design (FEED)	
11	EPC Contract Award	52 wks
12	Environmental Permitting	78 wks
13	**Phase III: Detailed Design & Construction**	**104 wks**
15	Detailed Engineering	
16	Procurement	
17	Permit Approved	
18	Construction	
19	Mechanical Completion	
20	Commissioning & Start-up Tests	18 wks
21	Commercial Operation Date (COD)	

Operations

A complete description of the design measures and procedures provided to enable this type of facility to start up and shut down in a well-controlled, orderly manner, and to handle transients such as unit trip, due to loss of load or other cause, is beyond the scope of this report. However, in recognition of the vital nature of these considerations, Appendix A provides a preliminary subjective view of plant operations, including the following subjects:

- Startup, Shutdown, and Transients
- Cold Startup Sequence
- Unit Trip Sequence
- Existing Boilers for Back-Up

Capital Cost and Economics Estimate

A summary of the estimated project costs and economics are presented here. Appendix A provides the following details:

- Basis for the Capital Cost Estimates
- Estimate Scope
- Construction Labor
- Contracting Methodology
- Contingency - Process
- Contingency - Project
- Exclusions
- Typical Owner's Costs

The estimated total plant costs are summarized below:

Case	Net output minimum steam	Net output Winter steam	Total Plant Costs
PFBC	11,570 kWe 10,000 pph steam at 125 psig	7,820 kWe 50,000 pph steam at 125 psig	$75,751,000

Annual Operations Economics

Exhibit 18 - Revenue from Electric Sales

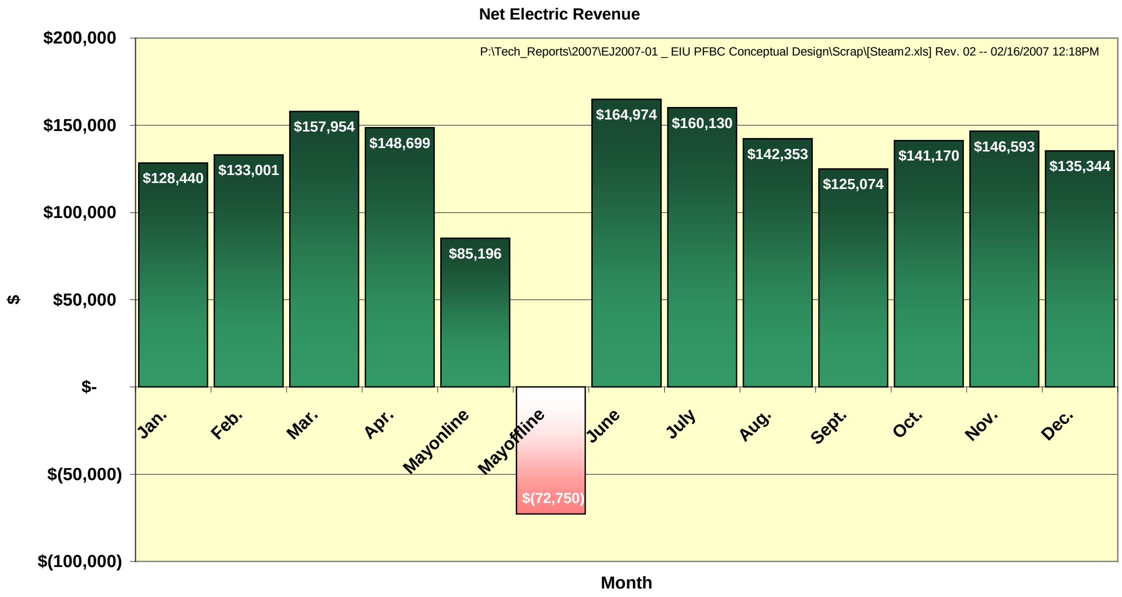
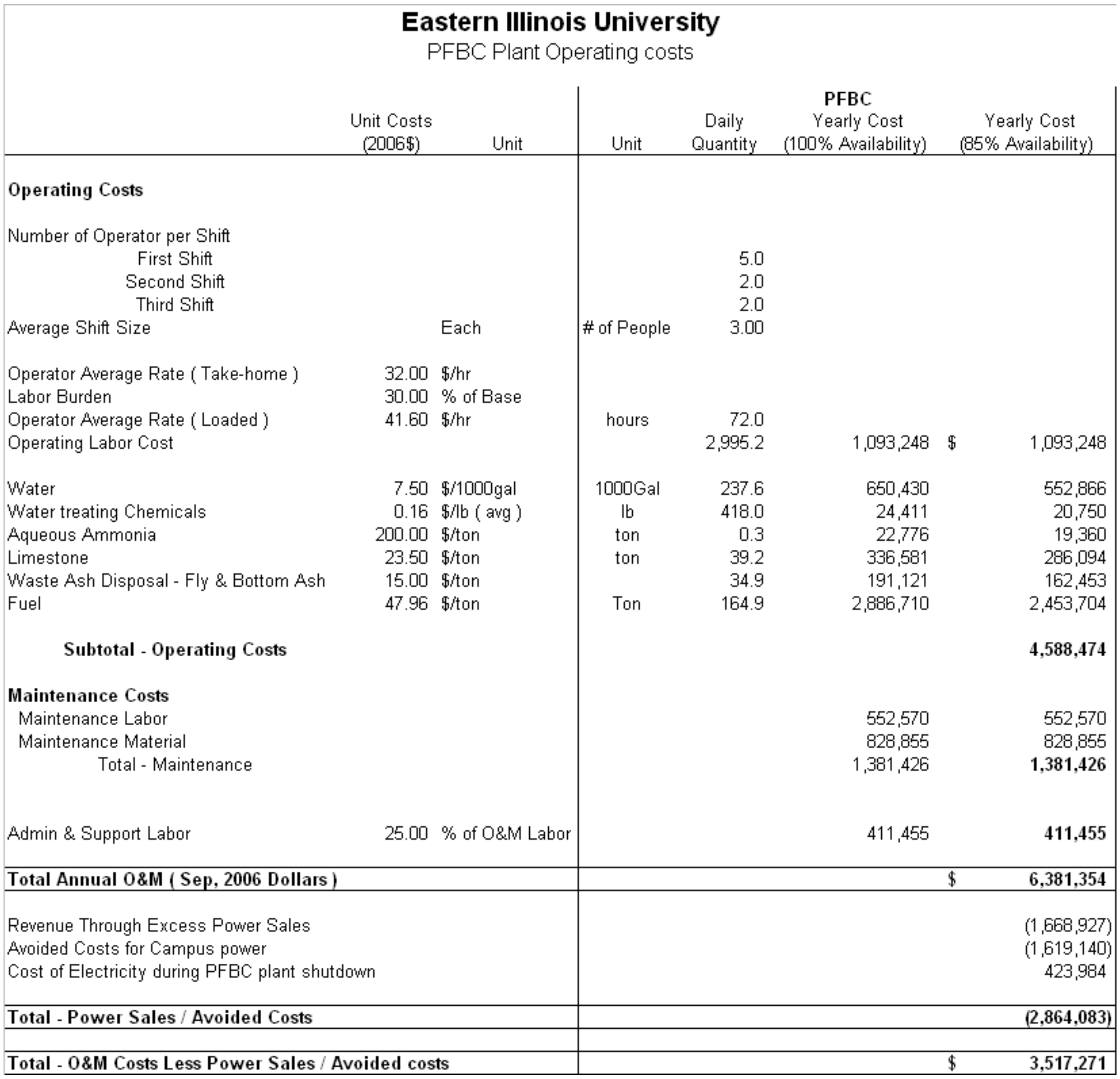


Exhibit 19 - Estimated PFBC Plant Operating Costs and Revenues



Eastern Illinois University

PFBC Plant Operating costs

	Unit Costs (2006$)	Unit	Unit	Daily Quantity	PFBC Yearly Cost (100% Availability)	Yearly Cost (85% Availability)
Operating Costs						
Number of Operator per Shift						
First Shift				5.0		
Second Shift				2.0		
Third Shift				2.0		
Average Shift Size		Each	# of People	3.00		
Operator Average Rate (Take-home)	32.00	$/hr				
Labor Burden	30.00	% of Base				
Operator Average Rate (Loaded)	41.60	$/hr	hours	72.0		
Operating Labor Cost				2,995.2	1,093,248	$ 1,093,248
Water	7.50	$/1000gal	1000Gal	237.6	650,430	552,866
Water treating Chemicals	0.16	$/lb (avg)	lb	418.0	24,411	20,750
Aqueous Ammonia	200.00	$/ton	ton	0.3	22,776	19,360
Limestone	23.50	$/ton	ton	39.2	336,581	286,094
Waste Ash Disposal - Fly & Bottom Ash	15.00	$/ton		34.9	191,121	162,453
Fuel	47.96	$/ton	Ton	164.9	2,886,710	2,453,704
Subtotal - Operating Costs						**4,588,474**
Maintenance Costs						
Maintenance Labor					552,570	552,570
Maintenance Material					828,855	828,855
Total - Maintenance					1,381,426	**1,381,426**
Admin & Support Labor	25.00	% of O&M Labor			411,455	**411,455**
Total Annual O&M (Sep, 2006 Dollars)						**$ 6,381,354**
Revenue Through Excess Power Sales						(1,668,927)
Avoided Costs for Campus power						(1,619,140)
Cost of Electricity during PFBC plant shutdown						423,984
Total - Power Sales / Avoided Costs						**(2,864,083)**
Total - O&M Costs Less Power Sales / Avoided costs						**$ 3,517,271**

Aesthetic Impacts

The Eastern Illinois University campus is quiet and beautifully landscaped. The buildings, principally brick, are consistent in architecture, and nicely situated.

By nature, power plants include numbers of large structures connected with piping, conveyors, and other elevated and visible members. Coal plants often have open coal piles. However, for a modest increase in cost, many of these features can be made more aesthetically appealing or can be shielded from view. Appendix A provides a discussion of aesthetic treatments that might be considered.

Plan to Provide Educational Opportunity

There are multiple opportunities to use the design, construction, and operation of this PFBC facility as a portion of the educational program for EIU students. This would require the active cooperation of the designers and operators of the cogenerating PFBC plant with the faculty. In addition, there might be added capital costs: for example, for more instrumentation than is normally installed, or for data loggers and other equipment to provide plant operational data that could be better applied for educational purposes.

Appendix A describes some of the potential opportunities that might be exploited for developing educational programs around this project. The costs to implement these would need to be developed. The Appendix indicates that opportunities may exist to tie in the project to portions of the following educational programs:

- College of Sciences / School of Technology
- College of Business & Applied Sciences
- College of Arts and Humanities

CONCLUSIONS AND RECOMMENDATIONS

Technical Readiness, Risks, and Uncertainties

The design of the 11 MWe cogenerating PFBC power plant for Eastern Illinois University is based on a number of technical concepts. Some of these concepts are well proven in commercial practice, others require design and demonstration. The readiness of the technical concepts that underlie the PFBC power plant are discussed below:

Turbomachinery for Air and Gas: The use of individual components for compression and expansion of air and clean combustion gases has an extensive history of application. For the conceptual design modeled herein, components manufactured by Dresser Rand were used to configure a turbomachine that met specified performance parameters to create a Brayton cycle machine.

The cycle parameters were based on optimizations performed in previous studies. These parameters are known to be well within the capabilities of Dresser Rand to manufacture the required machine elements, including axial and centrifugal compressors, hot gas expanders, gearboxes, clutches, etc. Dresser Rand also has the expertise to integrate these machine elements into a single turbomachine, mounted on a common baseplate, with a common lube oil system and controls system.

It is believed that other firms also have the capability to supply a turbomachine to meet the same performance and design conditions. However, Dresser Rand has cooperated in previous conceptual designs, and therefore their components were used here. The turbomachine components required to implement the design presented herein are considered to be fully available, and without risks or uncertainties.

Automatic Extraction Condensing Steam Turbine: This type of machine has an extensive history of application in a wide range of sizes and ratings. The basic principle of operation is the incorporation of a second set of valves in the steam path between the throttle and the condenser. The second set of valves maintains the pressure at a selected extraction point as load varies. Automatic extraction condensing steam turbines are ubiquitous in industrial applications, and are available from many manufacturers. The automatic extraction condensing steam turbine required to implement the design described herein is considered to be fully available, and without risks or uncertainties.

Pressurized Fluidized Bed Combustor and Steam Generation: The principle of pressurized fluid bed combustion combined with steam generation has been demonstrated in a series of commercial plants deployed around the world. Asea Brown Boveri (ABB) designed and built a series of plants designated as the P-200 Commercial Module. Each P-200 module is capable of generation of a nominal 80 MWe (net) or more, depending on the selection of steam cycle design parameters. A larger P-800 Commercial Module has also been constructed and operated at a net output of a nominal 375 MWe. The P-200 and P-800 PFBC technology units use a bubbling bed design.

ABB is now owned by Alstom which has retained the expertise to design the pressurized boiler and its ancillary parts. A special purpose gas turbine that was originally part of the P-200 equipment set has been sold to Siemens, where it continues to be manufactured as a conventional gas or oil fired machine. For the conceptual design described here, the special Siemens gas turbine that is used in the larger commercial PFBC units is here replaced by the turbomachinery described above.

A second approach to pressurized fluidized bed combustion relies on a circulating bed. This concept was explored and developed by Foster Wheeler in a series of prior attempts. This approach has not yet been deployed commercially. In order to implement this report's PFBC concept, either type of bed configuration (bubbling or circulating) may be used. The important requirement is the integration of the pressurized combustion process with steam generation and with the gas turbomachinery.

The PFBC technology required to support the design presented herein is considered to be available in concept, but not in detailed design. A specific design must be executed, built, and tested to support the 11 MWe PFBC that is the subject of this report. The expertise to perform this design is believed to exist in several large corporations, but has not been used to produce actual plants due to commercial considerations. Risks associated with design and development of a PFBC power plant similar to that described herein are considered moderate, and mainly relate to integration of the total design.

Hot Gas Filtration: The ABB bubbling bed concept described above is able to operate without a hot gas filter, instead relying on two stages of cyclones to remove the majority of particulate matter from the gas. The special purpose gas turbine noted above is designed to operate with a gas stream containing fine particulate matter.

The turbomachine concept based on Dresser Rand components requires a gas filter to remove the fine particulate matter. However, using the Dresser Rand components to create a custom designed turbomachine allows a wide range of sizes to be synthesized. The special Siemens gas turbine is only available in two sizes.

Filter designs using arrays of hollow candles (dirty gas inside/clean gas outside or vice versa) have been constructed and tested over the years. Candle materials available for the design presented herein can rely on iron aluminide, with useful service temperatures up to a nominal 1450ºF. Silicon carbide ceramic candle material is available, with service capability up to about 1650ºF. For this report, the iron aluminide is used as the gas turbine temperature is limited to about 1450ºF.

Risks associated with design and development of a candle filter similar to that described herein are considered moderate, and mainly relate to achieving very long candle life, in order to achieve low life cycle costs and forced outage rates.

Recommendations for Additional Study

To proceed with continued evaluation of the cogenerating PFBC power plant for Eastern Illinois University, it is recommended that the following issues be resolved in greater detail, and that the following steps be undertaken:

- EIU will need to balance the relatively high capital cost needed to build a PFBC plant versus the operational economy for steam and power production from low cost coal and opportunity fuels. An assessment of avoided costs, and income from electric sales is needed to establish if the cogenerating PFBC concept has sufficient economic feasibility for their steam and electric needs.
- Alternative investment alternatives exist that could also provide the campus with its steam and power needs using different combinations of technologies. These alternatives need to be weighed against the merits, costs, and potential risks of this cogenerating PFBC concept.
- Optimization of air and steam cycles:
  - The air and steam cycles used herein were selected by use of engineering judgment with reference to previous studies and designs.
  - The optimization needs to focus on reducing the capital cost per net kWe, rather than maximizing thermal efficiency.
  - The capital cost of small coal fired facilities tends to be much higher than for gas fired installations of similar size.
  - As there is now a wide disparity between coal and natural gas (and oil) on a $\$/10^6$ Btu basis, achieving the utmost in thermal efficiency is not as rewarding financially as reducing capital cost.
- Illinois #6 coal is the performance fuel, with nominal properties as presented later, in Exhibit 9. The campus fuel would be run-of-mine coal, which means there is likely to be a wide variation of fuel properties, ash, and moisture percentage throughout the plant life. If the design is to proceed, these variations need to be investigated so the design accommodates the range of variation anticipated.
- Since campus steam and electric demand is likely to grow from current levels, this design provides a reasonable margin over the present campus demand for both steam and electricity. If this project is to proceed, it is recommended that a more thorough assessment be made of the maximum expected demand profiles expected over the 30-year life assumed for the PFBC plant.
- Once the salient parameters for an optimized design are understood, the next step is to develop a revised conceptual design. The revised design parameters are then used by the major vendors of important subsystems and components to develop better cost models to incorporate into the overall cost rollup.
- The next step is likely to require that a test vessel be fabricated to verify performance of the PFBC and its ancillary components (fuel and sorbent injection, ash letdown, bed circulation characteristics, etc.) A test burn, firing the intended fuel and sorbent in a test rig, would probably cost in the vicinity of $100,000.
- If a decision is made to proceed with detailed design and construction, sufficient detailed design should be undertaken to define the specification requirements of the various components so that the respective manufacturers can provide

relatively accurate and firm quotations for the equipment. In order to proceed with this task, it is likely necessary to designate a lead agency or company to be responsible for the complete integration of the various components. The commercial structure of the endeavor needs to be spelled out and understood by all participants. In particular, warranty responsibilities and liabilities must be identified, and accepted by all parties.

- As this will be a first of a kind design in terms of scale and components used, some risk mitigation might be required by public funding as it is unlikely that private capital will sign up for the risks discussed above.
- The best condition existing boiler unit(s) should be maintained in serviceable condition to act as back-up for planned or forced outages of the PFBC unit.
- A source of funding for the project needs to be identified, and the costs of financing established.
- This study provides a reasonable approximation for assessing the general economic budget merit feasibility. However, a more detailed investigation into the value/costs of the electric power are recommended to better define economics. Investigation into the demand charges, demand, and service charges/requirements to leave the grid, the avoided cost value of self generation in reducing campus costs to meeting campus electric demand, establishing the value for power sales to the grid, and estimating the charges needed for backup power will each need to be developed in greater detail.
- A power purchase agreement needs to be established for the sale of electricity in excess of campus needs, and for the purchase of back-up electricity when the PFBC plant is out of service for maintenance or unplanned outages.
- Work to begin the licensing process should begin early in the project development.
- Public information and awareness campaign will need to begin so a supportive community can become favorably involved in embracing this clean coal power technology at the campus.
- A review should be made of the make-up water quality.

REFERENCES

The references used to prepare this report include the following:

[1] Burkett, J. “Required Environmental Goals for PFBC.” 2006 Coal Utilization Conference. Clearwater Florida. 2006.

[2] WorleyParsons Group Inc. and National Energy Technology Laboratory. Appendix A: STUDY DETAILS – Feasibility of a Pressurized Fluidized Bed Combustor Cogenerating Power Plant for Eastern Illinois University. WorleyParsons Encompass Tag No. PCS-ICCI-1-LI-011-0002. April, 2007.

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