3.6 Piping & Electrical

3.6.1 Piping Systems; Approximate Flows & Conditions:

Cold Reheat Steam Supply to & from HRSG/Ft Martin

This line will carry 10,000 lb/hr 850-950psig/600-650°F superheated steam approximately 1,800 ft. to the GPIF for startup, or up to 90,000 lb/hr steam at 850-950psig/600-650°F to the Ft. Martin Unit No. 2's No. 7 feed-water heater. It shall be ground supported on pre-fabricated concrete supports (sunk below frost line) within easy reach from the ground (approximately 3 ft. above grade).

Condensate & Make-up Feed-water from Ft. Martin (Includes Rental Equipment System)

This line will carry up to 100,000 lb/hr (222 gpm) of 150-200 psig, 110-170°F, condensate approximately 1,000 ft. from Ft. Martin to the GPIF. It shall be ground supported on pre-fabricated concrete supports (sunk below frost line) within easy reach from the ground (approximately 3 ft. above grade) and anchored in shallow drilled pier foundations.

Cooling Water to Gasifier Vessel

This line will carry approximately 2,000 gpm of cooling water from the Ft. Martin cooling tower sump approximately 500 ft. to the PyGas™ gasifier vessel and then back to the cooling tower via a common circulating cooling water header. It shall be ground supported on pre-fabricated concrete supports (sunk below frost line) within easy reach from the ground (approximately 3 ft. above grade).

Cooling Water to Air Compressor Intercoolers

This line will carry cooling water from the Ft. Martin cooling tower sump approximately 500 ft. to the air compressor intercoolers and then back to the cooling tower via a common circulating cooling water header. It shall be ground supported on pre-fabricated concrete supports (sunk below frost line) within easy reach from the ground (approximately 3 ft. above grade) and anchored in shallow drilled pier foundations.

Process Water to Hot Gas Outlet Temperature Control

This line will carry 20 gpm of cooling water from the Ft. Martin service water interface approximately 1,200 ft. to the hot gas outlet from the PyGas™ gasifer via a process water line common to it and the wet oxidation system. It shall be ground supported on pre-fabricated concrete supports (sunk below frost line) within easy reach from the ground (approximately 3 ft. above grade) and anchored in shallow drilled pier foundations.

Process Water to Wet Oxidation System Makeup

This line will carry 2 gpm of makeup water from the Ft. Martin filtered process water interface approximately 1,200 ft. to the wet oxidation system from the PyGas™ gasifier via a process water line common to it and the hot gas outlet temperature control system. It shall be ground supported on pre-fabricated concrete supports (sunk below frost line) within easy reach from the ground (approximately 3 ft. above grade) and anchored in shallow drilled pier foundations.

Potable Water to Laboratory, Lavatory & Showers

A 1-inch PVC gravity fed at approximately 120 psig line will be tied into the existing Ft. Martin 3-inch PVC line such that 1-GPM can be bled during off-use hours to a 5,000 gallon storage tank on the GPIF site for test facility use. It shall be ground supported on pre-fabricated concrete supports (sunk below frost line) within easy reach from the ground (approximately 3 ft. above grade) and anchored in shallow drilled pier foundations.

Fire Protection Around GPIF Facility

The primary firefighting water source will be from the existing two lagoons at the Ft. Martin site and shall be independent of the existing Ft. Martin firefighting water system. Lagoon water will be piped over the existing dikes to serve the GPIF's needs using horizontal shaft self-priming pumps with diesel backup.

A backup line will tie into the GPIF primary line and be tied into the existing Ft. Martin firefighting system at a point between their existing cooling tower and lagoon located approximately 200 ft from the GPIF. Up to 1,200 gpm at 85 psig is available from this source, however, the fire protection line should be sized to meet code requirements for the GPIF.

Rain Water & Spill Sump to Ft. Martin Water Treatment System

The stormwater holding sump located adjacent to the coal storage area will be provided with submersible solids handling capable, wastewater pumps. The pumps and forcemain will be sized for a maximum of 25 GPM, and shall carry the stormwater runoff to the Fort Martin wastewater treatment tank approximately 1200 feet away. The force main shall be routed below ground to the utility bridge. It will then be carried above ground, along the proposed utility sleepers as shown on the site plans to treatment.

Nitrogen Inerting to Air Compressor Intake

This line will convey low pressure nitrogen from storage tanks approximately 150 ft. to the air compressor intakes via a conditioning system for emergency system inerting.

Nitrogen from Tank Farm to Shaft Seals

This line will convey nitrogen to approximately 7 shaft seals all located at the PyGas™ gasifier within 150 ft. of the nitrogen tank farm.

Air Compressor to Dense Phase Pressurization Locks

This 4 inch diameter line will convey compressed air from the air compressor room to the vicinity of the gasifier.

Dense Phase Transfer to Pyrolyzer

This 4 inch diameter line will convey compressed air from the pressure locks to the pyrolyzer section of the PyGas™ gasifier.

HRSG to Pyrolyzer Steam Injection

This 1/2 inch diameter line will convey steam from the HRSG approximately 30 ft. to the pyrolyzer section of the PyGas™ gasifier.

Compressor to Gasifier Top Freeboard Compressed Air

This 4 inch diameter line will convey compressed air from the air compressor room approximately 50 ft. to the top of the PyGas™ gasifier.

HRSG to Gasifier Top Freeboard Steam

This 1/2 inch diameter line will convey steam from the HRSG approximately 30 ft. to the top of the PyGas™ gasifier.

Undergrate Compressed Air to Three Grate Zones

This 4 inch diameter line will convey compressed air from the air compressor room approximately 50 ft. to the under-grate section of the PyGas™ gasifier.

HRSG to Undergrate Steam to Three Grate Zones

This 3 inch diameter line will convey steam from the HRSG approximately 30 ft. to the undergrate section of the PyGas™ gasifier.

Hot Raw Coal Gas from Gasifier to HRSG

This 4-inch diameter line will convey hot raw low Btu coal gas at 600 psig/1400°F from the outlet of the PyGas™ gasifier approximately 40 ft. to the HRSG burner by way of the hot cyclone.

Hot Cyclone Solid Waste Dense Phase Transfer System

This 1-inch line will convey solid waste granules from the hot cyclone outlet hopper approximately 60 ft. to the ash silo.

HRSG to Gasifier Ash Depressurization Lock Hopper Steam Admission

This 1-incl line will allow 600 psig saturated steam admission to fill the ash depressurization lock from the HRSG approximately 40 ft. away.

Gasifier Ash Depressurization Lock Hopper Steam Vent to HRSG

This 1-incl line will allow 600 psig saturated steam to vent from the ash depressurization lock to the HRSG firing chamber approximately 40 ft. away.

Coal Crusher Vent Air to Filter

This 4-inch low pressure line (may even be round duct) vents dusty air in the vicinity of the coal crusher to its vent filter.

No. 2 Oil Main Line

This 3-inch line feeds light oil from the fuel oil main tie at the Ft. Martin interface point at Unit #2 approximately 1800 ft to the GPIF.

No. 2 Oil Coal Dryer

This 1-inch line feeds light oil from the fuel oil main tie at the GPIF approximately 100 ft from the fuel oil to the coal dryer burner.

No. 2 Oil Pyrolyzer Preheat

This 1-inch line feeds light oil from the fuel oil main tie at the GPIF approximately 100 ft to the pyrolyzer preheat burner located at the ash hopper level of the PyGas™ gasifier.

No. 2 Oil HRSG Ignitor & Support Flame

This 2-inch line feeds light oil from the fuel oil main tie at the GPIF approximately 80 ft to the HRSG burner.

Ash Silo Outlet Water Conditioning

This 1/2-inch line feeds the ash conditioning screw to minimize dusting under the ash silo from the filtered process water circulating header located approximately 50 ft. away.

Ash Silo Vent Air to Filter

This 4-inch low pressure line (may even be round duct) vents dusty air inside the ash silo to its vent filter located atop the silo.

Wet Oxidation System Slurry Transfer

This 3/4-inch low pressure line feeds filtered process water from the process water header located approximately 30 ft. away, to the wet oxidation system makeup tank.

Wet Oxidation System Vacuum Pump Vent to Atmosphere

This low pressure 3/4-inch vent line to atmosphere is approximately 20 ft. long and is located in the vicinity of the wet oxidation system on the third floor of the GPIF building.

HRSG Flue Gas Duct to Ft. Martin

This 42 inch diameter spiral wound duct will convey flue gas approximately 1,200 ft. from the fired HRSG outlet, via an induced draft booster fan, to the Ft. Martin Unit. No. 2 electrostatic precipitator inlet breeching. It shall be top of ground supported on pre-fabricated concrete supports within easy reach from the ground (approximately 3 ft. above grade), and protected by screen for personnel protection and insulated so as to maintain gas above dew point.

Instrument Dry Compressed Air

This 1/2-inch line is to provide dry compressed air from the compressor room dryers approximately 50 ft. to various instruments located in the vicinity of the PyGas™ coal gasifier reactor vessel.

HRSG Steam Sampling

This 1/4-inch line for HRSG steam sampling runs from the HRSG steam drum with a valved branch at the superheater outlet to the laboratory room located approximately 80 ft. away on the second floor.

CEM Sampling

This 1/4-inch line is located in the HRSG outlet flue gas line to the Ft. Martin Unit No. 2 electrostatic precipitator inlet breeching approximately 10-diameters downstream in a straight run of flue gas pipe (or round duct). The approximately length of line involved is 100 ft. from the sampling point in the flue gas duct to the GPIF laboratory room.

PyGas™ Reactor Products Sampling

This 1/4-inch line is located at several sampling points of the PyGas™ gasifier, and runs approximately 80 ft. to the GPIF laboratory room.

NH3 Monitor Sampling

This 1/4-inch line is located at several sampling points of the PyGas™ gasifier, and runs approximately 80 ft. to the GPIF laboratory room. It is similar but separate from the products sampling line.

3.6.2 Electrical System

General Requirements

Load Profile - New Gasification Plant

4160 V. Load	2.85 MVA.
Total Load	3.4 MVA.

Project Concept

The Project concept is to supply existing Fort Martin Generating Station with steam from the proposed gasification plant. This plant is to be a stand alone satellite facility to be located in the vicinity of the generating station. Utility scope of work ends at the 1200 amp 11.5 kV breaker inside the power station.

Codes and Standards

Except where noted, all electrical systems shall be designed, fabricated and installed in accordance with the latest edition of the National Electrical Code, and applicable ANSI, ICEA, NEMA, NESC, IEEE Standards as defined in the RFP (exceptions taken will be defined). Components that are UL listed and labeled shall be provided if required by local authorities.

Electrical Equipment

Selection and design of all electrical components and systems shall be in accordance with the applicable codes and standards. Reliability of operation shall be the primary consideration in the facility design. The Preliminary single line diagram will serve as a typical basis of supply (CRSS Drawing SK-E-001).

The electrical equipment shall include the following, located in the facility building:

MEDIUM VOLTAGE SWITCH GEAR HV-1
LOW VOLTAGE SWITCHGEAR LVSWG-1
175O HP STARTER WYE DELTA
2 (400HP) COMPESSOR WYE DELTA
1200A NON-SEGREGATED BUS
MCC-001-GPIF
STATION BATTERY AND CHARGERS
"UPS" UNINTERRUPTABLE POWER SUPPLY

15 kV Pole Line

A 15 kV pole line feeder with parallel overhead ACSR conductors will interconnect the GPIF with the existing facility's 11.5 kV breaker. This feeder line will be used to cold start the GPIF.

Plant's Primary Transformer

The plant's primary transformer "T1" will be 5 MVA, outdoor, oil filled, 11.5 kV delta to 4.16 kV resistance-grounded wye, standard impedance, equipped with special winding and cooling fans to permit temporary overloading and allow for future growth.

BUS DUCT.

The bus ducts shall be 5 kV, 1200 A, 3-phase, 3-wire plus ground, non-segregated phase type, rated to accommodate maximum design operating voltage. The rated momentary current will be based on the maximum three-phase fault current to which the bus can be subjected.

Coal Gasification Electric Power System (parasitic loads)

The electrical power system will perform the following functions:

Provide a reliable source of electrical power for plant auxiliaries during all operating conditions.

Provide rapid isolation of any faulted equipment without unnecessary loss of supply to other equipment.

Provide satisfactory motor starting and bus voltage regulation.

Medium Voltage Distribution Switchgear HVSWG-1
(4.16 KV, Vacuum Type, 350 MVA).

The circuit breaker and metering portions of the medium voltage switchgear will be a non-drawout, metal-clad, dead front, with each breaker cubicle isolated from the adjacent cubicle by a metal barrier. The interrupting ratings will be selected in accordance with ANSI Standard C37.010 making full allowances for asymmetrical symmetrical current ratios. Incoming breaker and internal bus continuous current ratings will be chosen to be greater than the maximum expected loading.

Medium Voltage Motor Controllers:

Motor controllers portion of the medium voltage switchgear will be of the draw-out full-voltage across-the-line or reduced vacuum type (as indicated on the single line diagram), rated a minimum of 400 MVA, double-stacked wherever possible.

The controller and the bus will be adequately rated for the voltage class, the continuous current and the available short circuit level.

The protective fuses will be ANSI Class "R" for motor starting duty, and class "E" for transformer feeder duty. Single-phase protection will be provided to open contactors whenever any fuse blows.

Overload, under-voltage, single-phasing and ground fault protection will be provided.

Control voltage will be 120 V AC.

Each controller will have an ammeter and an ammeter switch.

All motors shall have motor circuit protection.

The switchgear lineup will include provisions for future bus extension on one end.

Switchgear rooms will be mechanically cooled and pressurized with filtered air to prevent the entrance of dust and dirt. Switchgear rooms will have at least two exits to assure safe personnel egress.

Secondary Unit Substations.

The 480 volt systems will be 4-wire, 3-phase, wye connected, and solidly grounded at the transformer neutral.

Transformer "T2" shall be an indoor dry-type, cast-coil, standard impedance, rated 1000 kVA.

For ease of maintenance, the 480 volt switchgear will be located indoors in pressurized switchgear rooms or other clean areas. Cast-coil, dry type transformers will be used indoors.

Transformer cooling fans will be provided to allow for future load growth and permit temporary overloading. The unit substations will be physically arranged to allow future switchgear additions, and to allow for transformer removal and replacement.

Main circuit breakers will be fully-rated, manually-operated withdrawable, air-break, stored energy spring operated, dead-front type, complete with solid-state overcurrent and ground fault trip devices.

Bus shall be fully rated to supply a continuous load of 1600 A.

Loads supplied directly from unit substations will include motor control centers, and other 480 volt loads larger than 100 amperes.

Motor Control Centers and AC Distribution Panels.

MCC's will have NEMA Type 1A enclosures with gaskets on doors and filler plates, or NEMA Type 12 in Water Treatment Area. Locations will be chosen with care to avoid damp, dirty, or hot areas and to allow adequate front and rear access.

Motor control centers will utilize standard modules factory assembled in suitable shipping lengths.

Motor control centers will be rated 65,000 A.S.C. and have NEMA Class I, Type B wiring rated 600 volts for 480 volt service. The upper limit of motor size supplied from MCC starters will be 200 hp where application is continuous duty with infrequent starting. Larger motors may be controlled by MCC starters where the application involves intermittent duty. Dual mounted molded case circuit breaker feeder units will also be provided in MCC's to supply 480 volt unit-related loads that do not require remote control.

Bus shall be fully rated to supply a continuous load as shown on the drawings and specifications.

Each fully rated combination starter unit will be complete with a molded case circuit breaker having adjustable magnetic trips only, magnetic contactor, three bimetallic overloads, auxiliary contacts, control power transformer, and control wiring terminal block. Control power transformers will be adequately sized to power the motor starter as well as the auxiliary control devices. Starter controls will be 120 volt AC with a coil seal-in contact.

The breakers will have 65,000 A interrupting capacity adequate for the available short circuit current.

All motor starters will be of the same manufacturer to ensure interchangeability of parts and to minimize stocking of spare parts. In addition, circuit breaker distribution panels will be provided at selected locations, as required, to serve small loads.

A minimum of 20% fully equipped space shall be provided in the motor control center for future additions.

DC Battery Powered Systems (breaker control).

125 VDC battery system with an energy storage capacity of four (4) hour minimum will include a lead-calcium, solid state rectifier-battery chargers, and main DC distribution panels.

The battery capacities will be adequate to supply all associated loads for the required sequence, duration, and combinations that occur when each breaker unit must be operated with no other power sources available.

The battery nominal voltage, float voltage and end of discharge voltage will allow operation over a voltage range acceptable to standard NEMA equipment with only occasional need for recharging.

The battery chargers will be sized to supply those DC loads that exist continuously during normal unit operation while simultaneously recharging a fully discharged battery. The maximum battery recharge period will be 12 hours. Chargers must be capable of operation without the battery.

A circuit breaker DC distribution panel will be provided adjacent to the batteries to minimize the length and maximize the security of the battery feeder cables. The circuit breakers will have thermal-magnetic overload trips, except for circuits feeding emergency auxiliary motors, which will have magnetic trips only.

DC battery powered emergency lighting system shall be furnished similar to the above in all respects.

Grounding System.

In general, grounding system will be in accordance with the National Electrical Code and IEEE recommendations.

Instrument Grounding System.

A separate insulated grounding system will be provided for the computer and other noise sensitive electronic equipment. This will be a radial system, without loops and will be connected to the plant ground grid at one point only.

Instrument cable shields will be grounded at the load side only, leaving the sensor end ungrounded and insulated with the exception of thermocouples which are to be grounded at the instrument end.

Lightning Protection.

The lightning protection system will be designed in accordance with the National Fire Protection Association Lightning Protection Code (NFPA 78) Class I or Class II systems, UL96A, the National Electrical Code, IEEE Standards and the Lightning Protection Institute - Installation Code (LPI-175).

Electrical Heat Tracing.

Freeze protection and process heating systems will be provided for outdoor pipes, pumps, vessels and instrument sensing lines requiring process heating or freeze protection. The freeze protection system will automatically operate whenever the ambient falls below 40°F and will provide sufficient heat to prevent water freezing when the ambient temperature falls to 5°F less than the lowest ambient temperature recorded at the site. Control and monitoring systems for freeze protection will be centralized.

Lighting Systems.

Plant lighting will consist of normal lighting and self contained DC operated emergency lights.

Normal lighting will provide illumination during normal operating conditions.

Facility indoor lighting distribution will be three-phase, four-wire. A 480/277 volt system will be used. Facility outdoor lighting distribution will be 480 volt, three-phase, three-wire with phase-to-phase connected loads.

Indoor lighting circuits will be distributed through three-phase. four-wire lighting panels, which will be located centered to and near their respective loads to minimize voltage drops.

Distribution will be designed so that failure of any single lighting panel will not totally black out any floor or single large area.

Lighting equipment selection will be based on the requirements of specific areas. Incandescent, fluorescent, and high pressure sodium sources with appropriate luminaries will be used depending on the application and the needs of each location. High pressure sodium lighting will be used for outdoor installations.

Generally, the illumination levels for facility areas will be those recommended by the Illuminating Engineering Society.

Lighting circuits will be switched at their distribution panels. Rooms and small buildings will have light switches at each doorway. Outdoor lighting will be photoelectrically controlled with provisions for manual override.

Loop road lighting will be in accordance with recommendations of the National Illuminating Engineers Society. These fixtures shall be suspended from building structural walls or members.

Emergency AC and lighting system will be provided for purposes of personnel egress and continuation of critical activities during emergency conditions.

Design illumination levels for egress lighting will be those required by applicable Federal, state, or local fire codes.

Communication Systems.

Telephones will be provided in the control room, in the offices and electrical switchgear room.

A facility paging and two-party communication system, complete with amplifying equipment, handset stations and speakers will be provided.

UPS System.

UPS System shall be 30 KVA with two 200 A, 3 ph., 4W outputs plus isolated ground for process controls and system architecture power supplies, with 15 minute ride-through and lead-acid battery racks as required.

Emergency Process Equipment.

The compressed air, auxiliary boiler and gasifier jacket cooling water feed systems shall be capable of automatic switchover to the auxiliary DC power source in the event of AC power source failure for equipment protection against overheating.

Life Safety System (fire alarms).

The zone panel shall be stand alone and report to a central command station located in the Engineer's Office. Total number of zones shall be at least 8 active with four spares.

Fire Protection System.

The GPIF fire protection system shall be tied into the existing Ft Martin lagoon.

The existing 460 volt electric source from Fort Martin Generating Station shall be utilized to power a dedicated fire pump serving the GPIF area.

3.7 Provisions for Disposal of Fuel Gas

A GPIF on-site fired Heat Recovery Steam Generator (HRSG) shall be provided to both incinerate the coal gas produced during testing and to generate useful steam for Ft. Martin use from the available heat.

The HRSG will be provided with an "NFPA Class 1" continuous ignitor capable of providing steam for startup, and coal gas firing ignition stability, continuously if necessary.

The flue gas produced from the combustion of coal fuel gas and No. 2 oil (or natural gas) ignition support will then be boosted by an induced draft fan and ducted to the inlet of the existing Ft. Martin electrostatic precipitator.

3.8 Emissions Control System

Continuous Emission Monitoring System (CEM)

Emissions monitoring equipment will be provided on the HRSG flue gas outlet to measure CO, NO_X, and SO_2. These measurements are not required for Federal and State emissions requirements since the HRSG emissions are combined with the Ft. Martin Station flue gas prior to the Ft. Martin emissions monitoring equipment. These signals will be indicated on the DCS system for information and historical data collection. The system will not require certification.

3.9 Process Steam Characterization

The steam conditions required for transport back to Ft. Martin are 850-950psig/600-650°F superheated steam.

The process steam conditions required for injection into the GPIF gasifier are up to 10,000 lb/hr at only 650 psig/500°F.

Because of the apparent high cost of boiler feed make-up water to the HRSG, it may be more economical to install a second steam loop to produce a lower quality steam to be used exclusively as feed to the gasifier.

The Ft. Martin specifications for the GPIF return steam requires a maximum conductivity of 0.1 micromhos, a requirement for very high-pressure steam turbines normally resulting in expensive water treatment.

The process steam for the GPIF gasifier need not be that "clean" since it is only injected into the dirty gasification process.

The water treatment associated with making a lower grade steam is only a relatively inexpensive zeolite type water softener.

To effect such a dual steam conditions output, a secondary steam loop would be required, consisting of a small steam drum, feed pump, dearator, and associated controls. To properly evaluate these schemes, the additional capital cost of this additional equipment should be compared with the make-up condensate water cost from Ft. Martin during that Task 6 detailed design.

3.10 Process Control and Monitoring System

General

The Gasifier Product Improvement Facility will be equipped with a microprocessor based Distributed Control System for the primary control of the process from a central control room. The system will provide CRT based operator interface terminals for the data acquisition, monitoring, reporting, and control functions required to safely operate the process equipment. These terminals will be located in the operator control room. Various subsystems (such as the HRSG flame safety system) will be controlled by equipment vendor supplied Programmable Logic Controllers (PLC's) or other dedicated function control systems. These PLC controlled subsystems will have interfaces to the DCS so that the DCS is the operator's primary window of information to the process. Some startup and infrequent operations and monitoring will require attention local at the process. Field instrumentation and control devices will be installed to provide the information to the DCS/PLC's and to receive signals from the DCS/PLC's to regulate and control the process. This type control system provides flexibility for making control strategy modifications due to the programmable nature of the equipment.

Process Systems to be Controlled

1. Coal and Limestone Storage

The coal reclaim and storage and the limestone storage which consists of coal conveyors, storage bins, and dust collectors will have local controls independent of the DCS system. This will allow the limestone unloading and coal reclaiming to be operated by personnel at the equipment.

2. Coal and Limestone Feed System

The coal and limestone feed systems from the storage bins to the gasifier will be operated and controlled by the DCS. Any vendor supplied control subsystems will be integrated into the overall control system to the extent that the subsystem can be started and stopped from the DCS and the status indicated on the DCS.

3. Gasifier

The gasifier system including the air and steam flows to the gasifier and the cyclone will be controlled from the DCS. The flame safety system logic for the oil fired startup burner will be implemented in a PLC which will be interfaced to the DCS for the purpose of monitoring and controlling the safe firing of the oil. The gasifier system will include a gas analyzer to monitor the concentration of CO, CO_2, CH_4, and H_2.

4. Coal Gas Combustion in the HRSG

Regulatory control of the fuel flows, steam and water systems, and air and flue gas systems will be from the DCS. The coal gas and fuel oil burners are expected to be equipped with a vendor supplied PLC based flame safety system containing a complete package of instruments, safety shutoff valves, flame scanners and other required control devices to comply with the NFPA requirements for coal fired burners. The flame safety system will be connected to the DCS via a digital interface or hardwired connections and will be controlled and monitored from the CRT operator stations. Interlocks and permissives between this system and the Ft. Martin utility boiler's flame safety system will be provided. These will be hardwired signals between the two systems. Remote indication of coal gas combustion and steam generation status will be provided by a DCS connected terminal to be located in the existing Fort Martin Station control room. The sootblowers on the HRSG will be controlled from an independent vendor supplied control system.

5. Air Compressor System

The air compressor will have a vendor supplied local control system for the control of the inlet valve, bypass valve, and the motors. Local monitoring and indication will also be provided. A single alarm contact will be wired to the DCS to indicate the presence of an alarm condition at the compressor.

6. Flare Stack System

It is anticipated that the flare stack will have a vendor supplied control package for controlling and monitoring the flare. Connections will be provided so that the DCS system will have the capability to start-stop the flare and monitor the status.

7. Deaerator and Boiler Feed Pump

The feedwater system including the deaeator and the feedwater pump will be controlled and monitored from the DCS.

8. Miscellaneous Distribution Systems

The fuel oil distribution system, compressed air distribution system, auxiliary water distribution system, steam distribution system, waste water distribution system, and the solids waste treatment system will all be operated and controlled from the DCS.

9. Nitrogen Vaporization System

The nitrogen system will have a vendor supplied local control system.

DCS System Description -- See Figure 16

The DCS will include dynamic controllers, I/O racks, communication devices, and operator stations. The operator stations will have color CRT's and keyboards which will be programmed with color graphic displays and operator functions.

The DCS controllers will be configured to implement the GPIF control strategies using the DCS vendor supplied algorithms. This configuration will reside in non-volatile or battery backed memory so that the configuration will be retained on a power failure. Redundancy will be provided for power supplies, controller files, and DCS communication data highways to minimize the effect of single component or module failures. If the primary control processor were to fail, the secondary

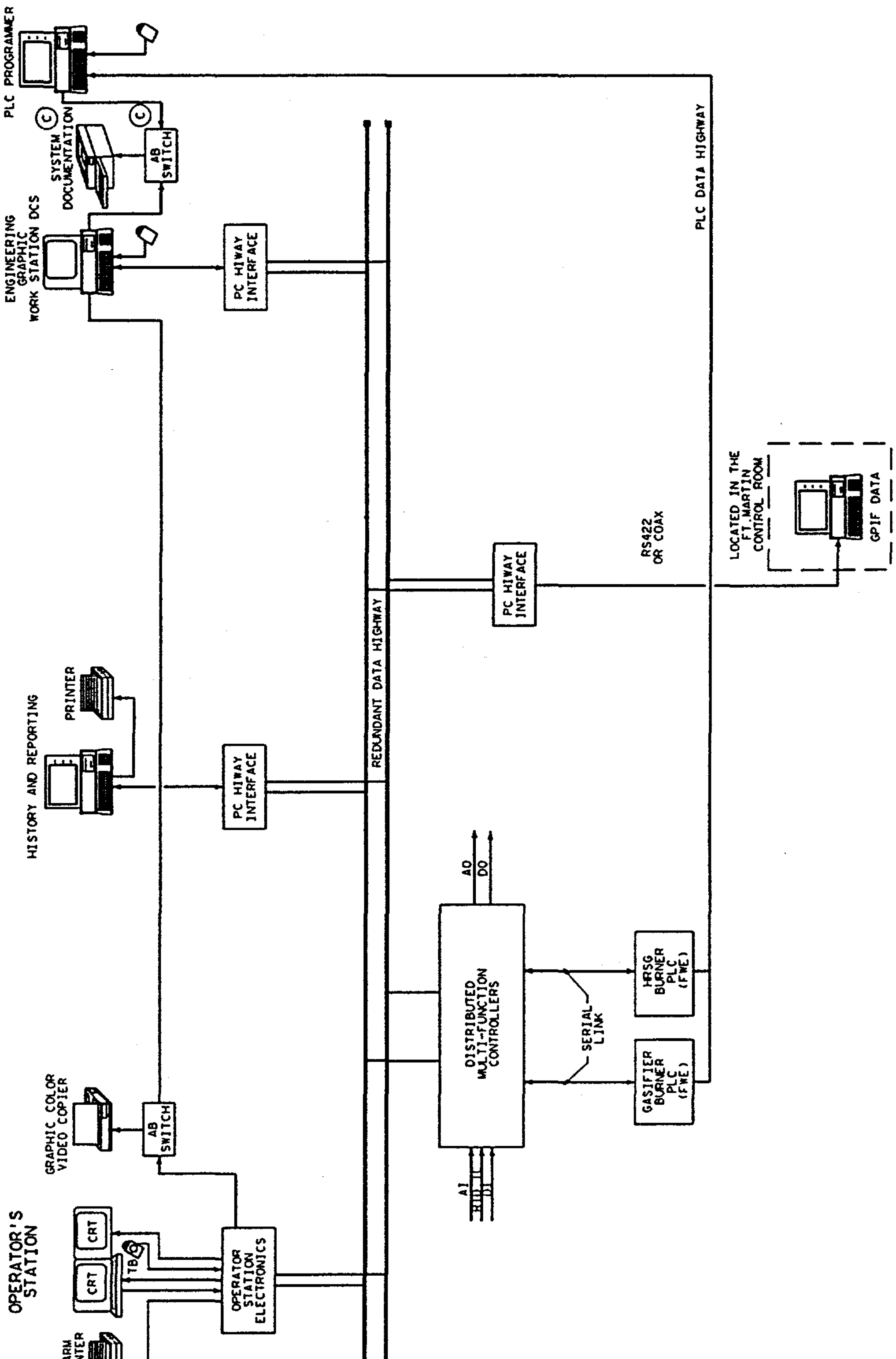

Figure 16
System Controls & Communications

processor operating in the hot standby mode would assume bumpless control of the process to keep the process under uninterrupted automatic control from the DCS system.

There will be communications to the PLC systems through digital serial interfaces to the DCS. This will allow selected operation and monitoring of the PLC controlled processes from the DCS.

The DCS will collect process information for trending displays on the operator stations and for historical data collection and storage.

A PC based display station will be connected to the DCS data highway and located in the Ft. Martin control room to provide information to the Ft. Martin personnel concerning the operating status of the GPIF.

An engineering function station will allow personnel to configure the operator consoles and the controllers. The software package will enable the engineer to design, configure, monitor, trend, tune, modify and document process activities. Graphic symbols and function codes will be used to build the control strategies on the screen. The engineering station will be used to initially implement the configuration, to de-bug and startup during the commissioning stage and to maintain, troubleshoot, and re-configure the system as required once the facility is operational.

The DCS will be field maintainable and configurable by the Owner's personnel after appropriate training.

The following DCS equipment/functions will be provided:

1. One operator station with two CRT's
2. One engineering station (PC based)
3. Historical Data Collection unit
4. One operator station (PC based) to be located in the Ft. Martin control room
5. Alarm and graphics printers with capability to print from operator or engineer station.
6. DCS rack cabinets containing controllers, power supplies, process I/O, and communication interfaces to the PLC's.

Our preliminary evaluation of the system control requirements indicates that the DCS should be able to support (approximately) the following quantity of I/O:

Table 28

Analog Inputs (TC's, RTD's, 4-20mA)	313
Analog Outputs (4-20 mA)	107
Digital Inputs	263
Digital Outputs	137

PLC System Description

Certain process equipment (such as the HRSG burners) will be supplied with PLC based controls. The various PLC systems will be connected to a common communication highway. A PC with programming software will be supplied for troubleshooting and maintaining the PLC programming. A printer will be supplied for printing the ladders and documentation.

Control Room Operator Panel

A control panel will be installed in the control room for equipment and functions that are not consistent with a DCS interface because of code requirements or accepted engineering practices. This will include hardwired safety trip functions (such as boiler trip buttons) and dedicated indications (such as HRSG drum level). The dedicated sootblower controls may be in this panel.
The DCS will be field maintainable and configurable by the owners personnel after appropriate training.

Conceptualized Scope of Work

A. The Gasifier Product Improvement Facility will be equipped with microprocessor based Distributed Digital Control (DCS), Programmable Logic Controllers (PLC), and Instrumentation System. This type of equipment provides a high level of reliability and availability. Because of the experimental nature of this facility requiring higher visibility for operating and testing personal and multiple control strategies where the exact process characteristics are unclear or require special attention, certain added capacity is provided in Controllers, Process I/O, Data Storage and Reporting. The capability to easily make changes in control strategy and displays is enhanced by the separate engineers work station.

The DCS Communications (Data Highway) and controller power supplies will, because of their vulnerability, will be redundant.

The primary operating position will be in the central control room from the DCS Dual CRT/KB Operation Station. (See referenced diagram) The DCS will integrate the subsystem controls providing this common interface. A second position, which in normal operation is used by the testing personal, provides for an assistant to operate during start-ups, shutdown, and during process upsets. It also provides a back-up operator interface. A panel containing certain hardwired trip and safety functions will also be located in the Control Room. Some start-up and infrequent operations will require attention local to the process.

The process systems are controlled and/or interfaced by partitioning them into logical functional groupings which fit conveniently into each DCS Controller's capability. The system is divided into four (4) groups.

1. Coal and Limestone handling, compressed air and ash systems.

2. Dense phase injection, coal gasification, and flare ignition.

3. Coal gas clean-up system and utilities..

4. Heat recovery steam generator and steam, water and electrical distribution systems.

In addition to these major partitions certain control subsystems will be specified and furnished with process equipment. They will be interfaced to the appropriate DCS Controller by communication links or I/O wiring. There will be four (4) such subsystems:

1. Coal dense phase pressurization system.
2. Multi-stage process air compressor system
3. Gasifier starting burner management
4. HRSG support burner management

A DCS communications will be established with the Fort Martin Power Plant to provide certain signals specified by Fort Martin. A terminal will be provided to be placed in the Fort Martin Control Room on which certain configured displays may be invoked via a keyboard.

B. Control Room Operating Equipment:

1. Operator Station - Dual CRT with keyboard, trackball and alarm printer.
2. Test Operation Station - Same as Operator Station. (Start-up/back-up Operator Station).
3. Control Panel - Special instruments and safety trip functions hardwired.
4. Sequence of Event Recorder Operator Station based with printer or part of the Logging station.
5. Logging Station - PC or Operator Station based (may be same as event recorder)
6. Color Video Graphics Printer with switch to print from operator, testing, and engineer station
7. Process Data Historian - PC or special processor including on line storage and removable archive media.

C. Rack Area (Process I/O) adjacent to Operating area will include the following.

1. DCS Engineer Work Station - PC with mouse and laser printer.
2. PLC Programmers Terminal - PC with mouse and switch for laser printer.

3. DCS rack cabinets containing controllers, communication links, interfaces to subsystems and Process I/O, including sequence of event special DCS input hardware or separate processor linked to a controller. Some I/O may be remote mounted in MCC rooms.

4. PLC CPU and communication link cabinets of the subsystems furnished with equipment. Some or all PLC I/O may be in MCC rooms or local in skid mounted cabinets.

D. The Instrument List (See References) identifies all estimated process measurement instruments, primary and final elements individually provided. In addition instruments and field switches furnished with equipment as well as subsystems with only a few interfaces signals will be connected to the DCS Process I/O.

For detailed multi-loop controller and I/O estimates see DCS Specification (See References).

E. Process Systems to be Controlled or Integrated

1. Coal/Limestone Loading System

Coal and Limestone Loading System which includes coal and pebble limestone bunkers, gravimetric feeders, a common belt conveyor with the corresponding drives will be operated and controlled by the DCS.

2. Compressed Air and Instrument Air System
(From Process Air Compressors)

These systems which include centrifugal and displacement type compressors, filters, dryers, and pressure regulators will be controlled by a PLC control subsystem via remote I/O rack with some measurements input directly to DCS I/O.

3. Dense Phase Coal Pressurization System.

This system from the outlet of the silo including the two stage pressure pots with fluidizing will have a PLC based subsystem and all rotary and other valves, switches etc. to control the process. DCS interface will be to the Gasifier System Controller.

4. Coal Gasifier System

The overall coal gasifier system, including the gasifier itself, coal feeding, air and steam supplies to the gasifier and coal gas system with the primary cyclone and flare, will be controlled from the DCS via a dedicated processor (controller).

In order to monitor and control the position and intensity of the gasification zone in the coal gasifier, we are proposing to install two (2) infrared (IR) monitors (scanners) on the sides and top of the gasifier. Each of these instruments will measure two parameters:

intensity and frequency of the IR radiation, which, as we expect, will characterize the intensity and position of the zone of max heat generation. These parameter measurements will allow the operators, during the initial testing and commissioning period, to establish patterns of normal operation and to recognize patterns of abnormal situations. By applying methods of pattern recognition, IR monitors in combination with temperature measurements and gas analyzers will allow development of methods of positioning of the gasification zone and of optimizing the overall gasification process. Nuclear level points or strip will be employed to determine bed height.

The gasifier system will also include a multipoint gas analyzer system to continuously monitor concentration of $H2S$, CO, CH_4, CO_2, H_2, NH_3/HCN samples will also be taken to measure alkali, toxic, metals, tar, and the gas HHV at cyclone output and within the process area. The gas analyzers will be located in the common sampling room.

5. Hot Gas Clean-up Systems

   Control requirements for these systems include a substantial number of control functions, mostly sequential logic operations. These system ill be controlled directly by DCS.

   The HGCU will also be served by the multipoint gas analyzer system to continuously monitor concentration of the above gaseous components.

6. Ash Handling System

   Bottom Ash Removal, Handling and Storage System will be controlled with the DCS.

7. Coal Gas Combustion in the HRSG.

   The coal gas burners are expected to be equipped with a vendor supplied (PLC-based) burner management system (BMS) containing complete package of instruments, valves, flame scanners, etc., to comply with the NFPA recommendations for coal-fired burners. The BMS will be connected to the DCS via control link or hardwired connections and will be controlled from the CRT operator stations. Interlocks and permissive consistent with the safety shutdown philosophy of the existing Fort Martin Station utility boiler's burner management system will be provided. Remote indication of coal gas combustion and steam generation status will be provided and located in the existing Fort Martin Station utility control room.

E. Continuous Emissions Monitoring System (CEMS) will include stack analyzers to continuously monitor HRSG Flue Gas for NO_x, SO_2, O_2, CO, H_2S and Opacity. The CEMS will be located on the exhaust breaching and in the sampling room. The CEMS I/O will be wired to the DCS.

II. Assumptions

A. Since the HRSG flue gas is directed to the Fort Martin No. 2 Unit precipitator this project does not require a full Continuous Emission Monitoring System (CEMS) with the data storage, and reports required by the EPA. The CEMS measurements and calculations with go to the DCS for display, historization and logging for local use.

B. The high degree of redundancy of processors, I/O and links sometimes employed in systems in which a failure, even with a meantime of 5 to 10 years, may result in lost production from one incident sufficient to more than pay for it is not justified in this project. The best use of capital is to have the extra capacity, measurements, and data processing.

C. The data terminal (PC based) to be supplied and placed in the Fort Martin Power Plant control room is in lieu of any link to the Plant control or data system.

D. Process simulation for engineering information or operator training should be given consideration in a later task. (7 or 8) when the empirical information necessary for the design of a process model has been obtained from the initial operation and tests. Simulation for the purpose of control system check-out is not cost effective.

E. The whole system is to be configured, tested, and shipped on the same schedule (check-out and start-up) and therefore will not be require extra support equipment (e.g., engineer station, etc.)

F. Instruments and equipment for use in the laboratory will be supplied by D.O.E.

G. The two IR Scanners on the Gasifier and the Multipoint Gas Analyzer for H_2S and HN_3/HCN are in contract to be supplied by PSIT (see Appendix F "PSI PowerServ Scope").

III. References

A. Functional Control System and Communication Diagram, 301604-60-S-001

B. DCS Specification

C. Preliminary Instrument List

D. Process Flow Diagrams

E. Standards which apply to the control and instrument system

- National Fire Protection Association (NFPA)
- National Electric Code (NEC)
- National Electrical Manufacturers Association (NEMA)
- Instrument Society of America (ISA)
- Institute of Electrical and Electronics Engineers (IEEE)
- American National Standards Institute (ANSI)

3.11 Host Site Interfaces

As shown in Table 29, there are many important interface ties with Ft . Martin Generating Station :

Table 29
Interfaces with Ft Martin Generating Station

- High Voltage Power Supply
- Medium Voltage Power Supply
- 600 psig Backup Steam for Startup
- No.2 Oil (or natural gas) Supply
- Cooling Water Supply/Return
- Wastewater to Treatment
- Potable Water Supply
- Flue Gas Breeching
- Coal Sourcing
- Condensate Supply
- Byproduct Steam Use Host

Fort Martin piping tie-ins and site piping appear in Figure 17 as follows :

Two power sources of different capacities will be utilized from Ft. Martin to the GPIF site. Additional power and sanitation requirements for METC office trailers will be added when information on their required capacities becomes available.

Valved steam supply and return, cooling tower supply and return, service water supply, condensate supply, fuel oil (or natural gas) supply, combined coal handling waste water runoff and process drain waste water return tie-ins (to Fort Martin) shall all be provided. The actual Ft Martin tie-ins will be designed and furnished by APS.

Steam lines shall be furnished from HRSG to gasifier, ash lock hopper nitrogen vaporizer, deaerator and from the GPIF to Ft Martin Unit No. 2's No. 7 Heater where APS will pick-up the design and installation of the actual tie-in. Quality requirements for the steam to Ft Martin shall include conductivity of 0.06 to 0.1 micromohs, and 75 to 100 TDS.

Condensate piping from all sources including steam line traps to condensate receiver tank, condensate piping from GPIF to Ft Martin Unit No. 2 building limits, as boiler and chemical feedwater make-up (through new condensate storage tank and transfer pumps), cooling water supply line from Ft. Martin's Unit No. 2 cooling tower sump to the GPIF, Air Compressor System and Waste Treatment Vacuum Pump and for seal water, cooling water return line from Gasifier, Air Compressor System , Waste Treatment Vacuum Pump and from seal water users to the cooling water return tank, and cooling water return piping from the cooling water return tank, through pumps, to the existing cooling tower sump with cantilevered submersible pump shall be furnished.

Service water piping from Ft Martin to the coal receiving and preparation area, oxidation reactor, blowoff and CBD Flash Tank discharge lines shall be furnished.

Metered fuel oil (or natural gas) piping from the Ft. Martin tie-in to Gasifier, Booster Pumps and Gasifier, Dry Air Heater, and HRSG shall be supplied.

Proposed Ties Between GPIF and Ft. Martin

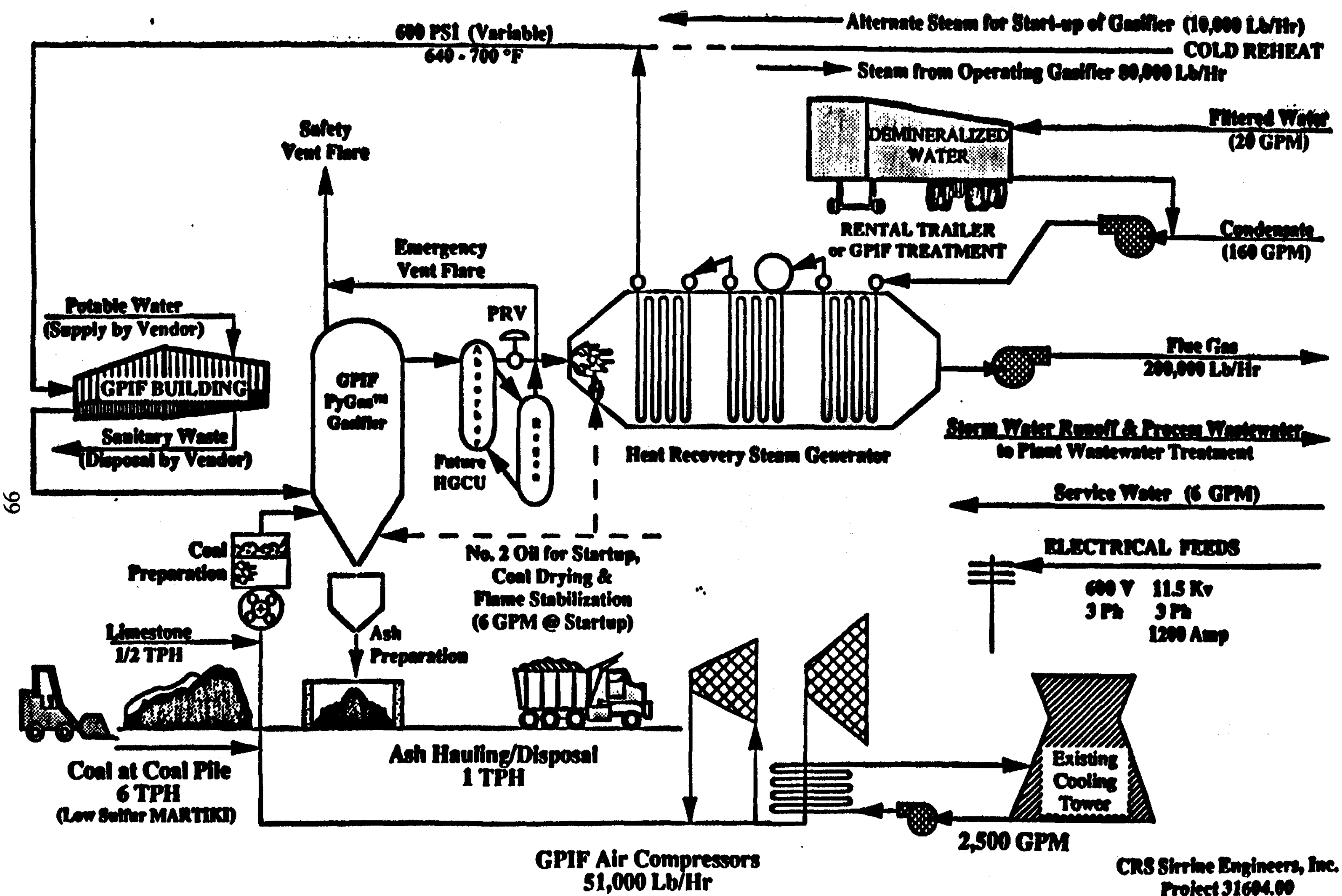

Figure 17
Host Site Interface Sketch

CRS Sirrine Engineers, Inc.
Project 31604.00
Approved by: R.S. Sadowski
October 13, 1993

Potable water piping from storage tank through pumps and to safety/eyewash showers, lab, battery room, and men's and women's wash rooms shall be included.

Plant air piping (no Ft Martin tie-in) to coal transfer pressure vessels, Gasifier/Pyrolyzer and to interconnecting vendor supplied equipment associated with air compressors and dryers, instrument air piping to coal receiving and preparation area, Gasifier area, boiler room area, HVAC equipment, and lab shall be included.

The new storage building will be located between the railroad fence and the Ft Martin rail spur approximately half-way between the GPIF and existing Unit No. 2.

Additional parking spaces will be located South of the GPIF in the vicinity of the former new storage building location.

The instrumentation tie-in to Ft Martin shall include one copper cable and one fiber optic cable from the GPIF to the Unit No. 2 control room. No copper instrumentation or tubing shall be utilized in the steam or condensate systems intertied into the Ft Martin system.

The existing three phase power feed to the GPIF shall include a Contractor furnished 600 to 460 volt transformer.

The flue gas duct design shall take into consideration flue gas acid dew point, flue gas exit temperature, and materials of construction. In an effort to avoid direct impingement of GPIF flue gas on precipitator elements, the flue gas from the GPIF duct shall exit into the Ft Martin Unit No. 2 electrostatic precipitator inlet breeching through a sparge pipe configuration to distribute and mix the flue gas into the existing ductwork.

Toxicity Characteristic Leaching Protocol (TCLP) and the disposal of any materials determined to be defined as "hazardous" shall be the responsibility of the DOE/METC. It is anticipated that the laboratory room furnished in the GPIF shall be used for such testing and determinations.

During normal operation, the GPIF is not expected to produce any waste water. However, to accommodate potential boiler chemical spills, facility washdowns, etc., a rate of 5 gpm has been anticipated to be collected in an in-building sump-tank and pump set for disposal via a single waste water line to your waste water treatment tank. In addition, an exterior in-ground sump and pump system is also provided for storm-water run-off, which when filled, will trigger one of two 100 gpm pumps. The sump and pumps have been sized for rainwater runoff from the covered coal pile and ash collection areas.

Process vent piping from the lock hoppers (2), oxidation reactor, and vacuum pump to a main header routed to the HRSG shall be supplied.

Vent or relief vent piping to atmosphere from Gasifier flare stack, steam drum (2), steam lines from HRSG, blowdown separator, fueled gas line from Gasifier, deaerator (3), air compressors, and air dryers shall be included.

Nitrogen piping from storage tank to vaporizer, vaporizer to Gasifier, lock hopper, lab, and deaerator shall be included.

Coal gas piping from the Gasifier to the gas cyclone and the HRSG with provisions for future Hot Gas Cleanup System piping integration shall be provided.

Water and waste piping associated with the oxidation reactor, settling tank, water injection tank and drum filter, process drain waste piping to Fort Martin wastewater treatment facility, and run-off wastewater pipe line to (from) north column line at coal preparation area (combine line with Item 2 above) shall all be provided.

Blowdown and drain piping associated with the HRSG, piping associated with the boiler feedwater system including condensate transfers, piping from blowdown and CBD tanks to the solid waste treatment system.

Chemical feed and interconnecting vendor supplied equipment piping for phosphate service, neutralizing amine service, and oxygen scavenger service shall be included.

The following services shall be insulated: steam, cooling water supply, cooling water return, condensate supply, coal gas piping, misc. vents and for personnel protection as required.

Section 4 Site Requirements, Revised Costs & Schedule

For the most part, site requirements and costs contained within this "Conceptual Design" reflect the best thinking of the contractor and METC at the time of contract award. The basic plan to construct the GPIF adjacent to the Ft. Martin Generating Station Unit No. 2 has remained in tact. The plans to design and fabricate the required vessels to be housed within the confines of the GPIF as self-supported entities has remained. The plan to use a pre-engineered building for both the process and administration containment areas is also unchanged from the originally proposed facility. As a result of either new technological information not available at the time of contracting, or new process requirements developed after contract date, site requirements have changed in several minor areas as are described in this section.

4.1 Site Preparation Requirements

4.1.1 Foundations/Pads, Designs

Drilled pier caisson or driven pile type supported foundations for Process Tower, Main Equipment Foundations, and Building shall be provided.

The building foundation and 6" concrete slab, with 4' X 4' X 6' sump and three (3) 4" floor drains to the storm runoff collection pit.

One sump pump, capacity 5 gpm, 52 HTDH, 2 HP

All process runoff shall be collected in a sump and pumped to the existing Fort Martin Generating Station waste water treatment system.

A spread type footing shall be utilized for minor equipment. A slab on grade to be 6 in. deep reinforced with W.W.F. shall be furnished, including a 6 mil vapor barrier and gravel sub-base, a 5 ft. by 5 ft. by 6 ft. deep process drain sump, and a 6 ft. by 10 ft. by 9 ft. deep sanitary waste sump.

Reinforced concrete foundations shall be furnished for Material Handling equipment and structures, including an open steel frame structure to support bucket elevator coal & limestone silos and screw conveyor, ash storage enclosure with roof and siding, 3 sides with push-up wall, 3-sides.

4.1.2 Steel Support , Blast Wall, Structure, Layout

The vertical process tower support structure is provided. Process tower is enclosed by pre-engineered building but is completely isolated from it. The tower structure will support Gasifier, Absorber, and other process equipment. Tower will contain grating, platforms, access stairs, reinforced concrete blast wall and hoist way with 5 ton monorail to support process. Two sets of steel stairs to 54' high elevation, with steel treads, landings and handrails per code.

The criteria for the blast wall design shall be per Factory Mutual Loss Prevention Data "DAMAGE-LIMITING CONSTRUCTION" I-44.

The pressure-resistant walls and their supports shall be capable of resisting explosion forces of at least 100 psf.

Monolithic walls or those which have a degree of elasticity are most desirable. Types of construction in this category include reinforced concrete, which is the GPIF conceptual design material of choice for construction.

4.1.3 Process Building & Area Major Features

The pre-engineered type building shell erected shall be approximately :
54'W X 148'L X 64'H.

For the heat protection in the winter to maintain 50°F ambient temperature at 0° exterior temperature (except in open gasifier bay), the steam-fired or electric unit heaters are included using existing 600 psi steam or electricity from Ft Martin Station.

Control room inside process building area 20' X 15', with 5' X 7' personnel door with half glass.

A 10' x 7' Input/Output (I/O) room , 10' x 8' Uninterruptable Power Supply (UPS) room, 50 sq ft telecommunications room, and a 10' x 10' office shall all be provided.

Second and third floors for gasifier and future hot gas cleanup system access, 3' X 7' personnel doors with half glass, entrance from the inter platforms. Ventilation fans are included, and grating floor steel form deck.

An electrically operated hoist located near the top of steel including monorail shall be provided for lifting top of gasifier and future hot gas cleanup system vessel heads for access and maintenance.

A lavatory facility, to include separate male & female showers, each with a toilet stall (suitable for handicapped persons), a single wash basin (suitable for handicapped persons), and a men's urinal all complete with standard fixtures will be provided. A pumping and storage tank for waste disposal by portable tank truck will also be furnished.

A furnished combination meeting/break and laboratory room complete with dry erase marker board, hooded sink and microwave oven, and with coffee making, snack and soda machine provisions will be provided. Furniture will consist of two 4 ft x 8 ft folding type tables and twelve (12) straight back chairs.

Piping between the GPIF and Ft Martin Unit #2 shall be ground supported on pre-fabricated concrete supports on sleepers.

Insulated carbon steel breeching with stiffeners and support steel for run from HRSG to Induced Draft Fan, 48 in. dia. non-insulated duct from fan for a run of 1800 ft. to Fort Martin precipitator shall be provided.

The existing shed building along with its slab and foundation shall be demolished. A new pre-engineered type structure with slab on grade and foundation to the same square footage as existing shed shall be furnished in a new location for Ft Martin.

A pre-engineered structure and related concrete work including 4 ft. x 11 ft. x 12 ft. deep sump shall be provided for the Fire Pump House.

4.1.3.1 Entrance Road

The entrance road, plant roads, and parking areas will be asphalt paved. The pavement cross section will consist of a 2 1/2 inch surface coarse, a 2 1/2 inch binder coarse, and a 10 inch aggregate base coarse. The roadways will be 20 feet wide with three foot shoulders. Asphalt aprons will be provided at the limestone unloading area, the ash disposal area, and the coal handling area. These areas shall include a 12 inch base of compacted crushed stone, prime coat, 4 1/2 inch thick base binder and a 1 1/2 inch wearing coarse. Four foot square man-door pads will be provided outside the exterior doorways and four foot wide sidewalks will be provided from parking areas to the office area. All sidewalks will be four inches thick non-reinforced concrete.

Six foot high chain link fence with three strands of barbed wire will enclose the plant property. There will be a motor operated slide gate at the main entrance. The gate will be operated by personnel in a remote location, viewing the gate by a TV monitor.

All disturbed earth areas on the site will have four inches of topsoil applied and be grassed with fescue.

A one inch potable waterline from the Fort Martin interface point to the facility reservoir tank will be provided.

An eight inch ductile iron pipe fire protection loop will be provided around the plant with fire risers to the building and other critical out buildings and facilities. Fire hydrants will be provided in the fire protection main loop at 300 foot intervals. All hydrants will be provided with gate valves and boxes. Post indicator valves will be used on fire riser lines. PIV division valves will be used to isolate each five major branches in the fire loop. The loop will be connected to a new 1500 GPM diesel fire water pump in an on-site fire pump house. A Jockey pump will also be provided.

Sanitary waste will be conveyed by gravity using six inch PVC sewer pipes. Sanitary waste will be collected in a holding tank to be pumped out by a local septic company.

4.1.3.2 Storm Water Collection

Provisions shall be made for storm water drainage consisting of ditching with concrete culverts where required to direct storm water to the detention pond before leaving the site via a natural drainage feature. Storm water discharged will be controlled. Storm water run-off from the coal and ash handling areas will be collected in a basin and be pumped to the Fort Martin waste treatment system. Provide two (2) 100 GPM storm water sump pumps.

4.1.3.3 Fire Protection

An automatic deluge system for the gasifier area shall be provided.

An automatic wet pipe system protecting all building areas except electrical rooms, control room, and IO room shall be provided. A similar system shall also be provided for the fire pump building. Fire pump intakes shall be from both existing lagoons such that one lagoon may be drained without impacting protection.

An automatic dry pipe system supplying vendor supplied sprinkler heads for bucket elevator, coal storage bin, dust collectors, sampler, crusher, fines bin, tote bins and charge hopper, transfer hopper, cyclone receiver and classifier shall be provided.

An automatic dry pipe system protecting the coal charge hopper, the chute from the coal weigh belt feeder to the coal dryer, and the 16" dia. duct from the coal prep. dust collector to the HRSG shall be provided.

Fire extinguishers shall be provided for all areas.

4.1.3.4 HVAC

Electric unit heaters and controls to maintain 40°F minimum, exhaust fan and air intake louver and motor operated dampers for ventilation to maintain 100°F maximum shall be furnished for the fire pump house, high voltage equipment room, and compressor room.

A makeup air unit shall be provided to supply makeup air to gasifier area air lock.

The gasifier area shall have roof mounted exhaust fans.

The boiler room shall have electric unit heaters and controls to maintain a minimum of 40°F, louvers and motor operated dampers for room ventilation, and exhaust fans to maintain room at a maximum temperature of 110°F.

The office area shall have a packaged, multi-zone, all electric, air conditioning unit to air condition all spaces. Design condition is 75°F with humidity uncontrolled. Outside air will pressurize area.

Separate exhaust fans shall be furnished for presentation/laboratory room, UPS room, control room, and two exhaust fans for men and women's locker rooms. A DDC control system shall be furnished with the HVAC system.

4.1.3.5 Plumbing

A sanitary waste and vent system for the men's and women's toilets shall be provided.

A lab waste and vent system serving the lab sink, under counter lab sink acid neutralization tank shall be included. Tank will drain to sanitary sewer.

A process waste and vent system for main building floor and hub drain collection and routing to the process waste sump shall be provided. A similar system for the fire pump house routed to sanitary sewer shall be provided.

A potable water system from the potable water tank and pump to toilets, urinals, sinks, showers, and water coolers shall be provided. The potable water piping shall be insulated.

An electric potable water heater shall be provided for showers and sinks.

4.1.4 Office Configuration

Administration Building to be single story with varying roof heights (i.e. no intermediate floors). Roof system to be insulated standing seam metal roof deck. Walls to be insulated metal siding.

4.1.5 Utility Service (Other than from Ft. Martin)

The design of the GPIF includes potable water, Uninterruptable Power Supply (UPS), telephone service, and portable sewage removal.

4.2 Revised Construction Cost Estimate

The revised Cost Estimate -- Budget for Phases I and II of the GPIF project (Table 30) along with a breakdown of anticipated sub-contract cost estimates including the potential impact of state taxes is shown on the following page. The complete Cost Estimate appears in Appendix G "Detailed Cost Estimate".

Table 30

GPIF PROJECT ESTIMATE SUMMARY
($)

PHASE I		
CRS SIRRINE ENGINEERS, INC.	6,536,609	
PSIT SUB-CONTRACT	926,800	
RILEY STOKER SUB-CONTRACT	20,332,520	
		27,795,929
PHASE II		
TOTAL DIRECT COST	2,967,000	
TOTAL INDIRECT COST	869,000	
SUBTOTAL	3,836,000	
ESCALATION	100,894	
		3,936,894
PROJECT TOTAL		31,732,823

4.2.1 Construction Cost Estimate

During the course of the development of Task 4, Riley Stoker Corporation and CRS Sirrine Engineers, Inc. painstakingly collaborated on the cost estimate. Specialists from both companies met on several occasions to identify all potential differences in assumptions and historical cost information in order to develop as accurate an estimate as possible.

After weeks of review and commenting, the detailed estimate which appears in Appendix G was completed to the satisfaction of both organizations. Appendix G includes the estimated CRS Sirrine Engineers, Inc. (CRSS) costs and hours to complete the remaining GPIF project tasks, the Riley Stoker Corporation detailed cost estimate including direct cost quantities and construction labor, and the current PSI Power Serv sub-contract cost estimate breakdown.

Backup detailed cost estimates for piping, instrumentation, and electrical are also included in Appendix G.

4.2.1 Value Engineering Cost Reduction Potentials

1. Consistent with METC's suggestion that we may include used and Government surplus equipment, we recommend consideration be given to not demolishing the existing storage building at Ft. Martin. We believe the cost of refurbishing it into a larger than proposed administration building for the GPIF will save METC trailer leasing costs, and provide them with the added storage capacity which METC has been seeking. The existing storage building was originally constructed as a field office which is the same purpose as the GPIF administration building. While its skin and roof need replacing, its steel internal structure and concrete flooring appear to be in excellent condition, and it currently is wired consistent with one of the contemplated GPIF project power sources. Since it occupies the same spot where the primary site GPIF administration building conceptual design is located, such a consideration should not impact the NEPA process. It is, therefore, recommended that METC give serious consideration to implementing this cost saving approach under the Task 6 "Detailed Design".

2. Locating the GPIF on the alternate site has the potential to cut the cost of the interconnecting piping, ducting, electrical, and communications lines to Ft. Martin by 50% since the distance is approximately cut in half. It would also result in an increase in the grade elevation of the GPIF by approximately 20 ft. in contrast to the primary site location which could have positive "flood plain" implications. We understand that from a NEPA perspective, however, the primary site is preferred due to less tree cutting required for the primary site. The METC decision to utilize the more costly primary site for NEPA reasons shows a high METC consciousness to protect existing vegetation in the vicinity of the GPIF site, a laudable position.

3. Identification of I & C equipment items recommended for testing the PyGas™ gasification process, but for METC to purchase separately under their "Data Base" program represents an additional potential project cost saving measure. This will result in METC absorbing the cost of these items as capitalized equipment for their future internal use thereby not associating such charges with the GPIF project funding.

As a minimum, the following items are included in this recommendation :

3.1 PSI-E's alpha-NH3 Monitor
3.2 PSI-E's Gastemp Monitor for Preheat Control
3.3 PSI-E's Gastemp Monitor for Cracking Burner Control
3.4 A Gas Chromatograph
3.5 A Mass Spectrophotometer

3.6. Test Conducting Position DCS Station -- This is a dual CRT DCS operator station that would allow viewing and analysis of process conditions, data, and historical trends. In addition, it would serve as a backup operator station.

3.7. PC based DCS Reporting Station -- The report generation PC was combined with the historian PC. Having separate PC's would allow for the collection of more points and faster sampling frequencies.

3.8. H_2S and HHV analyzers -- These were recommended by PSI, but were not included in the task 4 estimate.

3.9. Oxygen analyzer on the HRSG -- This would allow trim of the air/fuel ratio. This is especially important with a variable BTU fuel. The alternative is to always run with a very high excess air.

3.10. Opacity monitor on HRSG flue gas.

CRSS recommends retaining the $588,000 originally proposed cost figure in the PSI-E scope, and include additional funding for the PSI-E's alpha-NH3 Monitor and PSI-E's Gastemp Monitor from the "Data Base" program as required for PSI-E's instruments development. These instruments were not included in the original proposal or contract, however, subsequent investigations conducted under Task 4 has identified them as items worth development under a separate CRADA, and modified versions from the CRADA development results subsequently applied as a cost extra to the contract.

4.2.2 Recommended Project Scope Changes

The following actions are recommended to be followed-up with by the "Project Team" as part of the "Detailed Design" functions of Task 6 :

1. The original proposal and contract included a 5 ft diameter PyGas™ gasifier vessel. This was the result of extrapolating available carbonizer tube data (C. Lowell, et al) with the anticipation that approximately 50% of the gasification duty (DOE/METC Contract No. DE-AC21-78MC-10484) would be produced from the pyrolyzer tube of PyGas™. A review of the results of subsequent testing conducted by Foster Wheeler Development Corporation under DOE/METC Contract DE-AC21-86MC21023 and made available to CRSS after GPIF contract was entered into, indicated that almost 70% of the coal could be gasified in the pyrolyzer tube.

The implications of the new data are very positive to the likelihood of success with the PyGas™ gasifier, because it means that almost 20% more coal gasification can take place under rapid pyrolysis conditions than was originally thought to be possible. Original concerns expressed by METC that the pyrolyzer tube performance was critical to the success of PyGas™ should now be eliminated.

The "Project Team" recommends modifying the PyGas™ gasifier conceptual design to incorporate the ability to operate the pyrolyzer in the same mode that resulted in Foster Wheeler converting almost 70% of the coal to gaseous fuel in their carbonizer tube.

This will require operating the pyrolyzer with 36% of stoichiometric air rather than 27% as originally contemplated under the contract. In order to maintain the same superficial velocity through the lower pyrolyzer tube as originally contemplated, in must be increased from 20 inches diameter to 24 inches diameter. In addition, to lower its exit velocity to minimize spouting per METC recommendations, its diameter will need to be further increased to 34 inches. Increasing the pyrolyzer tube diameter results in the necessity to increase the overall gasifier vessel from 5 ft. to 6.5 ft. diameter in order to fit its rotating grate mechanical components.

While we may continue to contemplate a 5 ft. diameter gasifier as required under the contract, it is our understanding that METC does not want to penalize the "Project Team" for utilizing data developed from their other programs in ways that will increase the likelihood of success of the GPIF and PyGas™ gasifier when such data was unavailable at the time of our original proposal. We, therefore, recommend METC consider a contract change to include the aforementioned design modifications in detailed design Task 6.

2. The same technical premises which result in the recommendation of the larger test gasifier also impact the sizing of the high pressure air compressor. The CRS Sirrine Engineers, Inc. model predicts that going from the original design and operating conditions as was proposed and contracted for to the latest conditions determined from METC Contract DE-AC21-86MC21023 and utilizing Ft. Martin coal results requires an increase in the required air compressor capacity from 5,500 scfm to 8,770 scfm. Again, we recommend METC cover the added cost of a larger air compressor by issuing a contract change during the Task 6 "Detailed Design" period.

3. The original DOE/METC specifications contemplated piping the coal gas from the GPIF to Ft. Martin Unit No. 2 for combustion in the existing furnace. Due to potential legal concerns regarding indemnification, the decision was made to combust the coal gas at the GPIF in a package boiler and then duct the flue gas to the existing Unit No. 2 precipitator inlet. A 100,000 pph, 175 psig saturated steam package boiler was priced and included in both the proposal and the contract.

Subsequently, additional considerations associated with Ft. Martin operating conditions and steam needs has led to a new requirement for a fired Heat Recovery Steam Generator (HRSG) to operate with steam safety valves to relieve at 950 psig, and to produce 700°F steam of very high quality for use in the Ft. Martin cold reheat system.

Since these new HRSG requirements have little to do with the gasification test unit, and everything to do with the METC/Ft. Martin Site Access Agreement, we recommend METC issue a contract change during Task 6 to cover the increased costs associated with the currently contemplated HRSG design conditions.

4.3 Schedule for Detailed Design and Construction

The consolidated schedule reflecting the project team's latest assessment of remaining Task 5 through Task 9 appears in Appendix H of this report.

A bar chart type schedule showing major tasks and milestones (Figure 18) and including assumptions (Table 31) associated with its generation appear on the following pages.

4.3.1 Long Lead Items Description

There are four long lead items which either have had or will have an impact on the performance of this project. These include NEPA permitting, Gasifier Design & Fabrication, High Pressure Air Compressor Fabrication, and the Heat Recovery Steam Generator (HRSG) Design & Fabrication. Fortunately, one of the team members is a boiler manufacturer which will facilitate design and fabrication of the Gasifier & HRSG.

The development of the NEPA document, and process time (now expected to run through December, 1993) has already delayed the GPIF project by several months.

DOE F1332.3
(11-84)

U.S. DEPARTMENT OF ENERGY
MILESTONE SCHEDULE [X] PLAN [ ] STATUS REPORT

FORM APPROVED
OMB 1901-1400

1. TITLE: DEVELOPMENT OF STANDARDIZED GASIFICATION PRODUCT IMPROVEMENT FACILITY
2. REPORTING PERIOD: 1 Oct thru 31 Oct, 1993
3. IDENTIFICATION NUMBER: DE-RP21-91MC28202
4. PARTICIPANT NAME AND ADDRESS: CRS Sirrine, Inc. ATTN: Larry S. House, P. O. Box 5456, Greenville, SC 29606
5. START DATE: 1-Oct-92
6. COMPLETION DATE: 1-Sep-96

Legend: ====| DRAFT to METC, xxxx| METC REVIEW, oooo| FINAL to METC, Δ TASK COMPLETE

9. DURATION columns: O,N,D 1993 | J,F,M 1994 | A,M,J | J,A,S | O,N,D | J,F,M 1995 | A,M,J | J,A,S | O,N,D | J,F,M 1996 | A,M,J | J,A,S | FY | FY

7. ELEMENT CODE / TASK	8. REPORTING ELEMENT / DESCRIPTION Phase I	9. DURATION	10. PERCENT COMPLETE a. Plan	b. Actual
1	Env. Impact (NEPA spt)	Δ	100	100
2	Work Plan - Phase I	Δ	100	100
3	Permit Information	Δ	100	100
	Obtain Permits	====================Δ	0	0
4	Conceptual Design	=|x|o|Δ	100	90
5	Bench-Scale Tech. Con. Studies	========|xx|oo|Δ	0	0
6	Detailed Construction Design	==================|xxx|ooo|Δ	0	0
7	Site Preparation	========Δ	0	0
	Procurement & Delivery	==========================Δ		
	Construction	================================Δ		
8	Pre-Operational Test Plan	===========|xxx|ooo|Δ	0	0
9	Pre-Operational Testing	===========|xxx|ooo|Δ	0	0
			0	0
			0	0
			0	0
	Total Phase I			

11. SIGNATURE OF PARTICIPANT'S PROJECT MANAGER AND DATE

Figure 18
Major Task & Milestone Schedule

Table 31
Assumptions Associated with Schedule

DEPARTMENT OF ENERGY
GASIFICATION PRODUCT IMPROVEMENT FACILITY
SIRRINE JOB NO. 31604

ASSUMPTIONS

1. NEPA Report approval received by January 17, 1994.

2. DOE/RILEY/CRSS agrees with Gasifier design concept.

3. Gasifier and HRSG design will be by Riley.

4. Riley will be responsible for the bidding/procurement of subcontracts, equipment, and material. CRS Sirrine will provide drawings and specifications and will review bid tabulations.

4. Vendor drawings will not be a part of the Contract Bid Package, but will be received prior to mobilization.

5. HVAC will spec equipment (dampers, exhaust fans, unit heaters, (1) a/c unit) on drawings -- will not develop individual specifications.

6. All equipment will include motors provided by the vendor -- no separate motor purchases.

Care must be exercised to avoid future delays, as it is in our collective best interests to expeditiously complete this project at the earliest time possible.

4.3.2 Anticipated Time Requirements

The Project Team would prefer to go to a "Fast Track" schedule from this point to completion of the project. Riley, PSIT, and CRS Sirrine all see the "opportunity window" for the development of the PyGas™ gasification process and peripheral technologies to be now, such that it is in time to support commercialization of the product in the latter half of this decade when most utilities will be giving serious consideration to gasification processes and IGCC's for both Retrofit/Repowering as well as new installations.

The NEPA process has introduced about a year long delay in the originally anticipated GPIF design and installation schedule. This has put the testing and technology development schedules about a year behind what was thought to be a reasonable schedule. All parties now strongly urge DOE/METC to hasten the pace from this point on to completion of this all important project.

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DOE/MC/28202--4041
UC-109
DOE CONTRACT NO. DE-AC21-92MC28202

Conceptual Design Report

Gasification Product Improvement Facility (GPIF)

Appendix B

PyGas™ Kinetics Details

Prepared by : CRS Sirrine Engineers, Inc.
1041 East Butler Road
Greenville, South Carolina 29606

Prepared for : United States Department of Energy
Morgantown Energy Technology Center
Morgantown, West Virginia 26507-0880

September, 1994

Equations to find Cp of air (column 2)		
TEMP (k) =	K	
cp CO_2		
cp H_2O		
cp O_2		
cp N_2		
cp Ar		
Total		
Latent Heat of Vapor	989.19	Btu/lbm

Pyrolyzer Steam (column 3)	
Temp (K)	525.56
cp H_2O	0.481
Latent Heat of Vapor	730.85 Btu/lbm

Pyrolysis Gas (column 4)
Latent Heat of Vapor.
Products of Pyrolysis - Gase:
Finding Cp of Gases

delta h CO_2	53.83 B
delta h CO	68.51 B
delta h H_2O	52.76 B
delta h H_2	65.72 B
delta h CH_4	11.09 B
delta h H_2S	5.84 B
delta h N_2	230.65 B
delta h Ar	2.59 B
delta h NH_3	5.91 B
TOTAL	496.90 B
cp Gases	0.322 B

Coal Handling Considerations

Stoichiometric amount of air needed to combust coal
7.74 lb of air/lb of coal

Sensible heat (absorbed during crushing)		
Temp of coal (K)	338.89	300.00
C - delta h	17.42 Btu/lbm	3.67
H - delta h	310.49 Btu/lbm	71.64
O - delta h	18.30 Btu/lbm	4.06
N - delta h	22.15 Btu/lbm	5.11
S - delta h	12.32 Btu/lbm	2.85
ASH - delta h	12.20 Btu/lbm	2.40
Total of coal	426.84 Btu/lbm	93.95

Finding the Results of Pyrolysis

Positive sign means heat is absorbed in process / Negative sign means heat is released in process

Char & Ash

Sensible heat (absorbed during pyrolysis)	
Temp of coal (K)	1144.44
C - delta h	520.64 Btu/lbm
ASH - delta h	364.75 Btu/lbm
Total of coal	391.76 Btu/lbm
Total heat	3547596 Btu/hr

PYROLYSIS OUTPUT (COLUMN 10A,CH11)INPUTS FROM SKINNER

					Elemental Balance (Inputs vs Outputs)
27	6684	*CO	4515	14.55	
18	-64	*H2	323	14.46	
5	4274	*CO2	3551	7.28	0.98% C
3.5	810	*H2O	1834	9.19	-0.53% H
4	230	*CH4	230	1.29	-0.62% O
	0	*C2H6	0	0.00	0.28% N
	357	H2S	100	0.95	0.01% S
	0	COS	0	0.00	
		*N2	15715	50.63	
		Ar	366	0.83	
				99.17	

Gases of Pyrolysis
Predicted Temperature 1144.44 K

Heat Absorbed during Pyrolysis		Btu/hr
delta h CO_2	391.02 Btu/lbm	1388507
delta h CO	387.74 Btu/lbm	1750630
delta h H_2O	735.71 Btu/lbm	1349301
delta h H_2	5193.50 Btu/lbm	1677499
delta h CH_4	1253.60 Btu/lbm	288329
delta h H_2S	419.99 Btu/lbm	149958
delta h N_2	374.84 Btu/lbm	5890767
delta h Ar	180.40 Btu/lbm	65956
delta h NH_3	968.30 Btu/lbm	152548
Total		16261092

Equations in Pyrolysis

Reactant	+	Reactant		Product	+	Product	Btu/mol	Btu/lbm	Btu/hr
*C (2222 lb/hr)	+	O2 (5919 lb/hr)	------>			CO2 (8141 lb/hr)	-169294	-3846.71	-31317616
CO2 (3867 lb/hr)	+	*C (1055 lb/hr)	------>			CO (4923 lb/hr)	74196	2648.91	13039580
*C (667 lb/hr)	+	1/2 O2 (888 lb/hr)	------>	CO (1555 lb/hr)			-47549	-1697.57	-2638884
*C (89 lb/hr)	+	H2O (133 lb/hr)	------>	CO (207 lb/hr)	+	H2 (15 lb/hr)	56487	1881.28	389951
C (172 lb/hr)	+	2 H2 (58 lb/hr)	------>			*CH4 (230 lb/hr)	-32200	-2007.24	-461666
H2 (21 lb/hr)	+	S (336 lb/hr)	------>	H2S (357 lb/hr)			-8586	-251.97	-89965
0.5 N2 (130 lb/hr)	+	1.5 H2 (28 lb/hr)	------>	NH3 (158 lb/hr)			-19728	-1158.43	-182502
*H2 (105.55 lb/hr)	+	1/2 O2 (837.61 lb/hr)	------>	H2O (943.15 lb/hr)			-104036	-5774.98	-5446670

779 *CaS
1.74 *Air/Coal

CARBON AVAILABLE	8544 LB/HR	HEAT ABSORBED	16261092	22.49%	% Theo. Air to Pyrolyzer
CARBON USED	8631 LB/HR	HEAT FORMED	-26103454	0.0000015	*Pyrolyzer Steam/Coal
OXYGEN AVAILABLE	5494 LB/HR	TEMP Predicted	1600	1600	*Assumed Pyrolysis Temp (°F)
OXYGEN USED	7053 LB/HR	TEMP Calc. (Less No Assumed He	2578	35.00%	*Empirical Pyrolysis (FW)
				924	*CaS

	1559	1mole H2S		1559			Btu/lb mol	Btu/lbm	
CaCO3	+	H2S	------>	CaS +	H2O	+ CO2	27930	279.05	32468334
1162		397		838	210	511			
		CaCO3	------>	CaO	CO2		51901	1523	604318
		1744		618	767		42610	425.72	74300522
2.78*CaCO3	+	H2S	------>	CaS + 1.78 CaO + 2.78*CO2		+ H2O			-26103454

	Pyrolyzer Gases	WEN DATA		CRSS PREDICTION	Tech Paper	Empirical Analysis				
1. Match WEN's H2O	CO	27.15	CO	14.55		*				
2. Match WEN's CO2	H2	18.55	H2	14.46		*	24.02%	Energy Bal Error		
3. Match WEN's CO	CO2	4.71	CO2	7.28		*	111	Pyrolyzer Exit Gases (Btu/sc		
4. Adjust Eq. 4. to Match WE	H2O	3.5	H2O	9.19		*				
5. Adjust all to Match WEN	CH4	3.74	CH4	1.29		*				
6. Adjust Pred. Temp.	C2H6		C2H6	0.00		*				T
7. Balance C with MJB	H2S	0.66	H2S	0.95		*				c
8. Chk Reasonableness	COS		COS	0.00		*				c
(is delta T a few hundred de	N2	40.92	N2	50.63		*				c
			Ar	0.83		*				c
			HCl	0.00						c
			HCN	0.00						c
			NH3	0.83						c
			CS2	0.00						c
			SO2	0.00						T
			NO	0.00						
			O2	0.00						
			NaCl	0.00					16229.194	
			KCl	0.00						
			CaSO4	0.00					3168.1637	
			Ca(OH)2	0.00					224.00111	
			Cl2	0.00					3966.1205	
			Total	100.00					198.44111	
									864.51231	

Pyrolyzer Tube Sizing		Gasification	Pyrolyzer Tube Sizing		Gasification
FW Gasification Rate	931 lb/square foot	Ratios	Lowell's Gasification Rate	791 lb/sq ft	Ratios
GPIF to FW Ratio	23.62 @ 199 psig	3.87	GPIF to Lowell's Ratio	91.60 @ 15 psig	3.87
GPIF @ 600 psig	14 times FW area	24.49	GPIF @ 600 psig	14 times FW are	24.49
FW Diameter	10 inches diameter	14.14	Lowell's Diameter	5.512 inches diamete	14.14
FW Area	78.54 square inches	1.73	Lowell's Area	23.86 square inches	1.73
FW Area	0.55 square feet	6.32	Lowell's Area	0.17 square feet	6.32
GPIF per FW Data	7.44 square feet		GPIF per Lowell Data	2.40 square feet	
GPIF per FW Data	1071.14 square inches		GPIF per Lowell Data	345.61 square inches	
GPIF per FW Data	37 inches diameter Carbonizer Tube		GPIF per Lowell Data	21 inches diameter Carbonizer Tube	
	15 Ft FW Effective Carbonizer Tube Hgt			13 Ft Effective Carbonizer Tube Hgt	
Gasifier Sizing			Gasifier Sizing		
Gasifier Diameter	5 ft		Gasifier Diameter	5 ft	
Gasifier Area	19.64 square feet	Pyrolyzer Tube:	Gasifier Area	19.64 square feet	Pyrolyzer Tube:
Less Carbonizer Tube	12.20 square feet	600 psi	Less Carbonizer Tube	17.24 square feet	600 psi
Superficial Velocity	2.13 ft per second	1600 °F	Superficial Velocity	0.49 ft per second	1600 °F
Gasifier Diameter	6.5 ft	150 * °F actual	Gasifier Diameter	6.5 ft	150 * °F actual
Gasifier Area	33.18 square feet	600 * Act Pres	Gasifier Area	33.18 square feet	600 * Act Press
Less 37" Carb. Tube	25.74 square feet		Less Carbonizer Tube	30.78 square feet	
Superficial Velocity	0.29 ft per second	Riley Morg:0.33	Superficial Velocity	0.24 ft per second	
Less 24" Carb. Tube	30.04 square feet				
Superficial Velocity	0.25 ft per second above grate		Conventional Fixed-bed Gasifier Grate Velocity =	0.87496736 ft per second	
Superficial Velocity	0.51 ft per second above grate (2 ft above grate)			Solids Velocity Through Pyrolyzer Tube	

Determination of the makeup of air based on a given amount of moisture in the air

0.00696	LB H_2O / LB DRY AIR
144.32056	LB/HR OF H_2O
20735.713	LB/HR OF DRY AIR
15665.831	LB/HR OF N_2
4800.3175	LB/HR OF O_2
274.7482	LB/HR OF AR
9.8909351	LB/HR OF CO_2
559.49397	MOLS OF N_2
150.00992	MOLS OF O_2
6.8687049	MOLS OF AR
0.224794	MOLS OF CO_2
8.017809	MOLS OF H_2O
724.6152	TOTAL MOLS
0.7721256	MOLS % OF N_2
0.2070201	MOLS % OF O_2
0.0094791	MOLS % OF AR
0.0003102	MOL % OF CO_2
0.0110649	MOL % OF H_2O

Void Fraction Assumption	40.00%	Pyrolyzer Tube Volume : 27.52 cu ft	
Coal Feed Rate (pph)	12000		
Coal Density (lb/cu ft)	55		
Coal Volume (cu ft/ min)	9.09		
Coal Velocity (fpm)	3.79		

Solids Velocity Through Inner Annulus

Char Volume Reduction	20.00%		
Char Volume	7.27	cu ft/min	
Char Velocity Assumption	1.00	ft per min	
		Inner Annulus Volume, 6 ft hgt	
Inner Annulus Area (sq ft)	1.92	18.98	cu ft
Pyrolyzer OD (inches)	32	3.16	sq ft cross sect area
Pyrolyzer OD Area	5.59	1152	act cu ft/min gas flow
Inner Annulus + Pyrolyzer Area	7.51	6.07	fps @ 1700°F
Outside Diameter of IA (inches)	37.09		

Solids Velocity Through the Gasifier

Char Volume @ Mid-Gasidier	7.27
Inside Dia of Gasifier (ft)	8
Outside Dia of Pyrolyzer (ft)	2.67
Gasifier ID Area (sq ft)	50.27
Pyrolyzer OD Area	5.59
Gasifier Actual Area (sq ft)	44.68
Char Velocity (ft/min)	0.04
Char Velocity (ft/hr)	2.58

DOE - GPIF - PyGas™ Low Devol Spec Coal (Kinetically Balanced)
Conceptual Design Support Document, Mass Balance
CRSS Predicted Output
Contr. 31604
Inputs

Revision Number 1 CONTRACT NO. DE-AC21-92MC28202

	Dry Interactive Coal & Limestone		METC spec	Interactive	New Analysis		Limestone Analysis Input	
Coal Proximate Analysis, %		Fixed Carbon	52.00%	52.00%			CaCO3	
		Volatile Matte	30.00%	30.00%		Purity	95.94%	
		Moisture	3.00%	3.00%		Moisture	0.40%	
		Ash	15.00%	15.00%				
		Total	100.00%	100.00%		Calcium	1167	
Coal Ultimate Analysis	70.74%	Carbon	68.60%	68.60%			350	
	4.74%	Hydrogen	4.60%	4.60%				
	4.84%	Oxygen	4.70%	4.70%	need to verify		1398	
	1.24%	Nitrogen	1.20%	1.20%				
	2.89%	Sulfur	2.80%	2.80%				
	0.10%	Chlorine	0.10%	0.10%	need to verify			
	0.00%	Moisture	3.00%	3.00%			12 * Moisture	
	15.47%	Ash	15.00%	15.00%			124 *Ash	
	100.01%	Total	100.00%	100.00%			3050	
*Moisture remaining in coal/limestone after drying				376	lb/hr			
*Coal Feed Rate (per PyGas Gasifier)	6.5 ft Dia Test Size		12000	13335	lb/hr		109	-0.21% C
*Coal, Higher Heating Value			12500	12500	Btu/lbm			0.61% H
*Coal Feed Temperature			12000	150	F			-0.29% O
*Gasifier Pressure				600	psia			-0.62%
Pyrolyzer Steam to Coal Ratio (lb/lb)				0.0000015				-0.04%
*Enthalpy of Steam entering pyrolyzer				1203.70	Btu/lbm			
*Temperature of Feed Air to Pyrolyzer in Gasifier				150	F			
*Temperature of Feed Steam to Pyrolyzer in Gasifier				486	F		210	
*Moisture in Air				0.0064	lb H2O/ lb Dry Air		219	
*Percent Conversion of Coal Nitrogen to NH3 in gas				90.00%				
Pyrolyzer Temperature				1650	F			

*Air to Coal Ratio into top of Gasifier	0.0000	start by adding air to peak desired temp, make sure M317 = M318
*Temperature of Air into top of Gasifier	300	F
*Steam to Coal Ratio into top of Gasifier	0.000000	
*Temperature of Steam into top of Gasifier	700	F
*Enthalpy of Steam injected at top of gasifier	1351.80	Btu/lbm
*Peak Temperature at Top of Gasifier	1589	F(set = to G322, let iteration happen, then insert the number)
*Percentage Bed Voidage	38.00%	

In Determining Gas Composition at the top of Gasifier, you must enter lb/hr of H2 to be combusted. Balance oxygen. If some oxygen still remains after hydrogen is gone, input lb/hr of carbon monoxide to consume remaining oxygen. Then, increase steam to coal ratio until temperature balances.

*CH4 0

adjust G317 input until balanced

lb/hr of H2 available	226 lb/hr (=G113)	Oxygen Balance	
*lb/hr of H2 combusted	0.0000001 lb/hr	Oxygen available	0 lb/hr
lb/hr of CO combusted	0 lb/hr	Oxygen Consumed	0 lb/hr

Steam to Coal Ratio 0.0000001

=IF(G$322>G$323,G321+(G$322-G$323)*0.1,G321+(G$323-G$322)*0.1)

Temperature Estimated	1589 F (=AE142)	iterate to within 1° F by changing cell K301.
Temperature Desired	1589 F (=K301)	
Difference	0.04	

*Low-Btu Gas Exit Temperature 1500.00 F

Two reactions dominate the gasification of char. The rate at which these equations occur is a function of temperature and reactant and product concentration. As the gases move down through the upper bed, the char reacts with the gases fueled by the internal heat evolved from the partial combustion of the gases in the upper section of the gasifier. The gasification reactions slow down as the temperature of the bed and concentration of carbon decreases. To determine the gas composition exiting the upper bed, the rates for these two equations must be evaluated to find the amount of reactants consumed and amount of products produced. For accuracy, thr rate equations are evaluated at different points within the bed. This is done by calculating the rate per unit volume with the conditions and selecting a volume to "step" through the bed and calculate the heat absorbed by the gasification reactions. By iterating the temperature at the end of the volumetric step, we can balance the heat absorbed by the reactions with the heat released by the products of the reactions and inerts as they cool from the initial temperature to the final (iterated) temperature. Upon balancing heat, all variables within the rate equations are re-calculated and the process repeated by selecting larger volumetric steps until the final temperature reaches a predetermined gas exit temperature.

	Last iteration values		
Step One through upper bed			
	1466.225974	1413.51293 iteration formula	
*Volumetric Step (select between 2000 and 5000 ccm	3397.568	3768.902 ccm	
	2179.206753	2084 F	
*Predicted Temp after First Step (iterate Temp)	1405.803119	1413.51293 Kiterate to within +/- 1,000 Btu/hr	
Heat Released by Bed Cooling	2276950.66	3337522 Btu/hr	
Heat Absorbed by Gasification Reactions	2276950.569	3337522 Btu/hr	
	-0.09099674	0 Btu/hr	Difference
Step Two through upper bed			
	1371.852569	1325.41050 iteration formula	
*Volumetric Step (select between 4000 and 15000 ccr	10677.73333	11776.6 ccm	
	2009.334625	1926 F	
*Predicted Temp after Second Step (iterate Temp)	1322.306011	1325.41050 Kiterate to within +/- 1,000 Btu/hr	
Heat Released by Bed Cooling	3168950.672	2369312 Btu/hr	
Heat Absorbed by Gasification Reactions	3168950.665	2369312 Btu/hr	
	-0.00657716	0 Btu/hr	Difference
Step Three through upper bed			
	1296.024886	1252.26722 iteration formula	
*Volumetric Step (select between 8000 and 45000 ccr	31469.09333	34707.64 ccm	
	1872.844795	1794 F	
*Predicted Temp after Third Step (iterate Temp)	1247.847017	1252.26722 Kiterate to within +/- 1,000 Btu/hr	
Heat Released by Bed Cooling	2501434.795	1929246 Btu/hr	
Heat Absorbed by Gasification Reactions	2501434.785	1929246 Btu/hr	
	-0.00498772	0 Btu/hr	Difference
Step Four through upper bed (stay above 1700°F)			
	1237.66423	1199.68117 iteration formula	
*Volumetric Step (select between 16000 and 135000	85566.6	94989.9 ccm	
	1767.795615	1699 F	
*Predicted Temp after Fourth Step (iterate Temp)	1194.07830	1199.68117 Kiterate to within +/- 1,000 Btu/hr	
Heat Released by Bed Cooling	1899709.376	1367116 Btu/hr	
Heat Absorbed by Gasification Reactions	1899709.374	1367116 Btu/hr	
	-0.0022529	0 Btu/hr	Difference
Step Five through upper bed (go for approx. 1750 F, stay above 1700°F)			
	1175.22164	1173.71169 iteration formula	
*Volumetric Step (select between 32000 and 405000	323102.1667	225000 ccm	
	1655.398953	1653 F	
*Predicted Temp after Fifth Step (iterate Temp)	1161.46106	1173.71169 Kiterate to within +/- 1,000 Btu/hr	
Heat Released by Bed Cooling	2008708.379	669423 Btu/hr	
Heat Absorbed by Gasification Reactions	2008708.376	669423 Btu/hr	

	-0.00391865	0 Btu/hr	Difference

Step Six through upper bed

	1174.786878	1173.55445 Iteration formula	
*Volumetric Step (select between 64000 and 1215000	64469.33333	71104 ccm	
	1654.616381	1652 F	
*Predicted Temp after Sixth Step (iterate Temp)	1161.41290	1173.55445 K iterate to within +/- 1,000 Btu/hr	
Heat Released by Bed Cooling	13914.83086	4043 Btu/hr	
Heat Absorbed by Gasification Reactions	13914.84391	4043 Btu/hr	
	0.013055852	0 Btu/hr	Difference

Step Seven through upper bed

	1174.683486	1173.53105 Iteration formula	
*Volumetric Step (iterate volumetric step)	17088	18332 ccm	
	1654.430274	1652 F	
*Predicted Temp after Seventh Step	1161.40797	1173.53105 K iterate to within +/- 1,000 Btu/hr	
Heat Released by Bed Cooling	3309.003567	602 Btu/hr	
Heat Absorbed by Gasification Reactions	3309.008182	602 Btu/hr	
	0.00461485	0 Btu/hr	Difference

L O W E R B E D C A L C U L A T I O N S

*Air/Coal Ratio for air to grate (Range = 0.3 to 0.9)	Air/Carbon (Above Grate)	4.08	1.4251	iteration formula for balancing undergrate air with O2 consumed	
			1.425	iterate to within 1% carbon in ash	
*Temperature of Air Injected into grate of Gas	Steam/Carbon (Above Grate) =	0.92	225 F		111.44
*Steam to Air Ratio for steam input to grate(typ range is 0.14 bit,0.2 for anthr,0.5 char)			0.226	129 Low-Btu Gas HHV	127.81
*Temperature of Steam Injected into grate of Gasif	Air/Steam (Above Grate)=	4.42	700 F		126.73
*Enthalpy of Steam into Grate			1351.80 B	0.43% Carbon in Ash (wt%)	129.23
*Peak Temperature in Combustion Section of Gasifier			2500 F	0.00 lb/hr O2	

In order to calculate the gasification reactions in the bottom bed, the bed will be viewed from the grate up to the exit. Initially, we look at the temperature rise caused by the incoming steam/air mixture cooling down the exiting ash. Iterate steam/air mixture temperature until the heat released by the ash equals the heat absorbed by the steam/air mixture.
Note: The Ash is cooled from maximum peak temperature of gasifier to entry temperature of air/steam.

		533.82800 Iteration formula
*Temperature of air/steam mixture upon contact with	526.566637	533.82800 F iterate to within +/- 1,000 Btu/hr
Heat Absorbed by Steam/Air Heating		1228815 Btu/hr
Heat Released by Ash Cooling		1228815 Btu/hr
	Difference	0 Btu/hr

Once the steam/air mixture passes the ash cooling zone, the oxygen is assumed to combine with the char to raise the bed temperature high enough to support the gasification reactions in conjunction with the oxidation of carbon.
Vary lb/hr of carbon until the heat required to raise the bed temperature to 1700 F is reached. Carbon is iterated until the heat balances.

			612.44470 Iteration formula
	Available Carbo	4189	51%
*Carbon Consumed		546.8	612.44470 I iterate to within +/- 1,000 Btu/hr
Heat Released by Oxidation of Carbon to 1700 _F			8632002 Btu/hr
Heat Absorbed by Bed			8632002 Btu/hr
	Difference		0 E Adding 100 # C Reduces This 1.3-mil

Once 1700 F is met, the gasification reactions now begin in conjunction with the oxidation of carbon. Here, again, we iterate volume to determine reaction rates, and then iterate temperature until the heat released/absorbed by the reactions equals the heat released/absorbed by the bed. This process is done until the final gas temperature is reached. Finally, carbon conversion is computed. If the carbon conversion is unacceptable, change air input and redo lower bed iterations.

			0.21 A/C
Step One through lower bed			0.91 S/A
		1293.14371 iteration formula	-12.54 O2
Volumetric Step (select between 1000 and 4000 ccm)		1218.945313 ccm	
(If temp increases above limit, go back & add steam, or reduce air)		1868 F	
*Predicted Temp after First Step (iterate Temp)	1292.77978	1293.14371 Kiterate to within +/- 1,000 Btu/hr	0.21 A/C
			0.84 S/A
Heat Absorbed by Bed Heating		1459512 Btu/hr	-1.94 O2
Heat Released by Oxidation Reaction		1459512 Btu/hr	
Difference		0 EAdding 10_K Increases This by 150k	
			0.21 A/C
Step Two through lower bed			0.79 S/A
		5437.61083 iteration formula	-5.25 O2
*Volumetric Step (iterate volume to get to peak temp)	4838.061985	5437.61083 ccm iterate to within +/- 1,000 Btu/hr	
		2500 F Varies With Ash Fusion Characteristics	
Predicted Temp after Second Step	1533.3	1644.4 K	0.22 A/C
			0.88 S/A
Heat Released by Bed Cooling		6053613 Btu/hr	-1.14 O2
Heat Absorbed by Gasification Reactions		6053613 Btu/hr	
Difference		0 EAdding 1000 ccm Decreases This by 700k	
			0.23 A/C
Step Three through lower bed			0.92 S/A
		1552.48130 iteration formula	-21.8 O2
Volumetric Step (select between 1000 and 6000 ccm)		1167.96875 ccm	
		2334 F	0.23 A/C
*Predicted Temp after Third Step	1539.83090	1552.48130 Kiterate to within +/- 1,000 Btu/hr	0.86 S/A
			-0.23 O2
Heat Released by Bed Cooling		1691821 Btu/hr	
Heat Absorbed by Gasification Reactions		1691821 Btu/hr	0.23 A/C
Difference		0 EAdding 10_K Decreases This by 150k	0.81 S/A
			-2.53 O2
Step Four through lower bed			
		1477.18494 iteration formula	0.23 A/C
Volumetric Step (select between 2000 and 18000 ccm)		3333 ccm	0.85 S/A
		2199 F	-0.64 O2
*Predicted Temp after Fourth Step (iterate Temp)	1472.89351	1477.18494 Kiterate to within +/- 1,000 Btu/hr	
			0.23 A/C
Heat Released by Bed Cooling		1436771 Btu/hr	0.87 S/A
Heat Absorbed by Gasification Reactions		1436772 Btu/hr	0.99 O2
Difference		0 EAdding 10_K Decreases This by 150k	6.51 Ash Carbon
			0.25 A/C
Step Five through lower bed		11103.81393 iteration formula	0.86 S/A
*Volumetric Step (iterate until all oxygen is consumec	9842.436614	11103.81393 citerate to within 0.0-0.5 lb/hr of O2	0.86 O2
(If negative, go back & add more O2)			3.85 Ash Carbon
lb/hr of Oxygen	0.00 lb/hr	Adding 300 ccm Decreases This by 5#	
		1403.11399 iteration formula	0.26 A/C
		2066 F	0.86 S/A
*Predicted Temp after Fifth Step (iterate Temp)	1394.42812	1403.11399 Kiterate to within +/- 1,000 Btu/hr	-1.79 O2
			1.2 Ash Carbon
Heat Released by Bed Cooling		1516506 Btu/hr	
Heat Absorbed by Gasification Reactions		1516506 Btu/hr	0.26 A/C
Difference		0 EAdding 10_K Decreases This by 180k	0.85 S/A
			0.02 O2

Step Six through lower bed			2.57 Ash Carbon
		1392.47895 iteration formula	
Volumetric Step (select between 4000 and 65000 ccm)		1000 ccm	0.27 A/C
		2046 F	0.85 S/A
*Predicted Temp after Sixth Step (iterate Temp)	1383.25226	1392.47895 Kiterate to within +/- 1,000 Btu/hr	0.86 O2
			1.51 Ash Carbon
Heat Released by Bed Cooling		216265 Btu/hr	
Heat Absorbed by Gasification Reactions		216265 Btu/hr	0.28 A/C
Difference		0 EAdding 10_K Decreases This by 180k	0.85 S/A
			-1.7 O2
Step Seven through lower bed			-0.1 Ash Carbon
		33601.16695 iteration formula	
*Volumetric Step (iterate volumetric step)	31258.01789	33601.16695 citerate to within +/- 1,000 Btu/hr	0.28 A/C
		1500 F	0.84 S/A
Predicted Temp after Seventh Step		1088.7 K	0.17 O2
			-0.03 Ash Carbon
Heat Released by Bed Cooling		6341894 Btu/hr	
Heat Absorbed by Gasification Reactions		6341894 Btu/hr	0.28 A/C
Difference		0 EAdding 10_K Decreases This by 200k	0.845 S/A
			0.93 O2
			0.08 Ash Carbon

Carbon in Ash (wt%) 0%	% of Volume	Temperature (°F) Top to Middle	% of Vol	Temperature (°F) Bottom to Middle	Temperature (°F) Pyrolyzer	% of Vol	Char Temp Top to Middle	Char Temp Bot to Mid	Coal Temp Feed to Pyro	
			0%	484				534	150	0%
Bed Temperature Profile	83%	2302	25%	534	150	0%	1600	584	150	24%
Step 1	78%	2084	27%	1868	150	20%	1699	1584	150	27%
Step 2	77%	1926	28%	2500	1600	25%	1653	1600	1500	28%
Step 3	76%	1794	28%	2334	1600	50%	1652	1800	1600	28%
Step 4	71%	1699	28%	2199	1600	78%	1587	2334	1600	28%
Step 5	61%	1653	30%	2066	2302	83%	1587	2046		30%
Step 6	58%	1652	30%	2046			1587	1652		30%
Step 7	57%	1652	32%	1500			1587	1587		32%
Blend	55%	1587	35%	1500				1600		35%

)tal Volume (to Kinetic Limits) (cc)	459679	16.23 cuft need'	56863		
Total Gasif Inner Annulus Vol (cc)	537527 assuming 6 ft h	86%	850775	889699	
	18.98 cu ft for vert wall pyrolyzer				PAGE SETUP: 51% FOR MASS E
	29.86 calculated cu ft vol with increasing pyrolyzer tube diameter				PAGE SETUP: 72% FOR INPUT

*Input Moisture of Gas to HGCU		27.30%		
*Input Final Temperature of Gas		1150 F		
Steam Injection Required		49		
Water Injection Required		5,272	3041	
PHASE II, Hot Gas Cleanup Unit (HGCU) Input Data & References				
* PDU Capacity		150,000 scfh		
PDU vs GPIF Size (Ref:DOE 2/23/93, Table 3, Page 6)		7.60 GPIF Size vs. PDU Size		
*Zinc Titanate/Ferrite (Ref:DOE 2/23/93, Table 3, Page -9-)		7.6 lb/hr		
*Spent Zinc Titanate/Ferrite (Ref: DOE 2/23/93, Table 3, Page -9-)		6.8 lb/hr		
*Process Air (Ref: DOE 2/23/93, Table 3, Page -9-, then make SO2vol=12%)		111,000 scfh		
Ratio of Wgt% SO2 to vol% SO2 (Skinner 3/8/93)is 34/12 ---->	0.48305	3% SO2 Concentration (vol		10% SO2 (wgt)
*Process Steam (Ref: DOE 2/23/93, Table 3, Page -9-)		4,500 lb/hr		4%
*Process Steam (Scaled Up From PDU to GPIF)		34,200 lb/hr		16%
*Process Steam (Ref: DOE Bissett 8/15/90)		1,565 lb/hr		
*Process Steam (Scaled Up From PDU to GPIF)		11,892 lb/hr		
*Process Steam (Select Either Reference Above, K568 or K570)		0 lb/hr		

Finding the Results in Upper Area of Gasifier

Positive sign means heat is absorbed in process / Negative sign means heat is released in process

Char & Ash

Sensible heat			
Temp of coal (K)	1579.72		
C - delta h	457.54 Btu/lbm		
ASH - delta h	258.18 Btu/lbm		
Total of coal	389.89 Btu/lbm	840.888105	
Total heat	2,070,241 Btu/hr		96.44

Gases

Predicted Temperature 1579.72 K

Heat Absorbed Through Heating to 2383.5

			Btu/hr
delta h CO2	154.25	Btu/lbm	657,273
delta h CO	264.35	Btu/lbm	2,203,642
delta h H2O	583.63	Btu/lbm	1,606,299
delta h H2	3449.58	Btu/lbm	1,212,970
delta h CH4	1161.48	Btu/lbm	0
delta h H2S	317.77	Btu/lbm	113,613
delta h N2	326.85	Btu/lbm	9,062,030
delta h Ar	147.63	Btu/lbm	71,619
delta h NH3	799.65	Btu/lbm	126,150
		Total	17,125,836
			13,537
		2,383	

Heat of reactions (Btu/hr)

							HEAT OF FORMATION		
							Btu/mol	Btu/lbm	Btu/hr
H2	+	1/2 O2	---->	H2O			-104036.20	-5774.98	(2,670,972)
82 LB/HR		411 LB/HR		463 LB/HR					
CO	+	1/2 O2	---->	CO2			-121744.50	-2766.29	0
0 LB/HR		0 LB/HR		0 LB/HR					
CH4	---->	C	+	2H2			32200.2	2007.24	0
0 LB/HR		0 LB/HR		0 LB/HR					
C	+	1/2 O2	---->	CO			-47548.8	-1697.57	0
0 LB/HR		0 LB/HR		0 LB/HR					
CH4	+	1/2 O2	---->	CO2	+	H2O	-345165.80	-7842.89	-14392102
669 LB/HR		2,669 LB/HR		1,835 LB/HR		1,503 LB/HR			
								(17,063,073)	

O2 CONSUMED	3,079
O2 AVAILABLE	3,080
HEAT RELEASED	(17,112,301)
HEAT ABSORBED	17,125,836
TEMP CALC	2,383
TEMP EST	2,384

Total Heat needed from Water-Gas Shift

Equation	Heat Released
CO + H2O ---> CO2 + H2	17708.6 Btu/mol
	402.38 Btu/lb of CO2

Initial Gases Mass Flows

CO	8,414	lb/hr	300	mols/hr
H2O	2,806	lb/hr	156	mols/hr
CO2	4,139	lb/hr	94	mols/hr
H2	346	lb/hr	172	mols/hr

15.80 Temp (k)	1579.72
cp H2O	0.073
cp CO2	0.032
cp N2	0.180
cp O2	0.000
cp CH4	0.000
cp CO	0.057
cp Ar	0.001
cp H2	0.031
Total	0.374

Assume 1120 F average temp of absorber
Constant for water -gas shift reaction - K 0.3710

Mols of CO initially	300
Mols of H2O initially	156
Mols of CO2 initially	94
Mols of H2 initially	172

K = (yCO2*yH2)/(yH2O*yCO) = [(2278+z)*(2911+z)]/[(1716-z)*(5862-z)]

following quadratic equation exists (az2 + bz + c = 0) :

a= -0.6290307
b= -438
c= 1214

using the quadratic equation to solve
root 1 = -694.152
root 2 = 2.780

Mols of CO finally	297.6077169	8,336	lb/hr
Mols of H2O finally	152.9656716	2,756	lb/hr
Mols of CO2 finally	96.82387827	4,261	lb/hr
Mols of H2 finally	174.4189478	352	lb/hr

Heat Released in Water-Gas Shift
49,227 Btu/hr

Gasification of Char

Gases			
Predicted Temperature	1089.00 K		
			Btu/hr
delta h CO_2	-278.63	Btu/lbm	(510,919)
delta h CO	-258.63	Btu/lbm	(3,630,092)
delta h H_2O	-531.16	Btu/lbm	(307,660)
delta h H_2	-3374.08	Btu/lbm	(2,008,059)
delta h CH_4	-1138.96	Btu/lbm	0
delta h H_2S	-311.15	Btu/lbm	(111,249)
delta h N_2	-247.03	Btu/lbm	(6,848,997)
delta h Ar	-109.89	Btu/lbm	(53,313)
delta h NH_3	-783.53	Btu/lbm	(123,607)
			(13,794,115)
		Total	(14,874,468)
			(7,115,829)
	2001.37259		

Char & Ash		
Sensible heat		
Temp of coal (K)	1089.00	
C - delta h	-448.40	Btu/lbm
ASH - delta h	-252.50	Btu/lbm
Total of coal	-337.97	Btu/lbm
Total heat	(1,080,353)	Btu/hr

Heat of reactions (Btu/hr)

										HEAT OF FORMATION		
										Btu/mol	Btu/lbm	Btu/hr
CO		+	H_2O	---->	CO_2		+	H_2		-17708.60	-402.38	0
0	LB/HR		0	LB/HR	0	LB/HR		0	LB/HR			
C		+	$2H_2$	---->	CH_4					-32200.20	-2007.24	0
0	LB/HR		0	LB/HR	0	LB/HR						
C		+	H_2O	------>	CO		+	H_2		56487.40	2016.69	0
0	lb/hr		0	lb/hr	0	lb/hr		0	lb/hr			
CO_2		+	C	------>	CO					74196.00	2648.91	7758639
2,301	lb/hr		628	lb/hr	2,929	lb/hr						
												7758639

CARBON AVAILABLE	2113.24
CARBON USED	628.00
HEAT RELEASED	7,758,639
HEAT ABSORBED	-14874468
TEMP CALC	2001
TEMP EST	1500.2

Initial Conditions at the Top of Gasifier

PH2O	3.58	PH2	4.08
PCO	6.97	PCO2	2.27
Temp(K) =	1580		
Density of Coal (lbm/ft3)			40
(g/ccm)			0.641
carbon in char/ash (lb/hr)			3,508
ash in char/ash (lb/hr)			1,802
		Total	5,310

Percent Carbon in Char/Ash	66.07%
Bed Voidage	12.00%
Concentration of Carbon (gmol/ccm)	0.373
Volumetric Step	4000 ccm

$C + H_2O \rightarrow CO + H_2$

rate = 930e^(-45,000/(RT))*[C]*(PH2O-P*H2O)
where : P*H2O = PH2*PCO/(e^(17.29-16330/T)

First Iteration:

P*H2O = 0.027
rate = 0.00072569 g-mol/ccm-sec

After First Volumetric Step:

rate = 2.90274428 g-mol/sec

C Consumed	276.69 lb/hr
H2O Consumed	415.02 lb/hr
CO Made	645.28 lb/hr
H2 Made	46.44 lb/hr

$CO_2 + C \rightarrow 2CO$

rate = 930e^(-45,000/(RT))*[C]*(PCO2-P*CO2)
where : P*CO2 = PCO^2/(e^(20.92-20280/T)

P*CO2 = 0.015
rate = 0.0004598 g-mol/ccm-sec

rate = 1.8391849 g-mol/sec

C Consumed	175.31 lb/hr
CO2 Consumed	642.40 lb/hr
CO Made	617.71 lb/hr

Totals:

	lb/hr	mols/hr	wt%	mol%
CO	9,799	349.84	21.83%	19.64%
H2	398	197.46	0.89%	11.09%
CO2	3,619	82.23	8.06%	4.62%
H2O	2,341	129.93	5.22%	7.29%
H2S	358	10.49	0.80%	0.59%
N2	27,725	989.73	61.77%	55.57%
Ar	485	12.14	1.08%	0.68%
NH3	158	9.26	0.35%	0.52%
Total	44,882	1,781	100.00%	100.00%

	lb/hr	wt%
C	3,056	62.91%
ASH	1,802	37.09%
Total	4,858	100.00%

Heat Absorbed During Reactions: 3,467,371 Btu/hr

Temp after First Step		1470.79 K		2,187	F
delta h CO2	-84.31	Btu/lbm	(232,736)		
delta h CO	-89.01	Btu/lbm	(578,283)		
delta h H2O	-128.90	Btu/lbm	(294,700)		
delta h H2	-784.03	Btu/lbm	(304,139)		
delta h CH4	-279.66	Btu/lbm	0		
delta h H2S	-73.03	Btu/lbm	(26,109)		
delta h N2	-56.17	Btu/lbm	(1,557,410)		
delta h Ar	-24.39	Btu/lbm	(11,835)		
delta h NH3	-187.78	Btu/lbm	(29,623)		
			(3,034,834)		
		Total	(3,467,119)		

Temp of coal (K)	1470.79
C - delta h	-107.98 Btu/lbm
ASH - delta h	-56.77 Btu/lbm
Total of coal	-88.99 Btu/lbm
Total heat	(432,285) Btu/hr

Second Iteration
Conditions

PH2O	2.98	PH2	4.53
PCO	8.02	PCO2	1.88
Temp(K) =	1471		
Density of Coal (lbm/ft3)			40
(g/ccm)			0.641
carbon in char/ash (lb/hr)			3,056
ash in char/ash (lb/hr)			1,802
		Total	4,858

Percent Carbon in Char/Ash	62.91%
Bed Voidage	12.00%
Concentration of Carbon (gmol/ccm)	0.355
Volumetric Step	12000 ccm

C + H2O ---> CO + H2

rate = 930e^(-45,000/(RT))*[C]*(PH2O-P*H2O)
where : P*H2O = PH2*PCO/(e^(17.29-16330/T)

Second Iteration:

P*H2O = 0.075
rate = 0.00019508 g-mol/ccm-sec

After Second Volumetric Step:

rate = 2.34094957 g-mol/sec

C Consumed	223.14 lb/hr
H2O Consumed	334.70 lb/hr
CO Made	520.40 lb/hr
H2 Made	37.46 lb/hr

CO2 + C ---> 2CO

rate = 930e^(-45,000/(RT))*[C]*(PCO2-P*CO2)
where : P*CO2 = PCO^2/(e^(20.92-20280/T)

P*CO2 = 0.051
rate = 0.0001232 g-mol/ccm-sec

rate = 1.4781292 g-mol/sec

C Consumed	140.90 lb/hr
CO2 Consumed	516.29 lb/hr
CO Made	657.18 lb/hr

Totals:

	lb/hr	mole/hr	wt%	mol%
CO	10,977	391.88	24.26%	21.63%
H2	436	216.04	0.96%	11.93%
CO2	3,103	70.50	6.86%	3.89%
H2O	2,006	111.35	4.43%	6.15%
H2S	356	10.49	0.79%	0.58%
N2	27,725	989.73	61.28%	54.64%
Ar	485	12.14	1.07%	0.67%
NH3	158	9.26	0.35%	0.51%
Total	45,246	1,811	100.00%	100.00%

	lb/hr	wt%
C	2,692	59.90%
ASH	1,802	40.10%
Total	4,494	100.00%

Heat Absorbed During Reactions: 2,790,291 Btu/hr

Temp after Second Step	1381.17 K		2,026 F
delta h CO2	-51.87	Btu/lbm	(160,926)
delta h CO	-47.87	Btu/lbm	(525,404)
delta h H2O	-99.93	Btu/lbm	(200,456)
delta h H2	-622.14	Btu/lbm	(270,960)
delta h CH4	-218.60	Btu/lbm	0
delta h H2S	-58.39	Btu/lbm	(20,875)
delta h N2	-45.64	Btu/lbm	(1,265,452)
delta h Ar	-20.07	Btu/lbm	(9,736)
delta h NH3	-148.56	Btu/lbm	(23,437)
			(2,477,247)
		Total	(2,790,412)

Temp of coal (K)	1381.17	
C - delta h	-85.25	Btu/lbm
ASH - delta h	-46.44	Btu/lbm
Total of coal	-69.69	Btu/lbm
Total heat	(313,165)	Btu/hr

Third Iteration
Conditions

PH2O	2.51	PH2	4.87
PCO	8.83	PCO2	1.59
Temp(K) =	1381		
Density of Coal (lbm/ft3)			40
(g/ccm)			0.641
carbon in char/ash (lb/hr)			2,692
ash in char/ash (lb/hr)			1,802
		Total	4,494

Percent Carbon in Char/Ash	59.90%
Bed Voidage	12.00%
Concentration of Carbon (gmol/ccm)	0.338
Volumetric Step	36000 ccm

C + H2O ---> CO + H2

rate = 930e^(-45,000/(RT))*[C]*(PH2O-P*H2O)
where : P*H2O = PH2*PCO/(e^(17.29-16330/T)

CO2 + C ---> 2CO

rate = 930e^(-45,000/(RT))*[C]*(PCO2-P*CO2)
where : P*CO2 = PCO^2/(e^(20.92-20280/T)

Third Iteration:

P*H2O = 0.182
rate = 5.4605E-05 g-mol/ccm-sec

P*CO2 = 0.153
rate = 3.381E-05 g-mol/ccm-sec

After Third Volumetric Step:

rate =	1.97298422 g-mol/sec	rate =	1.2172801 g-mol/sec
C Consumed	169.07 lb/hr	C Consumed	116.03 lb/hr
H2O Consumed	282.09 lb/hr	CO2 Consumed	425.18 lb/hr
CO Made	438.60 lb/hr	CO Made	541.21 lb/hr
H2 Made	31.57 lb/hr		

Totals:

	lb/hr	mols/hr	wt%	mol%
CO	11,956	426.86	26.25%	23.24%
H2	467	231.69	1.03%	12.61%
CO2	2,677	60.84	5.88%	3.31%
H2O	1,724	95.69	3.78%	5.21%
H2S	358	10.49	0.79%	0.57%
N2	27,725	989.73	60.87%	53.89%
Ar	485	12.14	1.07%	0.66%
NH3	158	9.26	0.35%	0.50%
Total	45,550	1,837	100.00%	100.00%

	lb/hr	wt%
C	2,388	56.99%
ASH	1,802	43.01%
Total	4,190	100.00%

Heat Absorbed During Reactions: 2,318,122 Btu/hr

Temp after Third Step 1305.41 K 1,890 F

delta h CO2	-43.11	Btu/lbm	(115,415)
delta h CO	-39.98	Btu/lbm	(478,019)
delta h H2O	-82.06	Btu/lbm	(141,456)
delta h H2	-521.40	Btu/lbm	(243,541)
delta h CH4	-176.71	Btu/lbm	0
delta h H2S	-48.17	Btu/lbm	(17,221)
delta h N2	-38.18	Btu/lbm	(1,058,585)
delta h Ar	-16.97	Btu/lbm	(8,231)
delta h NH3	-121.42	Btu/lbm	(19,154)
			(2,081,622)
		Total	(2,317,992)

Temp of coal (K)	1305.41
C - delta h	-69.53 Btu/lbm
ASH - delta h	-39.05 Btu/lbm
Total of coal	-56.42 Btu/lbm
Total heat	(236,370) Btu/hr

Fourth Iteration
Conditions

PH2O	2.13	PH2	5.15
PCO	9.49	PCO2	1.35
Temp(K) =	1305		
Density of Coal (lbm/ft3)			40
(g/ccm)			0.641
carbon in char/ash (lb/hr)			2,388
ash in char/ash (lb/hr)			1,802
		Total	4,190
Percent Carbon in Char/Ash			56.99%
Bed Voidage			12.00%
Concentration of Carbon (gmol/ccm)			0.321
Volumetric Step			108000 ccm

C + H2O ---> CO + H2

rate = 930e^(-45,000/(RT))*[C]*(PH2O-P*H2O)
where : P*H2O = PH2*PCO/(e^(17.29-16330/T)

Fourth Iteration:

P*H2O = 0.410
rate = 1.4841E-05 g-mol/ccm-sec

After Fourth Volumetric Step:

rate = 1.6027852 g-mol/sec

C Consumed	152.78 lb/hr
H2O Consumed	229.16 lb/hr
CO Made	356.30 lb/hr
H2 Made	25.64 lb/hr

CO2 + C ---> 2CO

rate = 930e^(-45,000/(RT))*[C]*(PCO2-P*CO2)
where : P*CO2 = PCO^2/(e^(20.92-20280/T)

P*CO2 = 0.413
rate = 8.119E-06 g-mol/ccm-sec

rate = 0.8768808 g-mol/sec

C Consumed	83.59 lb/hr
CO2 Consumed	306.28 lb/hr
CO Made	389.86 lb/hr

Totals:

	lb/hr	mols/hr	wt%	mol%
CO	12,703	453.50	27.74%	24.43%
H2	493	244.41	1.08%	13.17%
CO2	2,371	53.88	5.18%	2.90%
H2O	1,495	82.97	3.26%	4.47%
H2S	358	10.49	0.78%	0.57%
N2	27,725	989.73	60.55%	53.31%
Ar	485	12.14	1.06%	0.65%
NH3	158	9.28	0.34%	0.50%
Total	45,787	1,856	100.00%	100.00%

	lb/hr	wt%
C	2,151	54.42%
ASH	1,802	45.58%
Total	3,953	100.00%

Heat Absorbed During Reactions: 1,751,268 Btu/hr

Temp after Fourth Step 1247.39 K 1,785 F

delta h CO2	-32.55	Btu/lbm	(77,181)
delta h CO	-30.32	Btu/lbm	(385,130)
delta h H2O	-61.42	Btu/lbm	(91,807)
delta h H2	-396.50	Btu/lbm	(195,371)
delta h CH4	-130.32	Btu/lbm	0
delta h H2S	-36.15	Btu/lbm	(12,925)
delta h N2	-28.99	Btu/lbm	(803,793)
delta h Ar	-12.99	Btu/lbm	(6,303)
delta h NH3	-90.40	Btu/lbm	(14,261)
			(1,586,771)
		Total	(1,751,540)

Temp of coal (K)	1247.39
C - delta h	-51.66 Btu/lbm
ASH - delta h	-29.76 Btu/lbm
Total of coal	-41.68 Btu/lbm
Total heat	(164,769) Btu/hr

Fifth Iteration

Conditions

PH2O	1.82	PH2	5.38
PCO	9.97	PCO2	1.18
Temp(K) =	1247		
Density of Coal (lbm/ft3)			40
(g/ccm)			0.641
carbon in char/ash (lb/hr)			2,151
ash in char/ash (lb/hr)			1,802
		Total	3,953

Percent Carbon in Char/Ash	54.42%
Bed Voidage	12.00%
Concentration of Carbon (gmol/ccm)	0.307
Volumetric Step	1705000 ccm

$C + H_2O \longrightarrow CO + H_2$

rate = 930e^(-45,000/(RT))*[C]*(PH2O-P*H2O)
where : P*H2O = PH2*PCO/(e^(17.29-16330/T)

Fifth Iteration:

P*H2O = 0.805
rate = 3.7536E-06 g-mol/ccm-sec

After Fifth Volumetric Step:

rate = 6.40014754 g-mol/sec

C Consumed	610.07 lb/hr
H2O Consumed	915.07 lb/hr
CO Made	1422.76 lb/hr
H2 Made	102.40 lb/hr

$CO_2 + C \longrightarrow 2CO$

rate = 930e^(-45,000/(RT))*[C]*(PCO2-P*CO2)
where : P*CO2 = PCO^2/(e^(20.92-20280/T)

P*CO2 = 0.940
rate = 9.023E-07 g-mol/ccm-sec

rate = 1.538491 g-mol/sec

C Consumed	146.65 lb/hr
CO2 Consumed	537.37 lb/hr
CO Made	684.02 lb/hr

Totals:

	lb/hr	mols/hr	wt%	mol%
CO	14,809	528.72	31.82%	27.55%
H2	595	295.21	1.28%	15.38%
CO2	1,834	41.67	3.94%	2.17%
H2O	580	32.18	1.25%	1.68%
H2S	358	10.49	0.77%	0.55%
N2	27,725	989.73	59.57%	51.56%
Ar	485	12.14	1.04%	0.63%
NH3	158	9.26	0.34%	0.48%
Total	46,543	1,919	100.00%	100.00%

	lb/hr	wt%
C	1,395	43.63%
ASH	1,802	56.37%
Total	3,197	100.00%

Heat Absorbed During Reactions: 4,681,170 Btu/hr

Temp after Fifth Step	1088.97 K		1,500 F		
delta h CO2	-86.80	Btu/lbm	(159,170)	Temp of coal (K)	1088.97
delta h CO	-81.46	Btu/lbm	(1,206,404)	C - delta h	-134.00 Btu/lbm
delta h H2O	-181.88	Btu/lbm	(93,830)	ASH - delta h	-80.50 Btu/lbm
delta h H2	-1070.22	Btu/lbm	(636,931)	Total of coal	-103.84 Btu/lbm
delta h CH4	-333.72	Btu/lbm	0	Total heat	(331,937) Btu/hr
delta h H2S	-95.44	Btu/lbm	(34,125)		
delta h N2	-78.06	Btu/lbm	(2,164,163)		
delta h Ar	-35.48	Btu/lbm	(17,211)		
delta h NH3	-236.42	Btu/lbm	(37,139)		
			(4,348,973)		
		Total	(4,680,909)		

Sixth Iteration
Conditions

PH2O	0.68	PH2	6.28
PCO	11.25	PCO2	0.89
Temp(K) =	1089		
Density of Coal (lbm/ft3)			40
(g/ccm)			0.641
carbon in char/ash (lb/hr)			1,395
ash in char/ash (lb/hr)			1,802
		Total	3,197

Percent Carbon in Char/Ash	43.63%
Bed Voidage	12.00%
Concentration of Carbon (gmol/ccm)	0.246
Volumetric Step	0 ccm

C + H2O ---> CO + H2

rate = 930e^(-45,000/(RT))*[C]*(PH2O-P*H2O)
where : P*H2O = PH2*PCO/(e^(17.29-16330/T)

Sixth Iteration:

P*H2O = 7.122
rate = -1.382E-06 g-mol/ccm-sec

After Sixth Volumetric Step:

rate = 0 g-mol/sec

C Consumed	0.00 lb/hr
H2O Consumed	0.00 lb/hr
CO Made	0.00 lb/hr
H2 Made	0.00 lb/hr

CO2 + C ---> 2CO

rate = 930e^(-45,000/(RT))*[C]*(PCO2-P*CO2)
where : P*CO2 = PCO^2/(e^(20.92-20280/T)

P*CO2 = 12.720
rate = -2.485E-06 g-mol/ccm-sec

rate = 0 g-mol/sec

C Consumed	0.00 lb/hr
CO2 Consumed	0.00 lb/hr
CO Made	0.00 lb/hr

Totals:

	lb/hr	mols/hr	wt%	mol%
CO	14,809	528.72	31.82%	27.55%
H2	595	295.21	1.28%	15.38%
CO2	1,834	41.67	3.94%	2.17%
H2O	580	32.18	1.25%	1.68%
H2S	358	10.49	0.77%	0.55%
N2	27,725	989.73	59.57%	51.56%
Ar	485	12.14	1.04%	0.63%
NH3	158	9.26	0.34%	0.48%
Total	46,543	1,919	100.00%	100.00%

	lb/hr	wt%
C	1,395	43.63%
ASH	1,802	56.37%
Total	3,197	100.00%

Heat Absorbed During Reactions: 0 Btu/hr

Temp after Sixth Step		1089 K	1,500 F
delta h CO2	0.02	Btu/lbm	30
delta h CO	0.02	Btu/lbm	226
delta h H2O	0.03	Btu/lbm	17
delta h H2	0.20	Btu/lbm	120
delta h CH4	0.06	Btu/lbm	0
delta h H2S	0.02	Btu/lbm	6
delta h N2	0.01	Btu/lbm	406
delta h Ar	0.01	Btu/lbm	3
delta h NH3	0.04	Btu/lbm	7
			814
		Total	875

Temp of coal (K)	1089.00	
C - delta h	0.02	Btu/lbm
ASH - delta h	0.02	Btu/lbm
Total of coal	0.02	Btu/lbm
Total heat	61	Btu/hr

Seventh Iteration
Conditions

PH2O	0.68	PH2	6.28
PCO	11.25	PCO2	0.89
Temp(K) =	1089		
Density of Coal (lbm/ft3)			40
(g/ccm)			0.641
carbon in char/ash (lb/hr)			1,395
ash in char/ash (lb/hr)			1,802
		Total	3,197

Percent Carbon in Char/Ash	43.63%
Bed Voidage	12.00%
Concentration of Carbon (gmol/ccm)	0.246
Volumetric Step	0 ccm

$C + H_2O \longrightarrow CO + H_2$

rate = 930e^(-45,000/(RT))*[C]*(PH2O-P*H2O)
where : P*H2O = PH2*PCO/(e^(17.29-16330/T)

Seventh Iteration:

P*H2O = 7.119
rate = -1.352E-06 g-mol/ccm-sec

$CO_2 + C \longrightarrow 2CO$

rate = 930e^(-45,000/(RT))*[C]*(PCO2-P*CO2)
where : P*CO2 = PCO^2/(e^(20.92-20280/T)

P*CO2 = 12.714
rate = -2.486E-06 g-mol/ccm-sec

After Seventh Volumetric Step:

rate =	0 g-mol/sec	rate =	0 g-mol/sec
C Consumed	0.00 lb/hr	C Consumed	0.00 lb/hr
H2O Consumed	0.00 lb/hr	CO2 Consumed	0.00 lb/hr
CO Made	0.00 lb/hr	CO Made	0.00 lb/hr
H2 Made	0.00 lb/hr		

Totals:

	lb/hr	mols/hr	wt%	mol%		lb/hr	wt%
CO	14,809	528.72	31.82%	27.55%	C	1,395	43.63%
H2	595	295.21	1.28%	15.38%	ASH	1,802	56.37%
CO2	1,834	41.67	3.94%	2.17%	Total	3,197	100.00%
H2O	580	32.18	1.25%	1.68%			
H2S	358	10.49	0.77%	0.55%			
N2	27,725	989.73	59.57%	51.56%			
Ar	485	12.14	1.04%	0.63%			
NH3	158	9.26	0.34%	0.48%			
Total	46,543	1,919	100.00%	100.00%			

Heat Absorbed During Reactions: 0 Btu/hr

Temp after Seventh Step		1089 K		1,500 F
delta h CO2	0.00	Btu/lbm	0	
delta h CO	0.00	Btu/lbm	0	
delta h H2O	0.00	Btu/lbm	0	
delta h H2	0.00	Btu/lbm	0	
delta h CH4	0.00	Btu/lbm	0	
delta h H2S	0.00	Btu/lbm	0	
delta h N2	0.00	Btu/lbm	0	
delta h Ar	0.00	Btu/lbm	0	
delta h NH3	0.00	Btu/lbm	0	
			0	
		Total	0	

Temp of coal (K)	1089.00
C - delta h	0.00 Btu/lbm
ASH - delta h	0.00 Btu/lbm
Total of coal	0.00 Btu/lbm
Total heat	0 Btu/hr

Ash Cooling & Steam/Air Heating

Combined Stream 12 & 13:

	LB/HR	MOLS/HR	WT%	MOL%
CO2	9	0.20	0.03	0.02
H2O	7498	416.20	29.23	39.91
N2	13706	489.29	53.43	46.92
Ar	240	6.01	0.94	0.58
O2	4198	131.19	16.37	12.58
TOTALS	25651	1042.87	100.00	100.00

ASH COMPOSITION

	LB/HR	MOLS/HR	WT%	MOL%
CARBON*	101	8.38	5.00	20.84
ASH	1911	31.81	95.00	79.16
TOTALS	2012	40.19	100.00	100.00

COMBUSTION ZONE TEMPERATURE IN GASIFIER = 2400 F
1589 K

ASH EXIT TEMPERATURE = 424 F
491 K

AIR/STEAM ENTRANCE TEMPERATURE = 423.94755 F
491 K

HEAT RELEASED IN COOLING EXITING ASH:

SENSIBLE HEAT		
C - delta h	-862.92	Btu/lbm
ASH - delta h	-539.81	Btu/lbm
TOTAL	-555.96	Btu/lbm
Total Heat	-1118614	Btu/hr

SENSIBLE HEAT		
CO2	34.81 Btu/lbm	301 Btu/hr
H2O	66.53 Btu/lbm	498854 Btu/hr
N2	34.67 Btu/lbm	475173 Btu/hr
Ar	17.19 Btu/lbm	4124 Btu/hr
O2	33.39 Btu/lbm	140162 Btu/hr
TOTALS		1118614 Btu/hr

Temperature of air/steam leaving ash bed = 567.8347769 K
562 F

0 Btu/hr difference

Calculation of Mean Cp of gases during combustion

Initial Temp	562 F	Final Temp	1700 F
	568 K		1200 K

Gases		Btu/hr
delta h CO2	322.55 Btu/lbm	852788
delta h CO	311.21 Btu/lbm	0
delta h H2O	596.54 Btu/lbm	4472713
delta h H2	4140.67 Btu/lbm	0
delta h CH4	1099.81 Btu/lbm	0
delta h H2S	346.69 Btu/lbm	0
delta h N2	299.94 Btu/lbm	4111049
delta h Ar	141.57 Btu/lbm	33970
delta h NH3	819.76 Btu/lbm	0
delta h O2	292.40 Btu/lbm	666623
	Total	10137144

Combustion Equations above ash bed:

						Btu/mol	Btu/lbm	Btu/hr
C	+	O2	------>	CO2		-169293.60	-3846.71	-10137102
719 lb/hr		1918 lb/hr		2635 lb/hr				
C	+	1/2 O2	------>	CO		-47548.80	-1697.57	0
0 lb/hr		0 lb/hr		0 lb/hr				

Heat absorbe	10137144	Btu/hr
Heat Release	-10137102	Btu/hr

Gas Composition after Combustion Zone

	LB/HR	MOLS/HR	WT%	MOL%
CO2	2644	60.08	10.03	5.76
H2O	7498	416.20	28.44	39.91
N2	13706	489.29	51.98	46.92
Ar	240	6.01	0.91	0.58
O2	2280	71.25	8.65	6.83
CO	0	0.00	0.00	0.00
TOTALS	26368	1042.81	100.00	100.00

Char and Ash Composition

	LB/HR	MOLS/HR	WT%	MOL%
C	820	68.26	30.02	68.21
ASH	1911	31.81	69.98	31.79
Total	2731	100.07	100.00	100.00

Once 1700 F is met, not only does oxidation of carbon occur, but also the gasification reactions occur

Determination of rate for chemical reactions:

PO2	2.93 atm		
Particle Size	0.635 cm	Part. Voidage	0.5
Film Coef. =	0.000392 (gmole/cm3-s-atm)		
Ash Layer Co	0.0002655 (gmole/cm3-s-atm)	Surface Reaction Rate	0.0055155 (gmole/cm3-s-atm)
Rate	0.0004506 gmole/cm3-s		

Conditions at Combustion Zone

PH2O	17.11	PH2	0.00
PCO	0.00	PCO2	2.47
Temp(K) =	1200		
Density of Coal (lbm/ft3)			40
(g/ccm)			0.641
carbon in char/ash (lb/hr)			820
ash in char/ash (lb/hr)			1911
		Total	2731

Percent Carbon in Char/Ash	30.02%
Bed Voidage	38.00%
Concentration of Carbon (gmol/ccm)	0.119
Volumetric Step	1219.287109 ccm

C + H2O ---> CO + H2

rate = 930e^(-45,000/(RT))*[C]*(PH2O-P*H2O)
where : P*H2O = PH2*PCO/(e^(17.29-16330/T)

First Iteration:

P*H2O =	0.000
rate =	1.194E-05 g-mol/ccm-sec

After First Volumetric Step:

rate =	0.0145634 g-mol/sec
C Consumed	1.39 lb/hr
H2O Consume	2.08 lb/hr
CO Made	3.24 lb/hr
H2 Made	0.23 lb/hr

CO2 + C ---> 2CO

rate = 930e^(-45,000/(RT))*[C]*(PCO2-P*CO2)
where : P*CO2 = PCO^2/(e^(20.92-20280/T)

P*CO2 =	0.000
rate =	1.7E-06 g-mol/ccm-sec
rate =	0.0021 g-mol/sec
C Consumed	0.20 lb/hr
CO2 Consumed	0.73 lb/hr
CO Made	0.93 lb/hr

C + O2 ---> CO2

rate =	0.5494477 g-mol/sec
C Consumed	52.37 lb/hr
O2 Consumed	139.54 lb/hr
CO2 Made	191.91 lb/hr

Totals:

	lb/hr	mols/hr	wt%	mol%		lb/hr	wt%
CO	4	0.15	0.02%	0.01%	C	874	31.37%
H2	0	0.12	0.00%	0.01%	ASH	1911	68.63%
CO2	2835	64.42	10.73%	6.18%	Total	2785	100.00%
H2O	7496	416.08	28.37%	39.89%			
H2S	0	0.00	0.00%	0.00%			
N2	13706	489.29	51.88%	46.91%			
Ar	240	6.01	0.91%	0.58%			
O2	2140	66.89	8.10%	6.41%			
Total	26422	1043	100.00%	100.00%			

Heat Absorbed During Reactions: -729233 Btu/hr

Temp after First Step	1238.453239 K		1769 F		
delta h CO2	21.31 Btu/lbm	60413		Temp of coal (K)	1238.45
delta h CO	19.92 Btu/lbm	83		C - delta h	33.34 Btu/lbm
delta h H2O	39.94 Btu/lbm	299375		ASH - delta h	19.63 Btu/lbm
delta h H2	261.19 Btu/lbm	61		Total of coal	23.93 Btu/lbm
delta h CH4	83.54 Btu/lbm	0		Total heat	66655 Btu/hr
delta h H2S	23.54 Btu/lbm	0			
delta h N2	19.07 Btu/lbm	261422			
delta h Ar	8.61 Btu/lbm	2066			
delta h O2	18.30 Btu/lbm	39158			
		662579			
	Total	729233			

Determination of rate for chemical reactions:

PO2	2.75 atm		
Particle Size	0.635 cm	Part. Voidage	0.5
Film Coef. =	0.0004014 (gmole/cm3-s-atm)		
Ash Layer Co	0.0002718 (gmole/cm3-s-atm)		
Rate	0.0004456 gmole/cm3-s		

Conditions at Combustion Zone

PH2O	17.10	PH2	0.00
PCO	0.01	PCO2	2.65
Temp(K) =	1238		
Density of Coal (lbm/ft3)			40
(g/ccm)			0.641
carbon in char/ash (lb/hr)			874
ash in char/ash (lb/hr)			1911
		Total	2785

Percent Carbon in Char/Ash	31.37%
Bed Voidage	38.00%
Concentration of Carbon (gmol/ccm)	0.125
Volumetric Step	12479.45085 ccm

$C + H_2O \rightarrow CO + H_2$

rate = 930e^(-45,000/(RT))*[C]*(PH2O-P*H2O)
where : P*H2O = PH2*PCO/(e^(17.29-16330/T)

$CO_2 + C \rightarrow 2CO$

rate = 930e^(-45,000/(RT))*[C]*(PCO2-P*CO2)
where : P*CO2 = PCO^2/(e^(20.92-20280/T)

Second Iteration:

P*H2O =	0.000
rate =	2.243E-05 g-mol/ccm-sec

P*CO2 =	0.000
rate =	3.5E-06 g-mol/ccm-sec

After Second Volumetric Step:

rate =	0.2798981 g-mol/sec
C Consumed	26.68 lb/hr
H2O Consume	40.02 lb/hr
CO Made	62.22 lb/hr
H2 Made	4.48 lb/hr

rate =	0.04333 g-mol/sec
C Consumed	4.13 lb/hr
CO2 Consumed	15.14 lb/hr
CO Made	19.27 lb/hr

$C + O_2 \rightarrow CO_2$

rate =	5.560224 g-mol/sec
C Consumed	530.01 lb/hr
O2 Consumed	1412.08 lb/hr
CO2 Made	1942.11 lb/hr

Totals:

	lb/hr	mols/hr	wt%	mol%
CO	86	3.06	0.32%	0.29%
H2	5	2.34	0.02%	0.22%
CO2	4762	108.20	17.65%	10.35%
H2O	7456	413.86	27.63%	39.58%
H2S	0	0.00	0.00%	0.00%
N2	13706	489.29	50.80%	46.80%
Ar	240	6.01	0.89%	0.57%
O2	728	22.76	2.70%	2.18%
Total	26983	1046	100.00%	100.00%

	lb/hr	wt%
C	1435	42.87%
ASH	1911	57.13%
Total	3346	100.00%

Heat Absorbed During Reactions: -7294199 Btu/hr

Temp after Second Step	1588.89 K		2400 F
delta h CO_2	202.29 Btu/lbm	963338	
delta h CO	186.83 Btu/lbm	16004	
delta h H_2O	389.50 Btu/lbm	2903977	
delta h H_2	2429.61 Btu/lbm	11447	
delta h CH_4	849.22 Btu/lbm	0	
delta h H_2S	227.49 Btu/lbm	0	
delta h N_2	178.20 Btu/lbm	2442427	
delta h Ar	78.48 Btu/lbm	18831	
delta h O_2	168.33 Btu/lbm	122585	
		6478609	
	Total	7300972	

Temp of coal (K)	1588.89
C - delta h	331.56 Btu/lbm
ASH - delta h	181.38 Btu/lbm
Total of coal	245.77 Btu/lbm
Total heat	822363 Btu/hr

Determination of rate for chemical reactions:

PO_2	0.93 atm				
Particle Size	0.635 cm	Part. Voidage	0.5		
Film Coef. =	0.0004838 (gmole/cm3-s-atm)				
Ash Layer Co	0.0003277 (gmole/cm3-s-atm)	Surface Reaction Rate		0.08815297	(gmole/cm3-s-atm)
Rate	0.0001819 gmole/cm3-s				

Conditions at Combustion Zone

PH_2O	16.97	PH_2	0.10
PCO	0.13	PCO_2	4.44
Temp(K) =	1589		
Density of Coal (lbm/ft3)			40
(g/ccm)			0.641
carbon in char/ash (lb/hr)			1435
ash in char/ash (lb/hr)			1911
		Total	3346

Percent Carbon in Char/Ash	42.87%
Bed Voidage	38.00%
Concentration of Carbon (gmol/ccm)	0.170
Volumetric Step	1168.164063 ccm

$C + H_2O \longrightarrow CO + H_2$

rate = 930e^(-45,000/(RT))*[C]*(PH2O-P*H2O)
where : P*H2O = PH2*PCO/(e^(17.29-16330/T)

$CO_2 + C \longrightarrow 2CO$

rate = 930e^(-45,000/(RT))*[C]*(PCO2-P*CO2)
where : P*CO2 = PCO^2/(e^(20.92-20280/T)

Third Iteration:

P*H2O = 0.000
rate = 0.0017206 g-mol/ccm-sec

P*CO2 = 0.000
rate = 0.00045 g-mol/ccm-sec

After Third Volumetric Step:

rate =	2.0098902 g-mol/sec	rate =	0.52549 g-mol/sec
C Consumed	191.59 lb/hr	C Consumed	50.09 lb/hr
H2O Consume	287.37 lb/hr	CO2 Consumed	183.54 lb/hr
CO Made	446.80 lb/hr	CO Made	233.63 lb/hr
H2 Made	32.16 lb/hr		

C + O2 ---> CO2

rate =	0.2124833 g-mol/sec
C Consumed	20.25 lb/hr
O2 Consumed	53.96 lb/hr
CO2 Made	74.22 lb/hr

Totals:

	lb/hr	mols/hr	wt%	mol%		lb/hr	wt%
CO	766	27.35	2.81%	2.57%	C	1697	47.02%
H2	37	18.29	0.14%	1.72%	ASH	1911	52.98%
CO2	4653	105.72	17.08%	9.92%	Total	3608	100.00%
H2O	7168	397.91	26.31%	37.34%			
H2S	0	0.00	0.00%	0.00%			
N2	13706	489.29	50.31%	45.92%			
Ar	240	6.01	0.88%	0.56%			
O2	674	21.07	2.47%	1.98%			
Total	27245	1066	100.00%	100.00%			

Heat Absorbed During Reactions: 1234440 Btu/hr

Temp after Third Step	1532.865223 K		2299 F		
delta h CO2	-33.31 Btu/lbm	-154975		Temp of coal (K)	1532.87
delta h CO	-30.50 Btu/lbm	-23370		C - delta h	-56.34 Btu/lbm
delta h H2O	-65.60 Btu/lbm	-470257		ASH - delta h	-29.26 Btu/lbm
delta h H2	-394.38 Btu/lbm	-14541		Total of coal	-41.99 Btu/lbm
delta h CH4	-146.41 Btu/lbm	0		Total heat	-151500 Btu/hr
delta h H2S	-37.94 Btu/lbm	0			
delta h N2	-29.02 Btu/lbm	-397731			
delta h Ar	-12.55 Btu/lbm	-3011			
delta h O2	-27.09 Btu/lbm	-18265			
		-1082148			
	Total	-1233648			

Determination of rate for chemical reactions:

PO2	0.85 atm					
Particle Size	0.635 cm	Part. Voidage	0.5			
Film Coef. =	0.000471 (gmole/cm3-s-atm)					
Ash Layer Co	0.000319 (gmole/cm3-s-atm)			Surface Reaction rate	0.06448992	(gmole/cm3-s-atm)
Rate	0.0001607 gmole/cm3-s					

Conditions at Combustion Zone

PH2O	16.01	PH2	0.74
PCO	1.10	PCO2	4.25
Temp(K) =	1533		
Density of Coal (lbm/ft3)			40
(g/ccm)			0.641
carbon in char/ash (lb/hr)			1697
ash in char/ash (lb/hr)			1911
		Total	3608

Percent Carbon in Char/Ash	47.02%
Bed Voidage	38.00%
Concentration of Carbon (gmol/ccm)	0.187
Volumetric Step	3333.75 ccm

C + H2O ---> CO + H2		CO2 + C ---> 2CO	
rate = 930e^(-45,000/(RT))*[C]*(PH2O-P*H2O)		rate = 930e^(-45,000/(RT))*[C]*(PCO2-P*CO2)	
where : P*H2O = PH2*PCO/(e^(17.29-16330/T)		where : P*CO2 = PCO^2/(e^(20.92-20280/T)	
Fourth Iteration:			
P*H2O =	0.001	P*CO2 =	0.001
rate =	0.0010569 g-mol/ccm-sec	rate =	0.00028 g-mol/ccm-sec
After Fourth Volumetric Step:			
rate =	3.523305 g-mol/sec	rate =	0.93604 g-mol/sec
C Consumed	335.85 lb/hr	C Consumed	89.22 lb/hr
H2O Consume	503.75 lb/hr	CO2 Consumed	326.95 lb/hr
CO Made	783.24 lb/hr	CO Made	416.17 lb/hr
H2 Made	56.37 lb/hr		

C + O2 ---> CO2

rate =	0.5358325	g-mol/sec
C Consumed	51.08	lb/hr
O2 Consumed	136.08	lb/hr
CO2 Made	187.16	lb/hr

Totals:

		lb/hr	mols/hr	wt%	mol%		lb/hr	wt%
CO		1965	70.17	7.09%	6.37%	C	2173	53.20%
H2		93	46.25	0.34%	4.20%	ASH	1911	46.80%
CO2		4513	102.54	16.28%	9.31%	Total	4084	100.00%
H2O		6665	369.95	24.04%	33.60%			
H2S		0	0.00	0.00%	0.00%			
N2		13706	489.29	49.44%	44.44%			
Ar		240	6.01	0.87%	0.55%			
O2		538	16.82	1.94%	1.53%			
	Total	27721	1101	100.00%	100.00%			

Heat Absorbed During Reactions: 1961988 Btu/hr

Temp after Fourth Step	1445.531971 K		2142 F			
delta h CO2	-51.19 Btu/lbm	-231033		Temp of coal (K)	1445.53	
delta h CO	-47.07 Btu/lbm	-92517		C - delta h	-85.30	Btu/lbm
delta h H2O	-99.62 Btu/lbm	-663916		ASH - delta h	-45.43	Btu/lbm
delta h H2	-610.26 Btu/lbm	-56902		Total of coal	-66.64	Btu/lbm
delta h CH4	-220.15 Btu/lbm	0		Total heat	-272168	Btu/hr
delta h H2S	-57.95 Btu/lbm	0				
delta h N2	-44.83 Btu/lbm	-614495				
delta h Ar	-19.56 Btu/lbm	-4693				
delta h O2	-42.10 Btu/lbm	-22657				
		-1686212				
	Total	-1958380				

Determination of rate for chemical reactions:

PO2	0.65 atm				
Particle Size	0.635 cm	Part. Voidage	0.5		
Film Coef. =	0.0004507 (gmole/cm3-s-atm)				
Ash Layer Co	0.0003052 (gmole/cm3-s-atm)	Surface Reaction rate		0.03774835	(gmole/cm3-s-atm)
Rate	0.0001186 gmole/cm3-s				

Conditions at Combustion Zone

PH2O	14.40	PH2	1.80
PCO	2.73	PCO2	3.99
Temp(K) =	1446		
Density of Coal (lbm/ft3)			40
(g/ccm)			0.641
carbon in char/ash (lb/hr)			2173
ash in char/ash (lb/hr)			1911
		Total	4084

Percent Carbon in Char/Ash	53.20%
Bed Voidage	38.00%
Concentration of Carbon (gmol/ccm)	0.211
Volumetric Step	17866.36335 ccm

C + H2O ---> CO + H2

rate = 930e^(-45,000/(RT))*[C]*(PH2O-P*H2O)
where : P*H2O = PH2*PCO/(e^(17.29-16330/T)

Fifth Iteration:

P*H2O = 0.012
rate = 0.0004401 g-mol/ccm-sec

After Fifth Volumetric Step:

rate = 7.8631417 g-mol/sec

C Consumed	749.53 lb/hr
H2O Consume	1124.24 lb/hr
CO Made	1747.99 lb/hr
H2 Made	125.81 lb/hr

CO2 + C ---> 2CO

rate = 930e^(-45,000/(RT))*[C]*(PCO2-P*CO2)
where : P*CO2 = PCO^2/(e^(20.92-20280/T)

P*CO2 = 0.008
rate = 0.00012 g-mol/ccm-sec

rate = 2.17726 g-mol/sec

C Consumed	207.54 lb/hr
CO2 Consumed	760.48 lb/hr
CO Made	968.01 lb/hr

C + O2 ---> CO2

rate =	2.118979 g-mol/sec
C Consumed	201.98 lb/hr
O2 Consumed	538.14 lb/hr
CO2 Made	740.13 lb/hr

Totals:

	lb/hr	mols/hr	wt%	mol%		lb/hr	wt%
CO	4682	167.14	16.21%	14.16%	C	3332	63.54%
H2	219	108.66	0.76%	9.20%	ASH	1911	36.46%
CO2	4493	102.08	15.56%	8.65%	Total	5243	100.00%
H2O	5540	307.54	19.18%	26.05%			
H2S	0	0.00	0.00%	0.00%			
N2	13706	489.29	47.46%	41.44%			
Ar	240	6.01	0.83%	0.51%			
O2	0	0.00	0.00%	0.00%			
Total	28880	1181	100.00%	100.00%			

Heat Absorbed During Reactions: 3242272 Btu/hr

Temp after Fifth Step	1308.865003 K		1896 F		
delta h CO2	-78.31 Btu/lbm	-351825		Temp of coal (K)	1308.87
delta h CO	-72.48 Btu/lbm	-339313		C - delta h	-127.30 Btu/lbm
delta h H2O	-149.80 Btu/lbm	-829969		ASH - delta h	-70.59 Btu/lbm
delta h H2	-943.92 Btu/lbm	-206769		Total of coal	-106.63 Btu/lbm
delta h CH4	-324.76 Btu/lbm	0		Total heat	-559078 Btu/hr
delta h H2S	-87.77 Btu/lbm	0			
delta h N2	-69.17 Btu/lbm	-948136			
delta h Ar	-30.61 Btu/lbm	-7344			
delta h O2	-65.55 Btu/lbm	-3			
		-2683359			
	Total	-3242438			

Determination of rate for chemical reactions:

PO2	0.00 atm				
Particle Size	0.635 cm	Part. Voidage	0.5		
Film Coef. =	0.0004184 (gmole/cm3-s-atm)				
Ash Layer Co	0.0002833 (gmole/cm3-s-atm)	Surface Reaction rate		0.01414561	(gmole/cm3-s-atm)
Rate	0.0000 gmole/cm3-s				

Conditions at Combustion Zone

PH2O	11.17	PH2	3.95
PCO	6.07	PCO2	3.71
Temp(K) =	1309		
Density of Coal (lbm/ft3)			40
(g/ccm)			0.641
carbon in char/ash (lb/hr)			3332
ash in char/ash (lb/hr)			1911
		Total	5243

Percent Carbon in Char/Ash	63.54%
Bed Voidage	38.00%
Concentration of Carbon (gmol/ccm)	0.252
Volumetric Step	10000 ccm

$C + H_2O \longrightarrow CO + H_2$

rate = 930e^(-45,000/(RT))*[C]*(PH2O-P*H2O)
where : P*H2O = PH2*PCO/(e^(17.29-16330/T)

$CO_2 + C \longrightarrow 2CO$

rate = 930e^(-45,000/(RT))*[C]*(PCO2-P*CO2)
where : P*CO2 = PCO^2/(e^(20.92-20280/T)

Sixth Iteration:

P*H2O =	0.194
rate =	7.799E-05 g-mol/ccm-sec
P*CO2 =	0.162
rate =	2.5E-05 g-mol/ccm-sec

After Sixth Volumetric Step:

rate =	0.7798852 g-mol/sec
C Consumed	74.34 lb/hr
H2O Consume	111.51 lb/hr
CO Made	173.37 lb/hr
H2 Made	12.48 lb/hr

rate =	0.25193 g-mol/sec
C Consumed	24.01 lb/hr
CO2 Consumed	87.99 lb/hr
CO Made	112.01 lb/hr

$C + O_2 \longrightarrow CO_2$

rate =	0 g-mol/sec
C Consumed	0.00 lb/hr
O2 Consumed	0.00 lb/hr
CO2 Made	0.00 lb/hr

Totals:

	lb/hr	mols/hr	wt%	mol%
CO	4967	177.33	17.14%	14.92%
H2	232	114.85	0.80%	9.66%
CO2	4405	100.08	15.20%	8.42%
H2O	5429	301.35	18.73%	25.35%
H2S	0	0.00	0.00%	0.00%
N2	13706	489.29	47.30%	41.15%
Ar	240	6.01	0.83%	0.51%
O2	0	0.00	0.00%	0.00%
Total	28978	1189	100.00%	100.00%

	lb/hr	wt%
C	3430	64.22%
ASH	1911	35.78%
Total	5342	100.00%

Heat Absorbed During Reactions: 646332 Btu/hr

Temp after Sixth Step	1281.282872 K			1846 F			
delta h CO2	-15.54 Btu/lbm	-68431			Temp of coal (K)	1281.28	
delta h CO	-14.45 Btu/lbm	-71787			C - delta h	-24.77 Btu/lbm	
delta h H2O	-29.38 Btu/lbm	-159519			ASH - delta h	-14.17 Btu/lbm	
delta h H2	-188.86 Btu/lbm	-43728			Total of coal	-20.98 Btu/lbm	
delta h CH4	-62.62 Btu/lbm	0			Total heat	-112046 Btu/hr	
delta h H2S	-17.28 Btu/lbm	0					
delta h N2	-13.82 Btu/lbm	-189358					
delta h Ar	-6.18 Btu/lbm	-1482					
delta h O2	-13.18 Btu/lbm	-1					
		-534305					
	Total	-646351					

Determination of rate for chemical reactions:

PO2	0.00 atm					
Particle Size	0.635 cm	Part. Voidage	0.5			
Film Coef. =	0.0004117 (gmole/cm3-s-atm)					
Ash Layer Co	0.0002788 (gmole/cm3-s-atm)			Surface Reaction rate	0.01131259	(gmole/cm3-s-atm)
Rate	0 gmole/cm3-s					

Conditions at Combustion Zone

PH2O	10.87	PH2	4.14
PCO	6.39	PCO2	3.61
Temp(K) =	1281		
Density of Coal (lbm/ft3)			40
(g/ccm)			0.641
carbon in char/ash (lb/hr)			3430
ash in char/ash (lb/hr)			1911
		Total	5342

Percent Carbon in Char/Ash	64.22%
Bed Voidage	38.00%
Concentration of Carbon (gmol/ccm)	0.255
Volumetric Step	107272.0102 ccm

C + H2O ---> CO + H2

rate = 930e^(-45,000/(RT))*[C]*(PH2O-P*H2O)
where : P*H2O = PH2*PCO/(e^(17.29-16330/T)

CO2 + C ---> 2CO

rate = 930e^(-45,000/(RT))*[C]*(PCO2-P*CO2)
where : P*CO2 = PCO^2/(e^(20.92-20280/T)

Seventh Iteration:

P*H2O =	0.281	P*CO2 =	0.251
rate =	5.238E-05 g-mol/ccm-sec	rate =	1.7E-05 g-mol/ccm-sec

After Seventh Volumetric Step:

rate =	5.6186189 g-mol/sec		rate =	1.78222 g-mol/sec
C Consumed	535.57 lb/hr		C Consumed	169.88 lb/hr
H2O Consume	803.33 lb/hr		CO2 Consumed	622.50 lb/hr
CO Made	1249.03 lb/hr		CO Made	792.38 lb/hr
H2 Made	89.90 lb/hr			

C + O2 ---> CO2

rate =	0 g-mol/sec
C Consumed	0.00 lb/hr
O2 Consumed	0.00 lb/hr
CO2 Made	0.00 lb/hr

Totals:

	lb/hr	mols/hr	wt%	mol%		lb/hr	wt%
CO	7008	250.21	24.18%	21.05%	C	4136	68.39%
H2	321	159.44	1.11%	13.41%	ASH	1911	31.61%
CO2	3782	85.94	13.05%	7.23%	Total	6047	100.00%
H2O	4626	256.76	15.96%	21.60%			
H2S	0	0.00	0.00%	0.00%			
N2	13706	489.29	47.30%	41.15%			
Ar	240	6.01	0.83%	0.51%			
O2	0	0.00	0.00%	0.00%			
Total	29684	1248	102.43%	104.94%			

Heat Absorbed During Reactions: 4617844 Btu/hr

Temp after Seventh Step	1088.70 K		1500 F		
delta h CO2	-105.91 Btu/lbm	-400579		Temp of coal (K)	1088.70
delta h CO	-99.28 Btu/lbm	-695779		C - delta h	-164.23 Btu/lbm
delta h H2O	-197.88 Btu/lbm	-915303		ASH - delta h	-98.00 Btu/lbm
delta h H2	-1303.35 Btu/lbm	-418933		Total of coal	-143.30 Btu/lbm
delta h CH4	-409.86 Btu/lbm	0		Total heat	-866521 Btu/hr
delta h H2S	-116.64 Btu/lbm	0			
delta h N2	-95.10 Btu/lbm	-1303456			
delta h Ar	-43.13 Btu/lbm	-10349			
delta h O2	-91.44 Btu/lbm	-5			
		-3744403			
	Total	-4610924			