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Conceptual Design Report

Gasification Product Improvement Facility (GPIF)

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Conceptual Design of the Gasification Product Improvement Facility

Section 1 Summary & Overview

The problems heretofore with coal gasification and IGCC concepts have been their high cost and historical poor performance of fixed-bed gasifiers, particularly on caking coals.

The Gasification Product Improvement Facility (GPIF) project is being developed to solve these problems through the development of a novel coal gasification invention which incorporates pyrolysis (carbonization) with gasification (fixed-bed). It employs a pyrolyzer (carbonizer) to avoid sticky coal agglomeration caused in the conventional process of gradually heating coal through the 400°F to 900°F range. In so doing, the coal is rapidly heated sufficiently such that the coal tar exists in gaseous form rather than as a liquid. Gaseous tars are then thermally cracked prior to the completion of the gasification process. During the subsequent endothermic gasification reactions, volatilized alkali can become chemically bound to aluminosilicates in (or added to) the ash. To reduce NH3 and HCN from fuel borne nitrogen, steam injection is minimized, and residual nitrogen compounds are partially chemically reduced in the cracking stage in the upper gasifier region . Assuming testing confirms successful deployment of all these integrated processes, future IGCC applications will be much simplified, require significantly less mechanical components, and will likely achieve the $1,000 /kWe commercialized system cost goal of the GPIF project .

The management plan calls for a two phased program (Figure 1). The initial phase includes the proprietary PyGas™ gasification invention, necessary coal and limestone receiving/storage/reclaim systems to allow closely metered coal and limestone to be fed into the gasifier for testing. The coal gas is subsequently combusted in a closely coupled Heat Recovery Steam Generator (HRSG) located at the GPIF. The combusted flue gas then passes through an induced induced draft fan and is piped to the existing Fort Martin Unit #2 electrostatic precipitator breeching for passage out the existing Fort Martin Unit #2 stack. Gasification process steam is generated by the HRSG located at the GPIF.

Major peripheral equipment such as foundations, process water treatment system, coal and limestone receiving/storage/handling, ash handling, ash storage silo, emergency vent stack, administration building, lavatories, electrical interconnect, control room, control system, storm-water collection and pumping to an existing wastewater treatment system are all included in Phase I.

This gasifier test facility will initially utilize the proprietary PyGas™ gasification invention nominally rated (for materials handling purposes) at 6 tons per hour coal throughput. Its capacity is therefore anticipated to be approximately six times the capacity of the previous 42 inch diameter METC test gasifier. The operating pressure is 600 psi, and the gasifier is expected to be 6.5 feet in diameter, and some 22 feet in height. It is designed to operate at a maximum coal firing rate of 150-MBtu/hr.

An optional future hot gas cleanup unit (HGCU) conceptualized to be a zinc titanate based fluidized bed process (Figure 2) constitutes the optional follow-on phase. Space is provided near the building to house the absorber, regenerator, hot cyclones, and sulfur recovery slip stream along with the necessary blower, piping and heat exchange system.

The limestone feed capability to the PyGas™ coal gasifier may be sufficient to reduce sulfur emissions by a significant amount. However, the need for the Phase II hot gas cleanup system is potentially of much greater significance to future emission limitations either legislated or required for future fuel cell based combined cycle application.

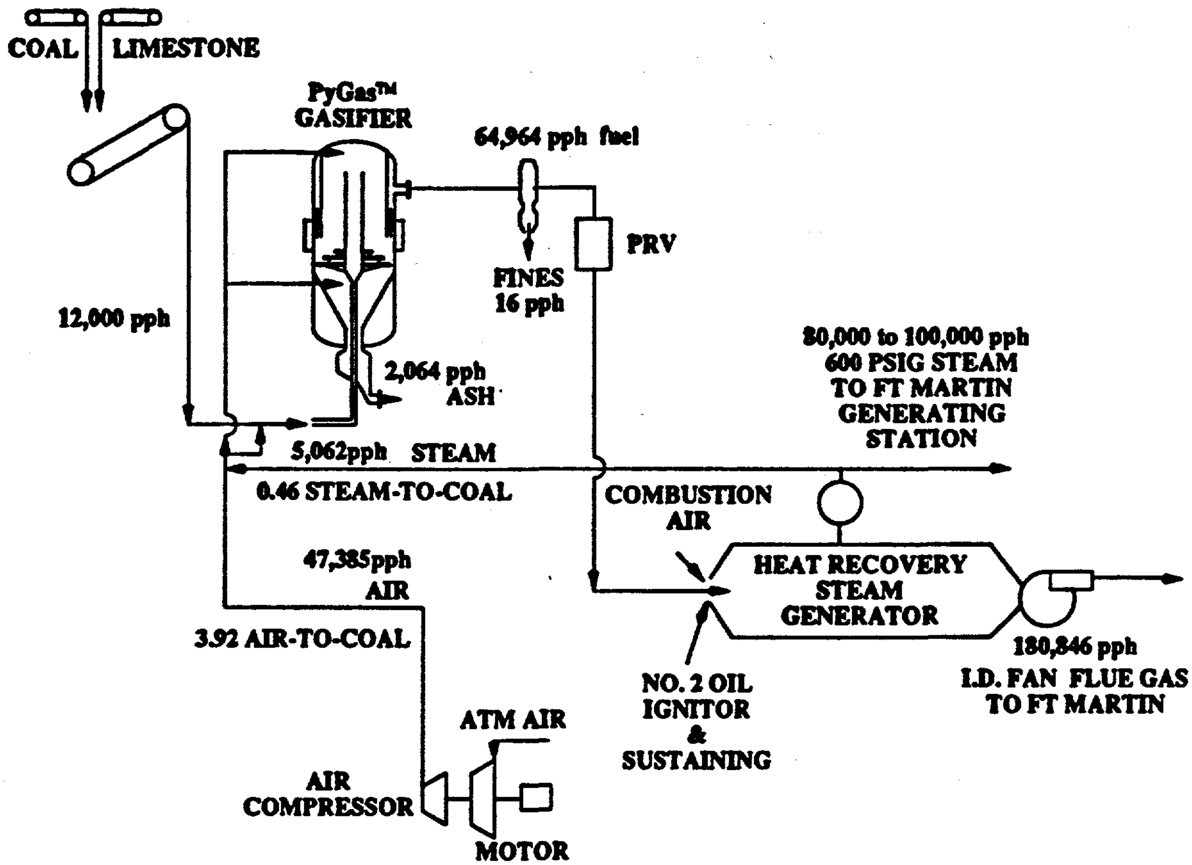


Figure 1 Process Schematic - Phase I
Gasification Product Improvement Facility
PyGas™ Coal Gasification Process

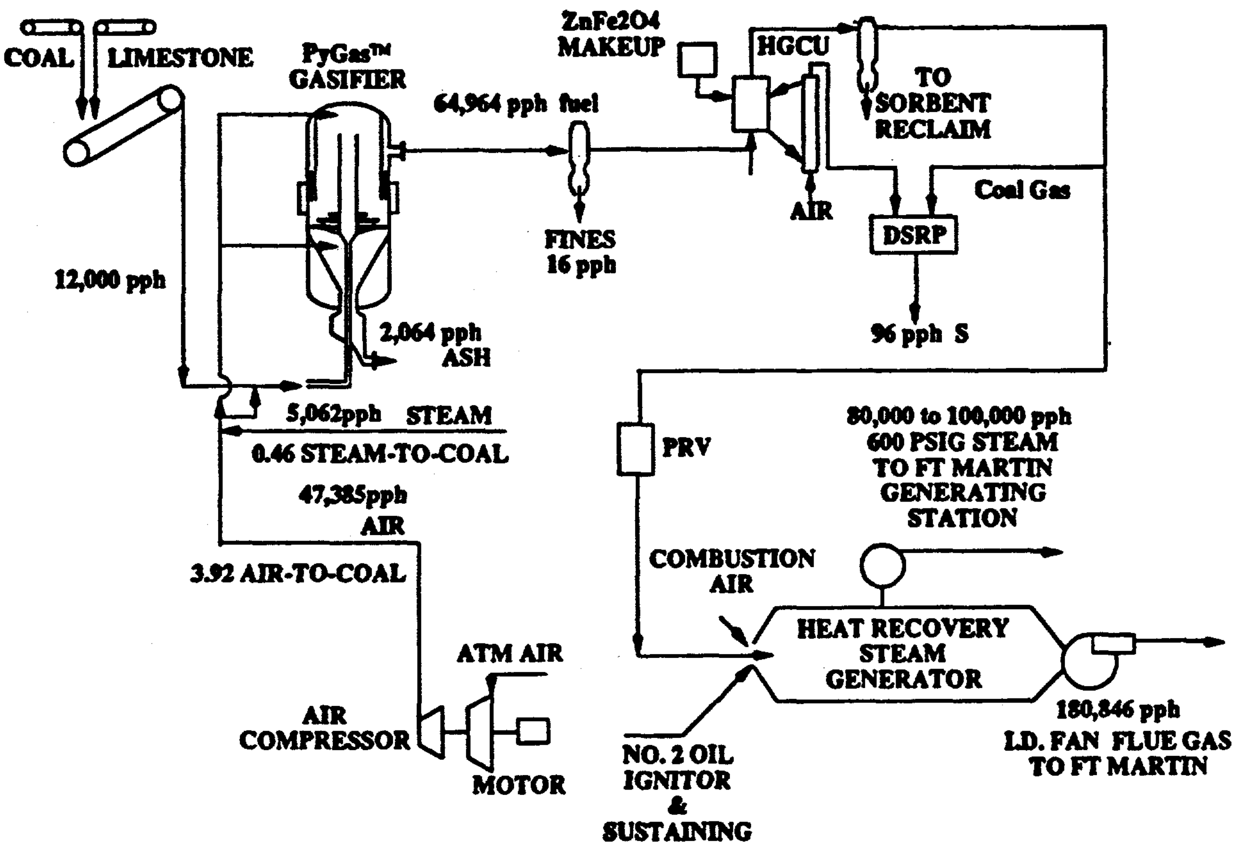


Figure 2 Process Schematic - Phase II
Gasification Product Improvement Facility
With Hot Gas Cleanup Unit

The PyGas™ process was separated into four discreet zones to allow for individual parametric studies of the specific requirements of each zone. Then the zones were integrated into a single process to be accomplished within a single pressure vessel.

Zone 1 - Pyrolyzer (including coal feed design criteria)
Many references to rapid devolatilization of granular coal in a variety of fluidized-bed regimes were available in the literature. The common denominator was that granular coal devolatilization is much more driven by rate of solid particle heat transfer than any other parameter. In all cases found, operation at elevated temperatures resulted in greater devolatilization. The design for the pyrolyzer tube therefore, became a heat transfer problem. While it is expected that most of the coal's volatile content will be rapidly driven off within the confines of the pyrolyzer tube, significant gasification is not expected at pyrolyzer normal operating temperatures. While Foster Wheeler data was studied and some aspects were found to be related to the PyGas™ pyrolyzer tube, it was determined that the Wormser data was more relevant because PyGas™ does not remove solids at the bottom of its pyrolyzer tube. Both Wormser and Foster Wheeler successfully exceeded 50% devolatilization conversion of solids. Since PyGas™ includes a cracking zone immediately downstream of the pyrolyzer tube, whatever volatiles escape pyrolysis are expected to become converted either in the high temperature cracking burner zone or within the co-current annulus. Therefore, it is not necessary to completely devolatilize coal in the pyrolysis zone, and the physical design of the pyrolyzer tube can be much simplified.

Zone 2 - Top (Cracking) Burner Zone
The primary purpose of the cracking zone is to raise coal gas temperature sufficiently to crack any gaseous tars remaining after pyrolysis. Foster Wheeler completely cracked tars without downstream cracking through the use of steam and carbonization temperatures in excess of previous experimenters. Therefore, at least two methods are now available for tar cracking. The PyGas™ top air method results in better quality gas than the Foster Wheeler steam introduction method, but poorer quality gas than if neither was used. The tradeoff here is lowered gas Btu value (but still sufficient for IGCC application) in exchange for eliminating caking coal agglomeration and tar related mechanical difficulties so common to traditional fixed-bed gasifier operation. Side benefits of raising the coal gas temperature in the top air burner zone include potential reductions to fuel nitrogen related oxides of nitrogen generation during subsequent combustion of the coal gas, and subsequent gasification reaction enhancement within the inner annulus since it is well known that gasification is much accelerated at such elevated temperatures.

Zone 3 - Inner Annulus Zone
The down-draft zone provides a third chance for tar destruction, however, the primary function of the co-current inner annulus zone is to gasify char. Since the solids residence time far exceeds that of the coal gases flowing in parallel, and since both the M-GAS and KRW kinetic reaction rates are very fast at 2300°F, the coal gas exiting the cracking burner zone will, no doubt, undergo significant endothermic gasification reactions within the inner annulus. The process is no different than gasification immediately above the combustion zone of the fixed-bed gasifier which is also driven by high temperatures. A final potential benefit of the inner annulus is the potential volatilized alkali chemical reactions with "getters" either existing in the coal ash, or added to the system with the coal feed. Char fines are expected to become gasified here to minimize carbon in the fly ash.

Zone 4 - Fixed-bed Gasifier
The fourth discrete zone is the fixed-bed gasifier. The design criteria utilized in the design of this zone was previous coke gasification parameters since the char on the PyGas™ grate is expected to react more like coke than coal. To the extent that a good deal of the coal will have already been gasified prior to partially gasified char solids accumulating in the fixed-

bed combustion/gasification zone, considerably less air and steam flows will be needed through the grate. This is significant where steam/carbon ratios are their highest. Grate air/steam velocities are expected to be only in the range of 0.1 ft per second 1 ft above the grate, and only 0.3 ft per second at the peak temperature combustion zone in the fixed-bed.

Integration of Gasifier Zones
Owing to the fact that many carbonizers have been designed and operated at a variety of superficial velocities throughout the range of fluidized-bed flow regimes, and virtually all of them used simple air to feed coal proportioning flow sometimes trimmed by set point bed temperature feedback controls, integrating the pyrolyzer into the PyGas™ vessel is not expected to pose significant operating problems. The pyrolyzer tube is being designed to insure that all solids inputted at the bottom eventually leave over the top. No further control functions (other than reliance on gravity) will be necessary.

While the top air admission burner provides for fuel nitrogen reduction, tar cracking, and sufficient temperatures to drive Boudouard Reaction (CO_2+C-->2CO) kinetics, its use is optional in the sense that it can be placed into service after the gasification process is fully established. Its controls are virtually the same as for the pyrolyzer except that it will also include flame scanning to further insure safe operation when in service.

The performance of the Inner Annulus Zone will mainly depend on two things. Solids inventory will determine pressure drop and gasification effectiveness, and Top Burner Zone operating gas temperatures will control gasification kinetics. The option will exist of either employing the inner annulus or not. While some of the aforementioned virtues of the top air burner and inner annulus are lost if char solids level in the fixed-bed zone are maintained below the inner annulus, we anticipate good coal gas and complete gasification will still be achieved.

The fixed-bed's performance will depend upon how well distributed (non-segregated) the granular char becomes on the bed. If good char size distribution is maintained on the fixed-bed, we expect the gasification process to proceed without the operational difficulties common to traditional fixed-bed gasifiers on lump tar laden caking coal.

Section 2.0 Process and Operation

This section describes the conceptual level processes included and functional requirements for testing this coal gasification test facility rated at 6 tons of coal per hour throughput, and includes system operational considerations, anticipated conditions, operating ranges, and operations limiting process issues.

The GPIF process is illustrated in the Simplified System Process Flow Sheet (Figure 3). Circled numbers from 1 to 18 serve to identify points within the system which are referred to in the accompanying Mass & Energy Balance consistent with the "Environmental Report" issued at the completion of Task 1 of this project.

The letter suffixes which accompany the circled numbers describing the process are used to tie in specific sub-system branches. An example is the high pressure air compressor which is identified as stream circled 9. Subsequent branching of this high pressure air stream is identified with a small letter suffix, such as circled 9a, which is a high pressure air branch to the pyrolyzer. This branch then includes subsequent branches 9b, which is the dense phase coal conveying stream, and 9c, air for pyrolyzer fluidization and temperature control.

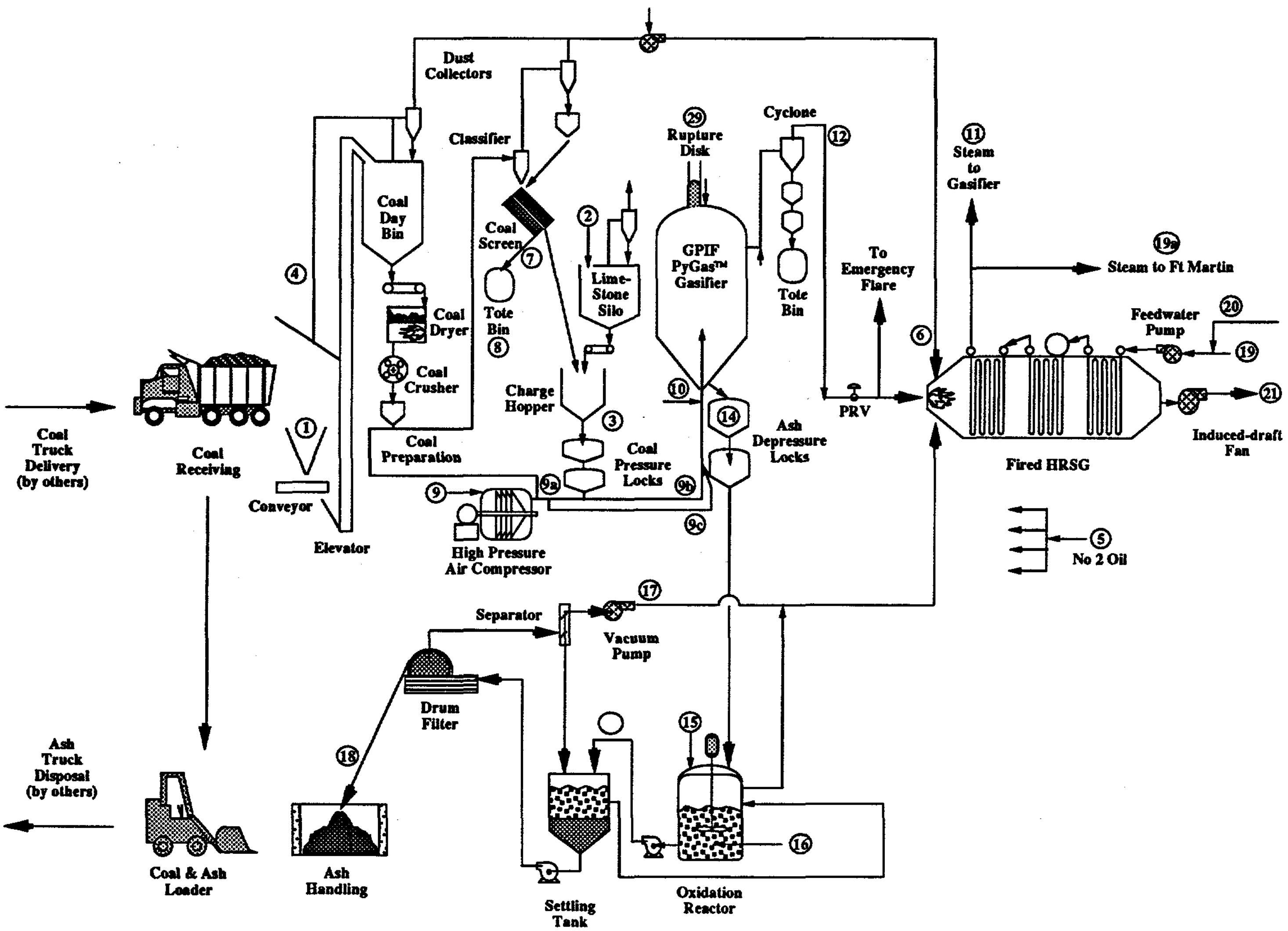


Figure 3
Simplified System Process Flow Sheet

Process conditions such as flow, pressure, temperature, and constituents can be found on the Mass and Energy Balance Tables (Appendix A) as numbered items 1 through 75 which appear in numbered columns corresponding to the circled numbered Process Flow Sheet streams.

Since this process requires the controlling of several process variables, particularly those contained within the PyGas™ gasifier, the Mass and Energy Balance Tables (Appendix A) included in this report are actually the printed results of interactive spreadsheet computations which incorporate kinetic rate equations from the METC - MGAS model (Appendix B "PyGas™ Kinetics Details"), conventional coal gasification process exothermic and endothermic chemical reaction formulas, empirical relationships anticipated to occur within the pyrolyzer tube as a result of recent carbonizer tube data generated from DOE/METC contract No.DE-AC21-86MC21023 (see Appendix C "Thermal Balance Details"), all tied together using volumetric heat generated equals heat absorbed balances. These balances have been limited by conventionally accepted coal gasification operating boundaries such as pyrolyzer operating temperature set point, top gas operating temperature set-point, and fixed-bed gasification operating temperature lower and upper limits.

Air flow to the pyrolyzer is consistent with that required to produce a predetermined pyrolyzer operating temperature set point tempered by empirically derived relationships from previous carbonizer tube operation (DOE/METC Contract No. DE-AC21-78MC-10484) and more recent Foster Wheeler results.

In similar fashion, air flow to the top of the gasifier is limited to that necessary to produce the required operating temperature to crack tar and react with ammonia without melting the inorganic fraction of the char.

Air and steam are introduced through the grate in sufficient quantities to consume the remaining carbon in the char while controlling peak fixed-bed operating temperature below the ash fusion temperature.

Other sub-systems are also chemically balanced consistent with historical data generated by PSI PowerServ relative to anticipated emissions from the GPIF.

Section 2.0.1 Anticipated Throughput Capacity

Traditionally, the throughput capacity of fixed-bed gasifiers has been most affected by operating pressure which follows the relationship :

$$C_2=C_1(P_2/P_1)^n$$

where : C_2 = Capacity at Increased Pressure, C_1 = Capacity at Atmospheric Pressure, P_2 = Elevated Pressure, P_1 = Atmospheric Pressure, and n = exponent of capacity increase with increased pressure

Starting from an assumed [1] anticipated specific capacity of 83 lb/sq ft-hr at atmospheric pressure, the impact of pressure on gasification throughput over a range of 14.7 to 600 psia is to increase it by from 6 to 13 times, depending upon the selection of exponent "n" from n=0.5 to n=0.7.

While it has been reported [2] that exponent n=0.73 by some, others [3] suggest exponent n=0.5. The following table illustrates the impact of this single factor on the likely capacity of the PyGas™ gasifier to be utilized in the GPIF :

Table 1
Anticipated Capacity of PyGas™ at Elevated Pressure on Bituminous Coal

Selected Gasifier Diameter (ft) :	5	6.5
Grate Area (sq ft) :	17.5	30
Assumed Pressure Exponent :	n=0.5/0.7	n=0.5/0.7
Specific Capacity (lb/sq ft-hr) :	310/649	524/1096
Test Unit Capacity (tons/hr) :	2.7/5.7	7.9/16.5

Highly caking coals have historically reduced the capacity of fixed-bed gasifiers in some cases by more than 50% [4]. Since the caking properties of coals are eliminated by PyGas™ in the pyrolyzer stage, it is expected that its capacity will not be similarly adversely affected. It should be acknowledged that excessive fines, if they carry out of the pyrolyzer and through the co-current annulus and out the gasifier exit ungasified, could introduce coal size limits. This potential limit can only be assessed through testing.

In comparing the above anticipated PyGas™ gasifier capacity with Lurgi, the specific capacity of the Lurgi-Dorsten 8.8 Ft Diameter Test Gasifier [4] indicates a capacity of 310 lb/sq ft-hr on low caking Leopold Coal, and only 108 lb/sq ft-hr on Pittsburgh No. 8 (Arkwright) Coal. At 6.5 ft. diameter, the PyGas™ GPIF gasifier capacity is anticipated to be at least 361 lb/sq ft-hr on Pittsburgh No. 8 coal (3.33 times Lurgi's capacity on the same coal) which doesn't even include anticipated capacity improvements associated with the faster gasification rates of coal granules over lump coal because we do not yet know how to quantify them.

Further addressing the capacity issue, PyGas™ has been conceived to first pyrolyze and crack coal tars in order to eliminate agglomerates from melting coal tar common to conventional moving-bed gasifiers. Subsequently, when tar free char fines temperature is controlled so as not to melt char ash, incipient clinkers can be avoided and channeling can be averted. Finally, char fines can react faster than lump coal [5] which will likely further increase the capacity of PyGas™ relative to traditional moving-bed gasifiers.

The two greatest determinations that will be made as a result of the utilization of PyGas™ in the GPIF will be the rate of coal devolatilization in the pyrolyzer, and the rate of granular char gasification on the fixed-bed. In deference to the known gasification rate limits of conventional fixed-bed gasifiers which the purpose of the GPIF is to improve upon, PyGas™ is being designed to exceed those limits in both areas of greatest potential positive impact on rapid devolatilization and enhanced gasification rates.

While it is easy to acknowledge that rapid devolatilization in a fluidized reactor at elevated temperatures will very likely exceed that from the relatively low temperature upper zones of fixed-bed gasifiers, the question of by how much can only be answered by building and testing it. The benefits of tar free pyrolysis gas from PyGas™ are not only logical, they have been proven many times by many investigators, most recently Foster Wheeler.

Lurgi suggests [6] that the combustion zone of a fixed-bed gasifier is only 5 to 10 times the diameter of the coal grain. This translates to from 10 to 20 inches for lump coal to only 1 to 2 inches for PyGas™ using granular sized coal. Lurgi also states that since gasification reactions start in the combustion zone, the solids residence time at high temperature is too short to heat the ash to the gas temperature, which explains why ash doesn't normally melt in the combustion zone. This is a departure from the METC M-GAS model which indicates the solids reach higher temperatures than the gas. Once again, PyGas™ testing will unlock the answers to questions like how thick is the combustion zone, how fast are the combustion and gasification reactions, how much below the ash fusion range can the hot zone be maintained while still achieving essentially complete carbon consumption, and can combustion zone temperatures be maintained below levels that might cause the release of SO2 from CaSO4, its subsequent reduction to H2S, and its ultimate loss of sulfur capture. Certainly, no one can deny that PyGas™ stands a better chance of being able to operate in temperature ranges which might retain sulfur capture better than traditional fixed-bed gasifiers.

It is anticipated that the transition from downflow to fixed-bed gasification of the char will result in the separation of fines from granular char (the winnowing effect). Since the fines' surface to volume ratio is considerably greater than that of the granular char, it can be expected that the downflow zone will gasify primarily the fines. This being the case, it would be logical to expect that whatever fines might be carried out of the gasifier with the coal gas will likely be low in carbon and high in ash content. Traditional fixed-bed gasifiers are sometimes capacity limited due to coal fines carryover into the coal gas stream. This is because the raw coal feed point is directly above and adjacent to the outgoing coal gas stream, and the coal gas stream contains the entire gaseous stream constituents of previously injected air and steam along with generated volatiles, and gasified carbon. It is easy to understand that fines in the raw coal feed of conventional fixed-bed gasifiers are likely to become entrained with the coal gas, never to reach the hot gasification zone, and are hence not gasified. The PyGas™ process is quite different, since the fines will have had to traverse the tortuous path of slug flow fluidized-bed pyrolysis and co-current gasification zones prior to being subject to entrainment with the coal gas. The u-turn from co-current to conventional counter-current flow will likely naturally classify the solids such that a fairly uniform granular char will migrate down through the fixed-bed where it can become gasified in the traditional fixed-bed manner, but at a considerably faster rate. Flyash fines would be entrained by the product gases exiting the outer annulus. Only through testing of the PyGas™ gasifier will the anticipated increase in the gasification rate be quantified.

Section 2.0.2 Increasing Performance and Operating Safety

The PyGas™ process is intentionally slightly different from that of traditional moving-bed gasifiers. It is different in areas intended to improve performance and safety relative to conventional moving-bed gasifiers. While some critics recognize the limitations of traditional moving-bed gasifiers, deviations from the 50 year old lore make some people very uncomfortable. For this reason, this section is intended to illustrate where and why PyGas™ is different from conventional moving-bed gasifiers.

The following points serve to illustrate shortcomings of conventional moving-bed gasifiers :

1. Many explosions (and fatalities) have occurred with moving-bed gasifiers.
2. Excess fines can cause channeling (misleading without reference to clinkers).
3. Channeling can cause oxygen breakthrough.
4. Oxygen breakthrough can cause explosions.
5. Theoretically, a moving-bed gasifier could be designed to gasify fines.
6. Contrary to theory, moving-bed gasifiers lose capacity with increasing fines.

The implication of the above observations is that if fines are used in a moving-bed gasifier, explosions are likely to occur, and capacity is likely to be reduced. These are all good reasons for developing a novel gasifier that will not function just like any conventional moving-bed gasifier. PyGas™ has been designed to avert these shortcomings associated with conventional moving-bed gasifiers, and is expected to be less likely to form agglomerates and incipient clinkers which will more likely result in a channeling free gasifier.

If traditional moving-bed gasifiers have operating characteristics that sometimes result in explosions and loss of life, consideration should be given to changing from the conventional process to a better and safer one.

Agglomerates and clinkers have been reported to cause channeling ultimately resulting in loss of gasifier capacity [7]. If agglomeration is defined as the accumulation of sticky coal during heat-up at the top of conventional moving-bed gasifiers, and clinkering is the accumulation of melted coal ash in the combustion zone, either action results in the lumping of solids which causes air and steam to bypass the lump rather than react with it. The phenomenon of gases following a path of higher porosity in a bed is referred to as channeling. Therefore, by definition, fines (unless segregated into high porosity paths) not only do not cause channeling, properly reacting fines promote heterogeneous action of air and steam with individual coal fines which is the opposite of channeling! Section 2.2.1.3.2 "Fines Impact on PyGas™ vs. Conventional Fixed-bed Gasifiers" deals with this issue in greater detail. It should be recognized that the gasification of smaller size gradations on a fixed-bed cannot be considered only from a reaction viewpoint and that other physical phenomena must be considered including carry-over, segregation, channeling, and fluidization.

PyGas™ is designed to utilize "run of mine" coal crushed to minus 1/4 inch top-size. Its coal sizing is, therefore, kept limited over a relatively narrow range of gradation, because experienced operators of moving-bed gasifiers have observed that incipient clinkers are more likely to form when lump coal and coal fines are fed together. That observation is logical since fines can sometimes segregate changing gasification rates across the bed, or be overheated forming incipient clinkers in an effort to consume carbon from lump coal. Since PyGas™ is sized for minus 1/4 inch coal, carbon burnout will be much easier to maintain than for typical fixed-bed gasifiers, so closely monitoring and maintaining control over peak oxidizing zone temperatures should not require compromise. The expected result is less propensity for channeling and explosion.

Theory indicates that fines should increase [8], not decrease gasifier capacity due to the increase in surface to volume ratio leading to faster gasification reactions. Therefore, the critical question should be why do some moving-bed gasifiers lose capacity with increasing fines, and how to change from the conventional, and what to change to, to improve output ? We believe the design considerations incumbent with PyGas™ make it much more forgiving of coal fines utilization than conventional fixed-bed gasifiers.

While the coal preparation system shall be capable of screening off both top and bottom coal sizes, the design for the 1/4 " x 0 coal size is based on previous Wormser Engineering (DE-AC21-78MC10484) pyrolyzer tube tests and Lurgi fixed-bed gasifier tests [9]. Results of tests with various fuels in a Lurgi gasifier at their Holten facility showed significantly higher coal throughput rate (323 lb/sq ft-hr) for a coal whose sizing was only 1 - 5 mm (0.04 to 0.2 inches), similar in size to that anticipated for PyGas™. This was in contrast to other tests which showed coal throughput rates of only about half as much (178 lb/sq ft-hr) on coal whose sizing was 10 - 30 mm (0.4 to 1.2 inches).

Experienced operators of moving-bed gasifiers have confirmed that fines (of themselves) do not cause channeling, agglomerates and/or clinkers do. They confirm that when their facilities are operating best, most of the gasifier bottom ash is fine, and channeling is not present. Their remedial action when bottom ash clinkers begin forming (become fist size) is to increase grate steam input slightly. This action cools the combustion zone and subtends clinker formation (eliminating channeling potential).

Therefore, since moving-bed gasifiers which are operating normally produce bottom ash fines, then fines, in and of themselves, obviously do not cause channeling. When a gasifier is designed to properly control peak combustion zone temperature, fines will remain fines, and channeling will not occur. If fines remain fines, then oxygen and steam can react to gasify the coal, channeling will not occur, and capacity will be increased because fine coal reacts faster than lump coal.

It has been postulated that there is a need for agglomerates in moving-bed gasifiers by suggesting agglomerates promote ash removal from the grate, and that bottom ash fines fluidize making ash removal difficult. This phenomenon of conventional moving-bed gasifiers, if it occurs, should not be considered a virtue, but rather a necessary evil, because of the potential for the agglomerates to cause channeling. The PyGas™ process, when optimized, is likely to result in only about one eighth the velocity through the grate of conventional moving-bed gasifiers because most of the gasification reactions will have been completed well above the rotating grate. Only the last remaining carbon in the char requires air and steam flow through the grate. Therefore, PyGas™ will be capable of operating with much finer ash without fluidizing the bottom ash (ash on grate).

While this report is not intended to include an economic evaluation of coal size gradations, the ability to utilize "run of mine" coal is always more cost effective than would be the case if fines had to be removed from the feed stock.

2.1 Process Descriptions - Preferred System

Following is a conceptual level description of the process organized by sub-system and arranged from solids inputs to peripheral support systems interfaces required to effect a complete Phase I operational facility.

2.1.1 Functional Descriptions of Test Facility - Phase 1

Coal & Limestone Receiving, Storage, Reclaim, & Pressurization

Coal will be dump truck delivered from the existing nearby Fort Martin low sulfur coal storage area to a tarpaulin covered 3 day storage pile on a concrete slab. A front end loader shall be utilized with an earthen ramp to charge an above ground covered hopper. The hopper discharges to a metering screw feeder onto a bucket elevator which discharges to a conveying screw conveyor to a 19 hour storage bin equipped with a vibratory discharge. A weigh belt feeder capable of 0 to 12,000 lbs /Hr coal feed rate then meters the coal from the bin at a controlled rate into a No.2 oil (or natural gas) fired coal dryer. A coal sampler located between the weigh feeder and the coal dryer will automatically sample coal. The coal dryer discharges into a roll-type crusher which reduces the coal to 1/4 inch top-size. A screen located at the crusher discharge scalps off coal fines sending them to a vented and filtered tote bin, and allows acceptable sized coal into the pyrolyzer feed system transfer pressure vessel. A 4 day capacity limestone storage bin will be filled by a pneumatic self-unloading truck. A weigh belt feeder capable of 0 to 4,000 lbs /Hr limestone feed rate meters the limestone from the bin at a controlled rate. A limestone sampler located at the discharge of the weigh feeder will automatically sample limestone. The coal from the crusher and the limestone from the limestone weigh feeder will become mixed in the charging hopper to the pyrolyzer feed system transfer pressure vessel (pressurization from atmospheric to approximately 650 psig, @ 80° to 150°F).

Provisions shall be made to collect all coal receiving, storage, and reclaim area rainwater runoff, and pump it to the existing Fort Martin waste water treatment system. The required front end loader for loading from the utility coal pile will be furnished, however, coal (also spent sorbent and ash) trucks are expected to be subcontracted to a local trucking company familiar with solids handling and current ash disposal requirements.

The feeding and conveying systems shall be properly ventilated, and the vented air shall be filtered before being released to the fired HRSG. Dust from the collectors will be loaded into tote bins, and returned to the Fort Martin Power Station (FMPS) coal pile.

It is anticipated that a coal feed size of 1/4 inch by 50 mesh, and pre-sized dolomite and limestone feed sizes of 1/8 inch minus dolomite and 16 x 200 mesh limestone size gradation will initially be fed into the pyrolyzer section of the PyGas™ coal gasifier. The successful Foster Wheeler test results (DE-AC21-86MC21023) on these sizes is the basis for their selection. Eventually, fines gasification tests will determine coal sizing limits.

All load change and accurate metering is accomplished by the weigh belt feeders.

The Ft Martin low sulfur coal (Table 2) is unusually dry (according to their specifications), however, a No. 2 oil (or natural gas) fired coal dryer air heater has also been anticipated and is included for use in the event of unusually wet coal conditions.

Ash Handling, Conditioning, Storage & Disposal

Ash sources include mainly the gasifier bottom ash along with a minor source from the gasifier outlet cyclone. Gasifier bottom ash will be conveyed via a steam inerted depressurization lock hopper (from 200 - 600 psig to 20 psig, @ 500° to 700°F) into a wet oxidation sulfation tank. Gasifier outlet cyclone solids will also be depressurized via a nitrogen inerted depressurization lock hopper and discharged to a tote bin for either addition to the wet oxidation sulfation tank or return to Ft Martin's coal pile.

It is expected that the total solids collection from the above sources shall be in the range of 2000 lbs per hour at full capacity operation. A temporary ash storage 4-day-bin shall be utilized to accumulate ash and spent sorbent. It shall be vented to the HRSG by way of a bag filter.

Since the PyGas™ process provides an oxidation zone immediately above the rotating grate, it is expected that retained sulfur in the ash will be predominantly in the fully sulfated form (see Appendix D "Gasifier Ash Thermodynamics").

Table 2
Typical Fort Martin Low Sulfur Coal & METC Specification Coal Analyses

Proximate Analysis:	Fort Martin Low Sulfur Coal		METC Specification Coal
	Volatile Matter	28.92%	30.00%
	Fixed Carbon	54.86%	52.00%
	Moisture	1.81%	3.00%
	Ash	14.41%	15.00%
Ultimate Analysis:			
	Carbon	69.03%	68.60%
	Hydrogen	4.48%	4.60%
	Oxygen	8.03%	4.70%
	Nitrogen	1.26%	1.20%
	Sulfur	0.98%	2.80%
	Moisture	1.81%	3.00%
	Ash	14.41%	15.00%
	Total	100.00%	100.00%

Ft Martin Ash Comp:	
SiO2	52.66
Al2O3	29.69
Fe2O3	6.76
TiO2	1.42
MgO	1.16
MnO	0.08
P2O5	0.26
K2O	2.54
CaO	0.86

Sulfur Content	Ft Martin %	METC Spec %
Pyritic	0.25	1.4
Sulfate	0.04	0.1
Organic	0.69	1.3

Ft Martin Ash Fusion Temperature: >2,700°F

METC Spec.	AFT
IDT	2200°F
H=W	2275°F
FT	2400°F

Coal Feed Rate:	Maximum	12,088 lb/hr
	Typical	12,000 lb/hr
	Minimum	1,200 lb/hr
Limestone Feed Rate:	Maximum	4,000 lb/hr
	Typical	1,061 lb/hr
	Minimum	400 lb/hr

METC Specified HHV = 12,500 Btu/lb FSI = 8 Fines (< 1/4 inch) = 25%

Ft Martin Coal Size Gradation:

Screen Size Passing Inches	Retained Inches	Direct %	Cumulative %
>2	0.2	0.2	
2	1.75	0.0	0.2
1.75	1.5	0.7	0.9
1.5	1.25	1.3	2.2
1.25	1.00	2.7	4.9
1.00	0.75	7.2	12.1
0.75	0.50	10.6	22.7
0.50	0.25	23.4	46.1
0.25	0.125	19.3	65.4
0.125	0.063	12.9	78.3
0.063	pan	21.7	100.0

In anticipation that the ash may contain unsulfated forms of sulfur, it will be first fed to a submerged air oxidation reactor (Figure 4) to complete the sulfation reaction prior to transfer to the temporary ash storage day-bin and subsequent disposal in the permitted Fort Martin existing coal ash landfill. The exhaust from this reactor shall be vented to the HRSG to assure complete oxidation of potential sulfide emissions. The treated ash is then dewatered through mechanical filtration equipment, temporarily stored in the ash 4-day-bin (holding area), and providing daily testing confirms the waste to be non-hazardous, transported by truck to the existing ash landfill area of the Fort Martin power plant.

Space shall be provided in the bottom ash discharge line below the ash depressurization lock for connecting a future dry ash discharge line in the event METC ever desires to separate hot dry ash effectively bypassing the wet ash conditioning system.

Fort Martin has an air permeable dust screen at their landfill site. While some air can pass through it, it does provide a good buffer on windy days resulting in less particulate becoming air-borne.

It is expected that there will remain approximately 15% to 25% free moisture in the GPIF solid waste. The anticipated properties include moist but dry handling granular solids, and the expectation is that conventional ash hauling trucks will be able to easily handle it.

While the quantity of GPIF ash to be added to the existing ash landfill is extremely small relative to current fill rates, it is likely to contain some unreacted alkali in the ash pile.

The temporary ash storage 4-day-bin is sized for 100 tons. This is about four days of ash at full load to accommodate weekends and holidays. We do expect to normally have ash hauls once or twice daily. Gasifier bottom ash handling from the wet oxidation system and process fines from the outlet of the hot cyclone shall be conveyed periodically on a timed basis into the 100 ton temporary ash storage day-bin, dimensions 30' X 30' X 14'Hgt (6' concrete walls atop a concrete slab).

The ash is removed from the temporary ash storage day-bin concrete slab into an ash disposal truck using the same 5 cubic yard front-end loader used for coal charging. Since each bucket's capacity will be approximately 3.5 to 5 tons of ash or coal, loading ash trucks or charging the coal hopper will likely not be very time consuming.

Air Compressor System

A four-stage centrifugal compressor will be used possibly in conjunction with (2) reciprocating compressors, if necessary, to boost ambient air to approximately 750 psia for injection into the gasifier. The centrifugal air compressor will incorporate two intercoolers and one aftercooler to control inlet air temperatures to stages 2 and 3 and the reciprocating compressor (if used), respectively. The total air compressor package will consume approximately 2 to 4 MWe. Cooling water needed for the intercoolers may be minimized by allowing larger temperature rises in the cooling water, if practical. Although this will increase power consumption and decrease compressor efficiency, it may allow the intercoolers to be used as economizers to preheat the necessary water for the cycle while at the same time decreasing water

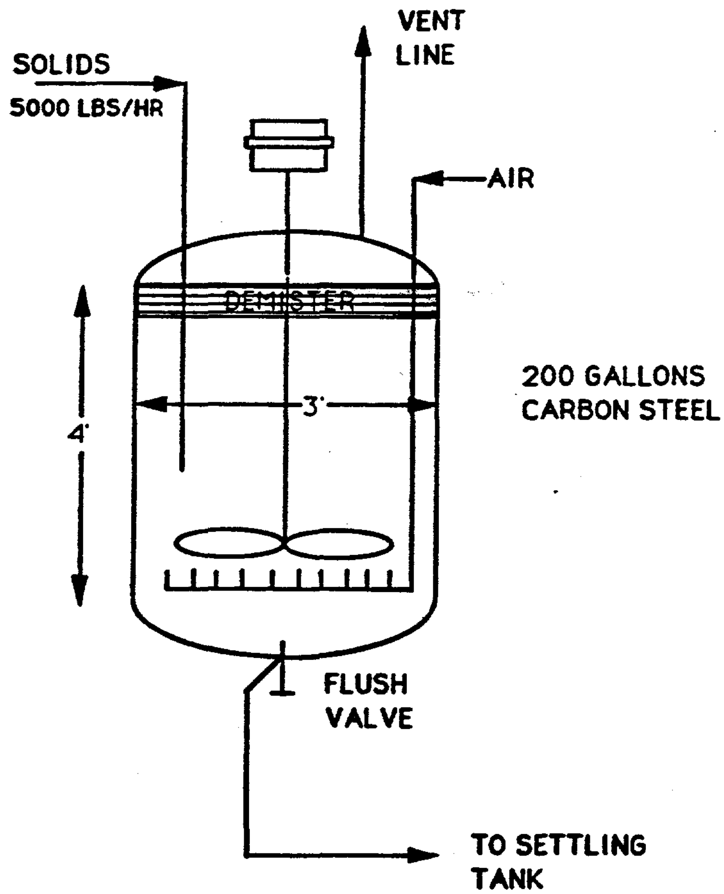


Figure 4
Oxidation Reactor

consumption from the host utility. Presently, cooling water is separate from boiler.

In addition to providing compressed air for the gasifier, the air compression system will be designed to allow instrument air bleed after the aftercooler which is placed in between the centrifugal air compressor. The instrument air will be extracted at 205 psia, 100°F, dried in conventional compressed air dryer and the pressure reduced to the instruments' requirements.

It is anticipated that the following equipment will require compressed air :

Pyrolyzer Feed Pressure Lock Inlet Valve

Pyrolyzer Feed Pressure Lock Outlet Valve

Pyrolyzer Feed Rotary Valve (or Screw)

Pyrolyzer Pre-heat Burner

Top Air Admission Nozzle

Under-grate Air Admission Zones

Nitrogen Inerting & Sealing

Emergency nitrogen inerting of the gasification system is provided by feeding nitrogen from a bulk storage tank via an evaporator into a separate high pressure nitrogen compressor system for compression and delivery to all areas requiring nitrogen above normal operating pressures.

It is anticipated that the following equipment will also require nitrogen for sealing :

Pyrolyzer Feed Pressure Lock Inlet Valve Seals

Pyrolyzer Feed Pressure Lock Outlet Valve Seals

Gasifier Ash Hopper Pressure Lock Inlet Valve Seals at All Times

Gasifier Ash Hopper Pressure Lock Outlet Valve Seals at All Times

Rotating Grate Shaft Seal at All Times (Steam or Air Optional)

Hot Cyclone Solids Removal Pressure Lock Inlet/Outlet Valve Seals at All Times

Hot Cyclone Solids Removal Tote Bin Seals Whenever Above 800°F

Blanketing for HRSG layup

Proprietary PyGas™ Gasifier

Pressure Vessel:

The gasifier (Figures 5) will be a three sectioned shop fabricated partially water cooled pressure vessel with two separatable flanged connections, capable of operation at gasification conditions up to 600 psig, 2500°F. The decision relative to alternate design selections will be made during the Task 6 detailed design effort. The pressure vessel shall include a cooling water inlet flange at or near the bottom, a cooling water outlet flange at or near the top, and three separate loops. It shall be designed for a cooling water temperature rise from ambient to 750°F at 600 psig, although the current plan is to continuously cool it by circulating Ft Martin cooling tower basin water at low water pressure. The inside dimensions of the vessel shall be 6 ft 6 inches diameter by 22 ft height. It shall be fitted with elliptical heads, include a conical ash hopper at the bottom and pyrolyzer pre-heat chamber.

PyGas™ Gasifier Nozzle Connections:

Metered air, steam, and water spray nozzles shall be furnished at three critical points within the gasifier vessel. The pressure locking valves will operate such that a continuous pressure seal and material throughput flow are continuously maintained. A suitable purge and vent system and media will be incorporated into the design to avert reverse flow of hot coal gas into the coal feed or ash removal systems. An emergency (only) vent (from the gasifier vessel) and flare stack will also be incorporated to automatically operate in the event of GPIF over pressure or a rare unrelated Ft Martin Unit 2 master fuel trip since the GPIF flue gas flow to it should be discontinued during such an upset condition

Air/Steam/Coal/Limestone injection into the pyrolyzer section of the PyGas™ gasifier shall be continuously metered and maintained using flow control valves and weigh-feeders. Injection into the pyrolyzer shall be by means of a pipe penetration through the gasifier vessel in the ash hopper vicinity. The nozzle penetration through the gasifier wall shall be of sufficient diameter so as to allow an Air/Steam/Coal/Limestone admission pipe to penetrate the gasifier vessel.

Under-Grate Air/Steam injection shall be metered via separate flow control valves to be located outside the gasifier pressure vessel to three discrete rotating grate zones within the gasifier pressure vessel by means of three pipe penetrations through the gasifier vessel in the ash hopper area.

Top of gasifier freeboard Air/Steam injection shall be metered using flow control valves to be located outside the gasifier pressure vessel to the top of the gasifier by means of a pipe penetration of sufficient diameter so as to allow a retractable swirl vane attachment around the Air/Steam admission pipe for flame stabilization within the gasifier vessel.

The rotating grate drive shaft sleeve penetration(s) shall be located at the grate drive level to allow a vertically oriented grate drive motor to drive the pinion gear from outside the gasifier vessel.

Upper Gasifier Shroud Tube:

A water-cooled upper-cylinder and heat resistant, high temperature corrosion resistant alloy lower-cylinder shall be afixed to the gasifier vessel at the top to prevent pyrolysis gas bypass, and allow for adjustments to its length. Its dimensions shall be approximately 2 ft 10 inches at the top, increasing to 3 ft 6 inch diameter by 10 ft height, and it shall be designed to facilitate simple additions to or removal from its length dimension.

Pyrolyzer Tube:

The Pyrolyzer cone and upper-cylinder tube shall be fabricated of high temperature corrosion resistant ceramic coated (or equal) heat resistant stainless steel with a thin walled ceramic or refractory packed studded liner on the inside surface where the fluidized-bed operating temperature is expected to range from 1200°F to 1900°F. The expected outside operating temperature range is from 1200°F to 2300°F with possible excursions to 2500°F at the gasifier top and fixed-bed core. The pyrolyzer tube will be water cooled in this area. The anticipated superficial velocity inside the pyrolyzer tube is 5 ft per second, and its height from cone-cylinder interface weld to pyrolyzer top exit is estimated to be 10 feet. The pyrolyzer tube inside cylinder diameter is estimated to be 22 inches.

Pyrolyzer Preheat Burner:

Prior to a start or restart of the PyGas™ gasifier preheat burner, the external pyrolyzer solids drain valve must be closed and proven shut and the preheat burner system made ready for a purge cycle. In addition, the No.2 oil (or natural gas) ignited and flame support fueled coal gas fired Heat Recovery Steam Generator (HRSG) must be in operation prior to placing the PyGas™ gasifier in service.

An NFPA Class 1 rated No. 2 oil (or natural gas) fired PyGas™ gasifier preheat burner shall be located on the exterior surface of the gasifier at the ash hopper vicinity. It shall be contained within a ceramic or refractory lined firing chamber such that hot preheat flue gas enters the pyrolyzer cone from below. Prior to startup, the pyrolyzer coal/limestone/air/steam feed pipe shall be oriented in its fixed position. During startup, the external pyrolyzer solids drain valve shall be placed in the closed position and the pyrolyzer tube shall initially be preheated to approximately 1200°F, at which point minimum air flow shall be established through the pyrolyzer feed nozzle, a "shot of coal" shall be introduced into the pyrolyzer tube via the Air/Steam/Coal/Limestone injection nozzle to ignite the coal. The pyrolyzer cone temperature will become slightly lowered, then recover once the coal becomes ignited. Once auto-coal ignition can be sustained, the preheat burner shall be shut down and the fluidizing air shall continue to flow into the pyrolyzer cone so as to seal off the preheat combustion chamber from solids infiltration. The external pyrolyzer solids drain valve shall remain closed until shutdown.

Pyrolyzer Solids Drain:

In the event a master fuel trip causes an emergency gasifier shutdown, the inventory of solids within the pyrolyzer tube shall be drained into the gasifier ash hopper. To accomplish this, the external pyrolyzer solids drain valve must be proven open and the pyrolyzer coal/limestone/air/steam feed systems are shut down.

Light-off of the fixed-bed gasifier section of the PyGas™ gasifier is effected by hot solids carryover from the pyrolyzer tube. Care shall be exercised to insure that the fixed-bed rotating grate is always protected from overheating by insuring that a minimum of 12 inches of ash is maintained directly above the grate to insulate it from hot solids which carry over from the pyrolyzer tube. The combustion zone of the PyGas™ gasifier is always a minimum of 12 inches above the grate.

Rotating Grate Assembly:

The grate shall be supported by a rail on temperature resistant weight bearing rollers (similar to a "Harrington Grate"), or be similar to a KGN grate. It shall also include grate centering bearings located either at its periphery or inside diameter. Three fixed heat resistant stainless steel scrolls shall be mounted atop the grate bars at the grate inside diameter to assist ash movement from the center of the fixed-bed gasifier radially to the ash discharge. It shall incorporate at least three plows beneath and affixed to the rotating grate to move ash from the grate discharge ledge inward and off the ash ledge to ash hopper discharge. The grate bars shall consist of overlapping pie shaped segmented flat heat resistant stainless steel stock with milled slots underneath to evenly distribute blast steam and air equally to the entire fixed-bed cross section without being subjected to ash plugging. This will require increasing the number of milled slots from the upper to the lower grate bars in proportion to the increased circumferences of the three grate bar levels. A "bull gear" and "pinion" set shall be utilized to electrically motor drive the grate at speeds consistent with continuous ash removal rates of from 500 lb/hr to 8,000 lb/hr. The undergrate steam and air blasts shall be separately piped to three sealed grate zones consistent with the three slotted grate bar levels to provide radial as well as total air/steam flow control. A KGN style grate may be alternatively selected.

Water Cooled Lower Pyrolyzer

Provisions have been made to utilize lance type (tube within a tube) water cooling of the lower pyrolyzer tube in the vicinity of the highest heat zone (fixed-bed combustion zone). This modification is being included as a resolution to concerns that the fixed-bed side (highest temperature zone) might accumulate deposits if not water cooled. Features include double ring headers (incoming & outgoing cooling water) inside the ash hopper, vertical internal riser tubes with vertical external downcomer tubes to avoid Departure from Nucleic Boiling (DNB) at the top transition (upward to downward cooling water flow) from incoming to outgoing cooling water, unrestricted pyrolyzer tube internals access from the bottom, welded external vertical finned tubes, vertical alignment on the fixed-bed side by imbedding the cooling tubes in a widening pyrolyzer tube transition, and a refractory (or ceramic) liner inside the pyrolyzer tube to maintain rapid devolatilization temperatures. This arrangement avoids undesirable water cooled spiders in the PyGas™ gasification zone.

Flow Straightening Venturi

A venturi is included inside the crushed coal injection tube to straighten out coal/air/steam(optional) flow to avoid "coal roping" typical in pneumatically conveyed coal piping systems. This will allow the coal to more evenly mix into the pyrolyzer cone and deter coal from concentrating on one side of the pyrolyzer.

Injection Nozzle Tip Spreaders

Initially the coal admission nozzle should be open ended since most successful carbonizer tube applications operated in such a manner. Mechanical spreaders at the nozzle tip (like those used in pulverized coal burner applications) should provide better mixing of the coal into the fluidized inerts, therefore, such designs should eventually be tested at the GPIF. Agglomerization can be averted by avoiding coal-on-coal impacting within the pyrolyzer. Therefore, coal injection can be optimized by developing good mixing and dispersion of coal into the inert fluidized-bed material within the pyrolyzer.

Auxiliary Equipment

Hot Coal Gas Piping & Hot Cyclone/Pressure Locks

The test gasifier includes four (4) inch diameter insulated and lagged stainless steel hot gas piping.

The hot low Btu gas produced by the gasifier shall be discharged to the primary gas cyclone via four (4) inch stainless steel piping insulated with calcium silicate insulation of a minimum of seven (7) inch thickness and lagged.

The gasifier outlet cyclone shall be an internally high temperature corrosion resistant ceramic coated externally insulated stainless steel device intended to capture solids which carryover from the gasifier with the coal gas. It is anticipated that a cyclone of a design similar to the GE cyclone installed be GEESI at the GE Research & Development Schenectady, New York facility will be scaled up to the size required for the gas throughput requirement (approximately a 12 to 1 scale up). The cyclone's captured fines stream discharge by gravity and requires a pressure locking chamber to partially depressurize the fines stream for conveyance to a tote bin or the ash silo, sampling, or for reinjection back to the gasifier. The hot cyclone shall be approximately 13 ft tall by 2 ft diameter.

The gasifier gas outlet cyclone may alternatively be a carbon steel device with 12" thick refractory liner, intended to separate solids carryover from the gasifier in the hot gas by centrifugal force. It is expected that the primary cyclone shall separate up to 600 lbs per hour of solids (char). As the gas stream and the cyclone shall operate at approximately 600 psig and 1500°F, the fines from the cyclone collection chamber shall be discharged via lock hopper and automatic valves operated in sequence.

These locks shall initially be pressurized with inert gas up to the cyclone's operating pressure to prevent coal gas escape when the upper valve is opened to admit solids. Before the fines are discharged via the pneumatic conveying system to ash storage silo, the lock hopper may be depressurized to near atmospheric pressure, or the inert media at pressure may be used to convey fines.

Vent Pipe, Rupture Disc, Detonation Arrester and Emergency Flare

An insulated rupture disc with nitrogen bleed, detonation flame arrester and vent stack for emergency flare (Figure 6) are anticipated to be required above that gasifier vessel or in the gas line between the gasifier and primary gas cyclone (depending on code requirements) for emergency pressure relief. These devises are specifically designed to relieve and arrest the high velocity and pressure flame fronts that may accidentally develop in the gas piping from gasifier, and to carry any deflagration front from the gasifier, away from personnel and out the top of the building for combustion at point of release to the atmosphere.

An insulated Protectoseal model F25006, 6" bi-directional detonation flame arrester in 316 SS housing or similar device shall be included.

In addition, a controlled pressure relief valve to flare stack shall be provided to reduce system pressure in a controlled manner in the event of an emergency shutdown which precludes the use of the fired HRSG.

To avoid pressures exceeding the design pressure of the gasifier vessel during startup, the system shall be designed to start up at low pressure and then be raised to operating pressure (200 psi to 600 psi) for testing.

Provisions shall be made to nitrogen inert the rupture disk and emergency flare stacks to avoid combustible mixtures in the stacks prior to the intended mixture point.

Coal Gas Burner

A single vortex type coal gas burner (Coen or equal), or multiple nozzle wall fired (Riley or equal) shall be utilized to add sufficient air to the coal gas to completely combust the gaseous fuel product of the gasifier in a fired Heat Recovery Steam Generator (HRSG) to be located at the GPIF site. The coal gas burner nozzle is rated at 154-million Btu/hr coal gas firing rate (including sensible heat in the coal gas). The coal gas firing rate is consistent with an excess air of approximately 10% at MCR which is normal for gas fired burners. While past experience has shown the ability to satisfactorily combust hot coal gas without support fuel requirements above 50% gasifier load, provisions shall be made to provide for flame

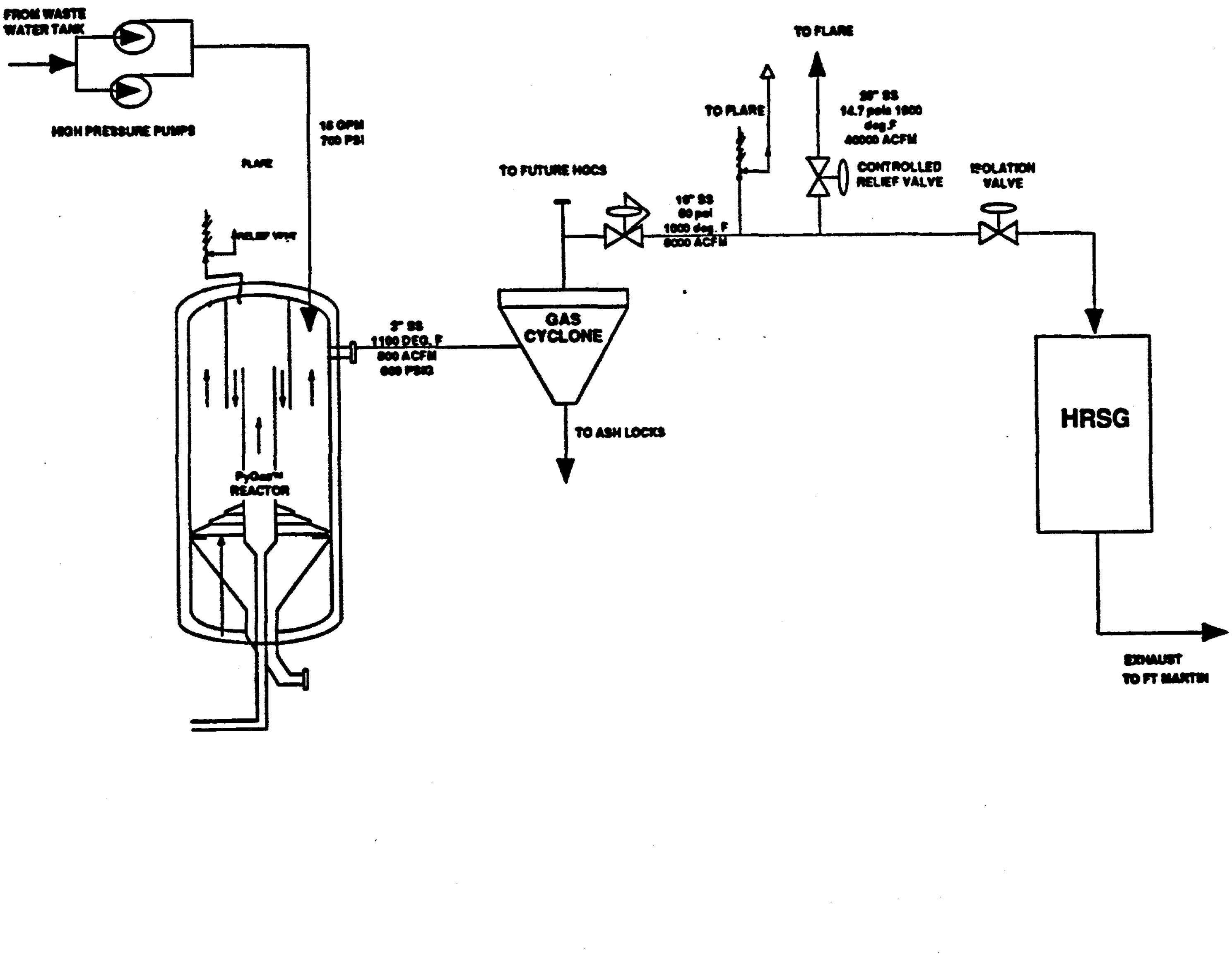


Figure 6
Gasifier Piping & Relief

stabilization support using light (No. 2) oil (or natural gas) fuel using an NFPA Class I ignitor flame. Therefore, under any operating load, whenever the main flame scanner indicates the need for support flame, the ignitor shall be capable of being automatically placed in flame support service.

It is anticipated that the coal gas will be utilized to produce gasification process steam as well as usable steam for return to Fort Martin Station. This will allow the GPIF facility to operate at full capacity while the existing utility boiler operates throughout its normal load range unaffected by the operation of the GPIF. Coordination of GPIF loads with Ft Martin may be necessary during off-peak seasons to insure compatible No.7 feedwater heater flows can be maintained.

Water Spray Injection

It is anticipated that water mist will be sprayed into the hot raw gas from the GPIF such that the coal gas pipe temperature to the fired Heat Recovery Steam Generator (HRSG), and eventually in Phase II to the hot gas cleanup system does not exceed a range of approximately 1075 to 1100 degrees F. In this manner the coal gas piping is protected from excessive temperature at the 600 psig operating pressure. The heat of evaporation minimizes water requirements.

Water/Steam Loop & Gasifier Water Jacket Cooling

A pump forced "once through" water cooled inter-cool loop is contemplated to control compressor temperatures up to 600 psia air compression. The same water cooling intercooler loop will then be circuited, either in parallel or series, to the gasifier water jacket, the gasifier pyrolyzer tube, and subsequently back to the Ft Martin cooling tower sump.

Due to the inability to develop a practical method of producing the superheated steam necessary to return it to the Ft Martin facility at cold reheat conditions from the gasifier water jacket, the PyGas™ gasifier test unit will not include steam generation heat recovery, however, useful steam will be generated in the HRSG for return to Fort Martin. The test facility will rely on the fired HRSG to provide startup steam to the gasifier with Ft Martin generating station steam as backup. It has been determined that the heat which will come from the compressor intercooler, gasifier water jacket, and the gasifier pyrolyzer tube cooling will be rejected directly to the Ft Martin cooling tower sump.

Feed Water Pump

The feed water booster pump shall be sized to provide sufficient water for steam generation for the gasifier pyrolysis tube, top freeboard injection, grate air blast injection, ash lock inerting and steam for return to Fort Martin to be taken from the Fort Martin feed-water system. The relatively long superheated steam piping line to the Fort Martin generating station may necessitate a pump operating pressure greater than the 700 psig pressure for superheated steam return. The feed-water booster pump bid specification documents shall include 750 psig operating pressure. The cost estimate shall also include a 300 gpm feedwater pump capacity for steam generation, steam injection into the gasifier and coal gas spray.

The plan is to receive feed water from Ft Martin using this feed-water booster pump, and make intermediate steam (approximately 650 psia/ 700°F) in the HRSG for use in the gasification system with all excess steam going back to the utility at Ft Martin cold reheat steam conditions.

Water/Steam Considerations

The fired HRSG will be used for startup with cold reheat steam from the Ft Martin generating station available for backup. The proprietary PyGas™ test gasifier will require up to 0.84 lb of steam per lb of coal for the gasification of caking coal. With the test gasifier consuming 12,000 lb of coal per hour, this equates to 10,080 lb/hr of steam. Some 11.8 MMBtu/hr of heat must be absorbed to generate 10,080 lb/hr of saturated steam at 650 psia.

There are several heat sinks within the cycle that might have been used to generate the needed saturated steam at gasifier pressure, however, equipment manufacturers balked at cooling water flows less than those consistent with a 10°F water temperature rise due to their materials of construction and thermal rise expansion limits. The statement of work indicates that the 650 psia steam is required at 640 F. This is well above the saturation temperature of 495 F associated with the above pressure. The heat sinks within the process could have provided enough heat to generate saturated steam at the gasifier pressure. The last heat sink would have been the gasifier water jacket and pyrolyzer tube. The saturated steam leaving the gasifier water jacket might have been mixed with the compressed air. Since the air leaving the compressor is approximately 700 F, the steam mixed with the air would have remained well above the saturation point and remain in a dry state.

Theoretically, to generate 10,080 lb/hr of 650 psia saturated steam, 11.85 million Btu/hr of heat must be absorbed by incoming water at 60 F. The heat sinks within the system are the intercoolers and aftercoolers in the air compression system, possibly the gasifier water-cooled pyrolyzer tube, and the water/steam jacket on the gasifier. The water/steam jacket absorbs 8.47 million Btu/hr and the gasifier pyrolyzer tube absorbs 1.97 million Btu/hr for a total of 10.44 million Btu/hr of the needed 11.85 million Btu/hr. The remaining 1.41 million Btu/hr of heat can be absorbed from the air compressor intercoolers.

The information above indicates that the needed steam could have been generated from the heat sinks within the process thus integrating the process as desired. Were it not for the inability to generate superheated steam for the Ft Martin cold reheat steam return and the unwillingness of the equipment manufacturers to accept the required temperature rises in their materials selection, this approach would have been technically viable. We recommend the eventual incorporation into the GPIF program of process equipment development along these lines, however, in the interest of getting on with the GPIF project under current budget constraints, the integrated cooling water to steam loop idea will be abandoned.

Sulfur Retention in PyGas™ Bottom Ash

METC reported low sulfur retention in the bottom ash of their 42-inch fixed-bed gasifier, and has expressed concern that PyGas™ may also retain insignificant levels of sulfur.

The conceptual design, therefore, presumes that PyGas™ will operate just like METC's fixed-bed gasifier did from a sulfur retention standpoint. The design will facilitate PyGas™ bottom ash removal and treatment consistent with previous METC reports relevant to their 42-inch fixed-bed gasifier operating conditions.

The Project Team concurs with METC comments that above 2300°F, SO2 may be released in the fixed-bed oxidation zone and converted back to H2S. Great Plains confirmed that due to the alkalinity of their "lignitic ash", they get about 10% sulfur retention with the bottom ash, and all of it is in the form of CaSO4. Pilot-scale results show that desulfurization of coal-derived gas at 816°C (1500°F) to 982°C (1800°F) for use in direct-reduction application is feasible [10]. The oxidation of CaS(s) results in the formation of CaO(s) or both CaO(s) and CaSO4(s) as products [11]. They stated that CaS(s) oxidation proceeds rapidly at a rate comparable to carbon oxidation to a (possible) limiting conversion due to the CaO(s)-CaSO4(s) eutectic or possible full sulfur loss for fine CaS(s).

In order to provide the ability to gasify in the fixed-bed zone at the lowest possible peak combustion zone temperatures with the least possible addition of under grate steam, the conceptualized PyGas™ process will include undergrate air and steam system sizing designed to achieve air to carbon ratios of up to 5, and steam to air ratios up to 1. The M-GAS rate equations applied to the CRS Sirrine Engineers, Inc. model (Appendix A-4) indicate it will be possible to completely consume all fixed-bed char carbon with a fixed-bed combustion zone peak temperature of only 2106°F. Only actual testing of PyGas™ can confirm such a possibility, and the degree of sulfur retention under such operating conditions will be determined at that time.

Wet Oxidation Ash System

The conceptualized wet oxidation system involves a process very much like the Great Plains Gasification's wet ash sluicing system which has been in service almost ten years now.

Great Plains Project technical personnel confirmed that, while their hot bottom ash quenching system does cause flashing, it does not result in plugging problems. We conceptualize adopting more of their wet bottom ash system removal principles, although our current conceptual design is already very similar to what they have been successful with (on a continuous basis) for so many years now. Great Plains recirculates the ash water, and due to the high alkalinity of their ash, their water sluice can see as high as a 13.7 pH. We will approach our wet oxidation system with the same high pH expectation, and select materials accordingly.

It appears that, based on the METC results from runs 106 and 107, and assuming 100% of the sulfur contained in the Fort Martin coal were captured and 100% of the gasifier ash became bottom ash, the available releasable sulfide levels in the ash would likely be an order of magnitude below RCRA hazardous waste limits.

To obtain significant sulfides in the ash during METC Tests 106 and 107, apparently a concentrated SO2 stream had to be bled into the gasifier, and the total ash sulfur content had to be an order of magnitude greater than is expected using PyGas™ at the GPIF site using Fort Martin coal.

Therefore, while the testing confirmed the presence of sulfides in the gasifier ash, the extent of conditions required to produce significant levels of releasable sulfides really cloud the issue more than provide any real cause for concern relative to the PyGas™ gasifier applied to the GPIF facility.

While sulfide hideout in the gasifier ash is not likely to be a problem for the GPIF facility, we continue to recommend the use of the wet oxidation process developed for this project just to be on the safe side.

The Project Team's hesitancy to conceptualize a dry ash storage and disposal system results from historical and current difficulties encountered in the fluidized-bed coal boiler industry. There have been numerous reports of (and personal experience with) caustic skin burns associated with dry ash systems designed very much like the current Fort Martin system. It should be pointed out that the existing Fort Martin system is perfectly suitable for their coal ash which does not contain calcined fluid-bed limestone.

2.1.2 Process Flow Sheets

2.1.2.1 Total System Process Flow Sheet

The entire process is illustrated in the Total System Process Flow Sheet (Figure 7, 31604-40-F-16P-001). Circled numbers from 1 to 18 serve to identify points within the system which are referred to in the accompanying Mass & Energy Balance consistent with the "Environmental Report" issued at the completion of Task 1 of this project.

As was the case for Figure 3, the letter suffixes which accompany the circled numbers describing the process are used to tie in specific sub-system branches. Another example is the No. 2 oil supply system which is identified as stream circled 5. Subsequent branching of this light oil stream is identified with a small letter suffix, such as circled 5a, which is a light oil branch to the coal dryer. Other branches include 5b, which is the HRSG burner support stream, and 5c, oil for pyrolyzer preheat.

2.1.2.2 Individual System Process Flow Sheets

Separate flow sheets have been generated for each sub-system, and are further separated by flow type. Solids flows are separately identified for the coal receiving, coal processing, limestone receiving and storage, and ash handling systems. High pressure air systems are separate from low pressure air systems. Separate flow sheets were developed for process water and waste water streams. Individualized flow sheets were also developed for each different interface stream between the GPIF and Ft. Martin to include condensate feed, cooling water, process water, wastewater, No. 2 oil (or natural gas), process steam, and flue gas return. Since they do not produce acceptably readable quality when reduced in size, these flow sheets appear in Appendix A at their normal size.

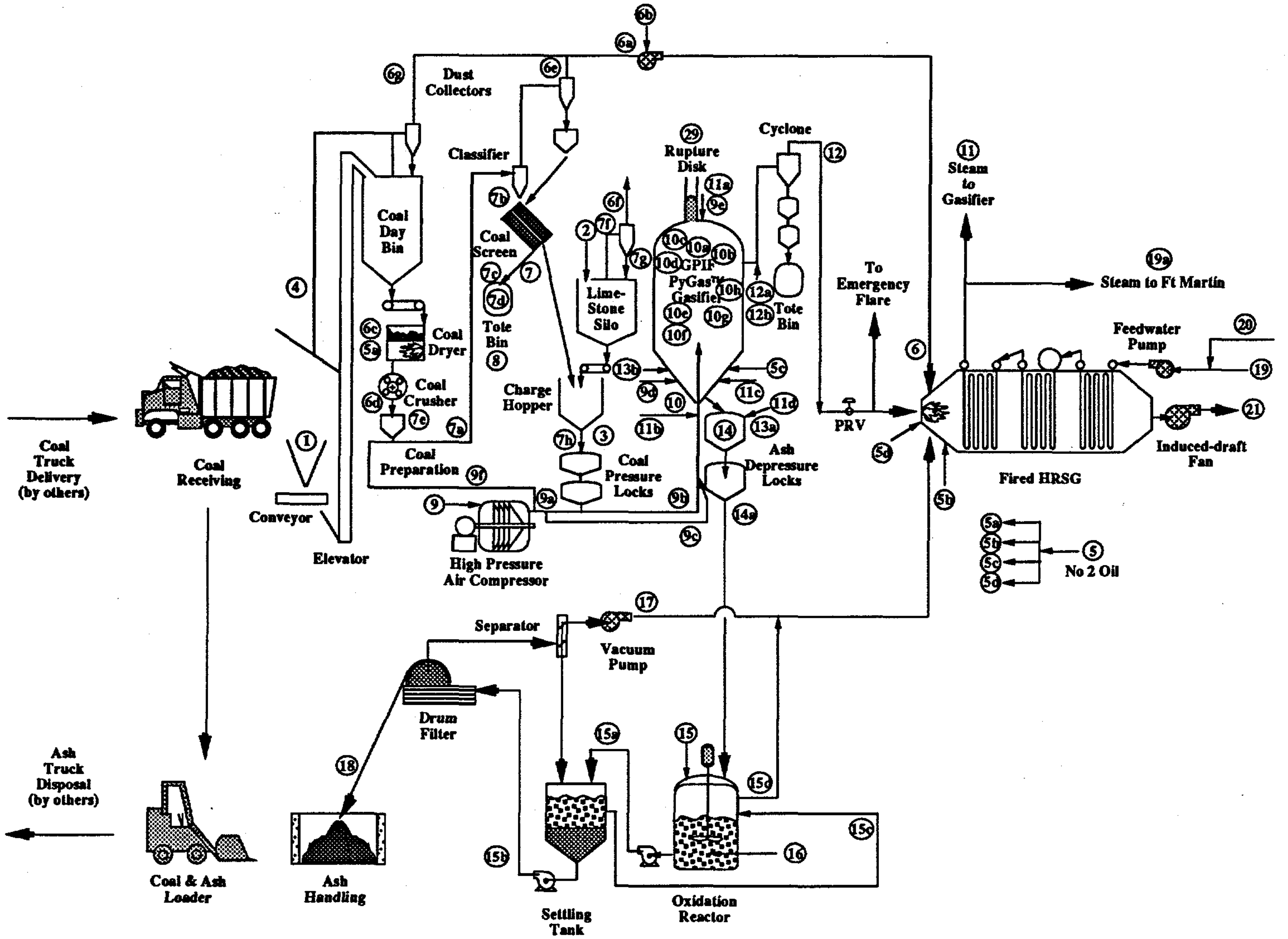


Figure 7
Total System Process Flow Sheet

2.1.3 Equipment Specifications

2.1.3.1 Materials of Construction

There are several Phase I areas within the GPIF project that require special attention to materials of construction. These include :

- Pyrolyzer Tube
- Outer Annulus Shroud Cylinder
- Gasifier Exit Raw Gas Piping
- Wet Oxidation Circulation Tank

The pyrolyzer tube will operate over an internal set point range from 1300°F to 1950°F. The external wall will be subjected to similar temperatures, except adjacent to the oxidation zone of the fixed-bed. Since the fixed-bed peak temperatures are a function of undergrate air and steam flow required to complete char-carbon burnout from the ash, they will be controlled to approximately 2300°F. Since the inside of the pyrolyzer tube will operate in the fluidized-bed velocity regime which transfers significant heat by conduction of moving solids with the walls, while the fixed-bed outside the pyrolyzer will operate with solids movement at the imperceptibly slow rate, it is likely that the pyrolyzer cylinder itself will be at very close to the fluidized-bed operating temperature.

It is expected that hydrogen sulfide and volatilized chlorides will be generated within the pyrolyzer tube. At the aforementioned temperatures and in the expected corrosive reducing atmosphere, the upper pyrolyzer materials of choice in non-water-cooled areas are likely to be high temperature resistant alloys with ceramic or refractory type corrosion resistant coatings. Where water-cooled, gasifier inside surface temperatures are expected to be within 200 °F of the water-side temperature.

The outer annulus will not be in a fluidized-bed environment, but will be subjected to the corrosive reducing atmosphere and receive thermal radiation from the top gas zone which may reach 2300°F. Therefore, the same high temperature resistant alloys should be applied to the non-water cooled lower portion of this component.

Since they are contained within the gasifier vessel, neither the pyrolyzer tube nor the outer annulus cylinder will be subjected to high pressure differentials, so stress levels will be less significant than for the pressure vessel itself.

The gasifier exit raw gas piping is expected to be tempered by introducing steam or water spray to reduce piping operating temperature to 1150°F. The conceptual plan, therefore, utilizes schedule 80, 316 stainless steel for piping downstream of the gasifier. During detailed design (Task 6), other high temperature alloys will be investigated for this application.

The wet oxidation circulation tank materials of construction will include carbon steel lined with corrosion resistant material.

A detailed equipment list appears in Appendix E "Equipment List".

2.1.3.2 Size of Significant Vessels

The most significant vessels which require special attention to their dimensional considerations include, in Phase I, the PyGas™ Gasifier, Hot Gas Cyclone, and in Phase II, the Absorber vessel.
Following (Table 3) are the conceptualized plant's sizes of these critical vessels :

Table 3
Critical Vessel Sizing

Vessel :	Inside Diameter Ft.	Overall Height Ft.
PyGas™ Gasifier (based on FW data)	6 1/2	22
Hot Gas Cyclone (from GEESI Quote)	2	14
Hot Gas Cleanup Absorber (per original proposal)	8 (upper) 6 (lower)	35

2.1.4 Functional Descriptions of Test Facility - Phase II

Hot Gas (Fluidized Zinc Titanate) Cleanup Unit (HGCU) System Planning and Approach

In planning for the follow-on Phase II HGCU, a plot of area immediately adjacent to both the gasifier containment bay and the ash collection area has been reserved for the Phase II HGCU.

The approach taken to facilitate the Phase II additions has been to provide for the convenient location of the HGCU, pre-engineer a part of the hot gas piping system to a point where a parallel piping addition to the HGCU can be added, and provide a simple ash holding area suitable for accommodating ash under the Phase I plan, and elemental solid sulfur for the Phase II addition.

In addition, the high pressure air compressor shall be sized under Phase I to accommodate Phase II needs as they were understood at the time of this conceptual design task.

The DCS control system shall also be sized under Phase I to accommodate the Phase II addition.

The gasifier outlet pipe and hot cyclone shall be designed to operate at 1200°F in Phase I in order to easily accommodate the addition of the Phase II HGCU inlet piping.

The current mass balance expectations for the Phase II system are shown in Appendix A page 13, columns 22 through 28 for each of the 9 test condition identified in Appendix A.

2.2 Operating Requirements

2.2.1 Operating Summary

2.2.1.1 Based on Modeling Results

The anticipated PyGas™ operating parameters have been modeled by CRS Sirrine Engineers, Inc. under two different operating cases.

The initial set of operating parameters was developed for low sulfur Ft Martin coal with limited knowledge of prior carbonizer tube performance capabilities (DOE/METC Contract No. DE-AC21-78MC-10484). We call this case our "Conservative Case" because it assumes only 50% conversion in the pyrolyzer tube.

The second operating case is the result of having reviewed recent Foster Wheeler carbonizer tube operating data.

During the development of in-house math models applicable to the PyGas™ process, significant effort went into generating interactive mass and energy balances.

To estimate the performance of the pyrolyzer tube, assumptions relative to solids to gas conversions and operating temperatures from actual data were combined with logical chemical reactions needed to develop the empirical relationships produced by operators of test carbonizer tubes.

To accomplish this, a mass balance approach was taken initially disregarding kinetics in favor of satisfying actual test carbonizer results. In so doing, the assumption of the input to output analysis becomes :

$$C_xH_yO_zN_wS_v + n_1H_2O + n_2O_2 + n_3N_2 + n_4CaCO_3 \dashrightarrow aCO_2 + bCO + cH_2O + dCH_4 + eH_2S$$

(see Appendix L for complete details of the reactions)

Knowledge of the following pyrolyzer operating parameters from test results limits the potential mass and energy balance to basically one adiabatic solution :

Inputs :	Outputs :
• Coal Feed Analysis	• CO
• Limestone Feed Analysis	• CO_2
• Steam Feed	• H_2
• Remaining Carbon in the Exit Char	• CH_4
• Pyrolyzer Exit Temperature	• H_2S/CaS
• Methane Formation is Minor	• H_2O
• Pyritic Sulfur Forms CaS or H2S	• N_2

While it is recognized that assumptions regarding methane formation and sulfur fate introduce variances in the calculated results, these errors can have only a very minor impact on the calculated pyrolyzer exit mass and energy balances. Therefore, for purposes of generating a simple workable mass and energy balance for the entire GPIF plant, these results were judged to be quite reasonable.

Similarly, this same logic process can be used to determine the gaseous constituents from the fixed-bed gasification of the remaining char, again using end point temperature as an inputted variable. When comparing the results with conventional fixed-bed gasifier operating data, it is necessary to discount the coal moisture and devolatilization evaporation processes which result in lower than kinetically limited gasification temperature limits (usually 1200°F to 1600°F depending on solids reactivity and steam input).

If it is assumed that all of the remaining carbon is to be gasified in the fixed-bed, and that the fixed-bed exit temperature is the same as the co-current flow exit temperature, then the thermal balancing program can be used to determine the gas constituents by adjusting the CO/CO2 ratio until the mass is balanced. This may result in the requirement of some steam addition in order to provide sufficient hydrogen to consume all of the available fixed carbon in the char. The only consideration then remaining is the peak temperatures reached within the process since thermal balance disregards kinetics. Utilization of the CRS Sirrine Engineers, Inc. math model resulted in confirming that the thermal balance model method resulted in reasonably close gas constituents to that obtained using the CRS Sirrine kinetically balanced model.

Thus the thermal balance model is a simple method of predicting major gasification constituents when empirical information regarding coal inputs, air, steam and solids to gaseous conversions are known (such as typical carbonizer tube test data).

The following chart (Table 4) identifies the significant parameters associated with both operating scenarios. It is likely that testing results will further alter these operating conditions as the PyGas™ process is further optimized.

Table 4
Anticipated PyGas™ Operating Parameters
Using Ft. Martin Low Sulfur Coal

Condition :	Lowell (Wormser) Case Using CRSS Model	FW Conditions Using CRSS Model
Pyrolyzer Air/Coal	2.27	3.06
Pyrolyzer Steam/Air	0	0
Pyrolyzer Coal Feed (lb/hr)	10,876	10,876
Pyrolyzer Feed Rate (lb/sq ft)	3,462	3,462
Pyrolyzer Limestone feed (Ca/S mol)	2.5	2.5
Pyrolyzer Limestone Feed (lb/hr)	954	954
Pyrolyzer Operating Temperature (°F)	1652	1812
Sorbent/Coal Ratio	0.088	0.088
Top Air/Coal	0.82	0.8
Top Steam/Air	0	0
Carbon Remaining at Top (%)	49.5	31.26
Top Gas Temperature (°F)	2300	2299
Top Char Temperature (°F)	1652	1812

Table 4 (continued)
Anticipated PyGas™ Operating Parameters
Using Ft. Martin Low Sulfur Coal

Fixed-bed Air/Coal to Grate	0.89	0.25
Fixed-bed Steam/Carbon	1.86	2.92
Fixed-bed Char Gasification Rate (lb/sq ft)	71	27
Fixed-bed Char Feed (lb/hr)	3,891	2,388
Fixed-bed Superficial Vel. (ft/sec @1600°F)	0.07	0.05
Fixed-bed Steam/Air	0.52	0.89
Carbon Remaining to Fixed-bed (lb/hr)	2,213	821
Bottom Ash Carbon Loss (% of heat input)	0.14	0.05
Bottom Ash Carbon Loss (% of ash)	0.73	0.07
Bottom Ash Quantity (lb/hr)	2,064	1,567
Over-all Air/Coal	3.92	4.11
Over-all Steam/Air	0.10	0.09
Total Gasification Rate (lb/sq ft Grate)	328	284
Over-all Gasification Rate (scf/lb)	86	86
Raw Gas HHV (Btu/lb)	88	104
Raw Gas Moisture (vol%)	11.81	9.87
Raw Gas Exit Temperature (°F)	1566	1639

2.2.1.2 Other Operating Considerations

Operation of the GPIF will require a combination of significant knowledge of the process of coal gasification, training and previous operating experience.

The fired HRSG shall be started up and brought to normal operating condition before any test runs commence.

2.2.1.2.1 Reagent Preparation

Prior to the start of a given test, coal will be dump truck delivered from the existing nearby Fort Martin low sulfur coal storage area to the tarpaulin covered 3 day storage pile on the concrete slab. The front end loader shall be utilized to charge the above ground covered hopper. The hopper discharges to a metering screw feeder onto a bucket elevator which discharges to a conveying screw conveyor to a 19 hour storage bin equipped with a vibratory discharge. Upon startup, the weigh belt feeder capable of 0 to 12,000 lbs /Hr coal feed rate then meters the coal from the bin at a controlled rate into the No.2 oil (or natural gas) fired coal dryer. The coal sampler located between the weigh feeder and the coal dryer will automatically sample coal. The coal dryer discharges into the roll-type crusher which reduces the coal to 1/4 inch top-size. The screen located at the crusher discharge scalps off coal fines sending them to the vented and filtered tote bin, and allows acceptable sized coal into the pyrolyzer feed system transfer pressure vessel.

The 4 day capacity limestone storage bin should be filled by a pneumatic self-unloading truck prior to the start of a test. The weigh belt feeder capable of 0 to 4,000 lbs /Hr limestone feed rate meters the limestone from the bin at the desired controlled rate. The limestone sampler located at the discharge of the weigh feeder will automatically sample limestone. The coal from the crusher and the limestone from the limestone weigh feeder will become mixed in the charging hopper to the pyrolyzer feed system transfer pressure vessel (depending on test requirements, pressurization from atmospheric to approximately 200 psig to 650 psig, @ 150° to 200°F) . The feeding and conveying systems shall be properly ventilated, and the vented air shall be filtered before being released to the operating fired HRSG. Dust from the collectors will be loaded into tote bins.

While it is not expected that there will be any limit to coal size, fines gasification tests will determine the carryover/reinjection rates, if any. For initial testing, the coal feed size shall be 1/4 inch by 50 mesh, and pre-sized dolomite and limestone feed sizes of 1/8 inch minus dolomite and 16 x 200 mesh limestone size gradation will initially be fed into the pyrolyzer section of the PyGas™ coal gasifier.

All load change and accurate metering is accomplished by the weigh belt feeders.

2.2.1.2.2 Air Supply and Compressors

Cooling water needed for the intercoolers and gasifier will be placed in operation prior to startup of the air compressor. The centrifugal air compressor will incorporate two intercoolers and one aftercooler to control inlet air temperatures to stages 2 and 3 and the reciprocating compressor (if used), respectively. The four-stage centrifugal compressor will be used possibly in conjunction with (2) reciprocating compressors, if necessary, to boost ambient air to approximately 200 psig to 600 psig for injection into the gasifier.

Instrument air should be placed in service prior to initiation of pre-heat. In addition to providing compressed air for the gasifier, the air compression system will be designed to allow instrument air bleed after the aftercooler which is placed in between the centrifugal and reciprocating (if used) air compressors. The instrument air will be extracted at 205 psia, 100°F, dried in conventional compressed air dryers and the pressure reduced to the instruments' requirements.

The following equipment will require proof of compressed air flow in operation prior to startup for a given test :

Pyrolyzer Feed Pressure Lock Inlet Valve Seals

Pyrolyzer Feed Pressure Lock Outlet Valve Seals

Pyrolyzer Feed Rotary Valve (or Screw) Seals

Pyrolyzer Pre-heat Burner

Top Air Admission Burner

Under-grate Air Admission Zones

Once the air purge cycle is complete, the No. 2 fuel oil (or natural gas) preheat burner may be placed into service in accordance with NFPA code requirements Section 85.

Metered air, steam, and water spray flows shall be initiated, proven operable, and then placed in standby mode at the three critical points within the gasifier vessel prior to the start of a given test. The pressure locking valves shall be checked for operability such that a continuous pressure seal and material throughput flow are continuously maintained prior to the initiation of a given test. The emergency (only) vent (from the gasifier vessel) and flare stack shall be proven operable prior to the initiation of a given test.

Once the preheat burner pyrolyzer temperature monitor indicates satisfactory ignition temperature in the pyrolyzer cone has been reached, a "shot of char (or coke, or anthracite)" shall be permitted into the pyrolyzer along with air/steam/limestone injection into the pyrolyzer section of the PyGas™ gasifier. Initially, the temperature is likely to drop, then increase when carbon ignition commences, at which time a mixture of gasifier ash and char (or coke, or anthracite) shall be continuously fed into the pyrolyzer until the tube filling process is complete. Note that nearly complete combustion conditions may be tolerated in order to expedite the startup cycle so long as pyrolyzer tube operating set point temperatures are maintained.

During startup, the external pyrolyzer solids drain valve shall be placed in the closed position and the pyrolyzer tube shall initially be preheated to approximately 1200°F. Once auto-coal ignition can be sustained, the preheat burner shall be shut down and fluidizing air allowed to continue to flow so as to maintain pyrolyzer tube fluidization and seal off the preheat combustion chamber from solids infiltration.

Once sufficient char and ash have overflowed the pyrolyzer tube sufficiently to provide sufficient temperature to support ignition of carbon on the fixed-bed grate, the fixed-bed electric ignition devices shall be "lit-off" and under-grate air/steam injection shall be initiated and metered via the separate flow control valves located outside the gasifier pressure vessel to the three discrete rotating grate zones within the gasifier pressure vessel by means of the three pipe penetrations through the gasifier vessel in the ash hopper area. Again, at the outset, sufficient excess air may be injected to support combustion until satisfactory operating temperatures are reached in both the pyrolyzer tube and fixed-bed to allow the reduction of air flow sufficient for gasification to commence.

Once the gasifier has reached set point operating temperature, air flow may then be reduced to both the pyrolyzer tube and the fixed-bed consistent with the requirements of the specific test to be run. Coal feed may then be commenced.

To initiate coal feed, the coal preparation system must first be placed into service. A normal purge air cycle is initiated with all air bypassing the gasifier and passing directly to the fired HRSG. Then the coal dryer No. 2 oil (or natural gas) fired burner may be ignited and must be proven in stable operation to avoid a coal preparation system trip. Once the coal dryer reaches set point temperature, coal (and limestone) flow may be initiated. To avoid potential overheating and feed measurement errors, the coal preparation system should not be batch feed operated, but should be continuous feed operated. An automatic tempering and hot air blend control system shall be utilized to assure satisfactory coal surface moisture drying to facilitate the pneumatic injection of fuel without the difficulties associated with wet coal pluggages.

Top of gasifier freeboard air/steam injection shall not be introduced until the coal gasification process has stabilized. It may then be metered into the gasifier vessel

2.2.1.2.3 Nitrogen Supply & Service

Emergency nitrogen inerting of the gasification system is placed in service by feeding from the bulk nitrogen storage into the air compressor system for further compression and dilution of the system's air supply to the point of inerting. This can be automated or operator initiated.

Prior to coal feed to the pyrolyzer tube, the nitrogen inerting system shall be placed in service and proven in operation for those areas where normal nitrogen inerting during testing is required.

The following equipment will require nitrogen (or possibly steam) for sealing :

Gasifier Ash Hopper Pressure Lock Inlet Valve Seals

Gasifier Ash Hopper Pressure Lock Outlet Valve Seals

Pyrolyzer Preheat Light Oil (or natural gas) Gun Retractor (fixed bolted position) Seal

Rotating Grate Shaft Seal

Hot Cyclone Solids Removal Pressure Lock Inlet Valve Seals

Hot Cyclone Solids Removal Pressure Lock Outlet Valve & Tote Bin Seals

2.2.1.2.4 Gasifier Start-up

The gasifier pressure vessel will be a three sectioned shop fabricated partially water cooled vessel with two (minimum) separatable flanged connections, capable of operation at gasification conditions up to 600 psig, 2500°F. The pressure vessel cooling water flow shall be started and proven in operation prior to the start of a given test.

Prior to the initiation of a given test, the gasifier grate shall be manually covered with 12 inches of coarse ash or other suitable insulating material (manual ash, wood, and char loading shall be via the side vessel flanged access door). A 12 inch layer of wood followed by a two inch evenly distributed layer of char (or coke, or anthracite) shall then be placed on top of the ash layer above the grate (after startup, the ash bed level shall be controlled by thermocouple monitoring above the grate and below the combustion zone).

Light-off of the fixed-bed gasifier section of the PyGas™ gasifier is effected by hot solids carryover from the pyrolyzer tube (if necessary, electric charges may be used to ignite the wood as is done in conventional fixed-bed gasifier applications). Care shall be exercised to insure that the fixed-bed rotating grate is always protected from overheating by insuring that a minimum of 12 inches of ash is maintained directly above the grate to insulate it from hot solids which carry over from the pyrolyzer tube. The combustion zone of the PyGas™ gasifier is always a minimum of 12 inches above the grate.

using the flow control valves located outside the gasifier pressure vessel at the top of the gasifier by means of the pipe penetration so as to promote flame stabilization within the gasifier vessel. The top air flame scanner must prove stable flame within ten seconds, or the top air shall trip off, and another nitrogen purge cycle must be completed for the top air burner prior to reinitiating top air flow.

A nitrogen sealed rotating grate drive shaft sleeve penetration shall be proven in service at the grate drive level to allow a vertically oriented grate drive motor to drive the pinion gear from outside the gasifier vessel. Proof of grate rotation must be fed back by the controls system to the control room operator to allow periodic ash plowing to be initiated. The ash plowing cycle shall be determined by the ash and limestone conditions for each specific test, and may be indicated by the position of the combustion zone above the grate assuming thermocouples function properly. The operator should make the ash plowing cycle decision from the control room.

The anticipated superficial velocity inside the pyrolyzer tube shall normally be 5 ft per second. Changes to air/coal ratio may be made with air only changes (within a reasonable velocity range), or by coal flow changes.

Prior to a start or restart of the PyGas™ gasifier preheat burner, the external pyrolyzer solids drain valve must be closed and proven shut, the pyrolyzer drain plug must be placed and proven in the open position, and the preheat burner system made ready for a purge cycle. In addition, the No.2 oil (or natural gas) ignited and flame support fueled Heat Recovery Steam Generator (HRSG) must be in operation prior to placing the PyGas™ gasifier in service.

In the event a master fuel trip causes an emergency gasifier shutdown, the inventory of solids within the pyrolyzer tube shall be drained into the gasifier ash hopper. To accomplish this, the external pyrolyzer solids drain valve must be set to and proven open and pyrolyzer coal/limestone/air/steam feed is shut down.

The undergrate steam and air blasts which shall be separately piped to three sealed grate zones consistent with the three slotted grate bar levels shall provide radial as well as total air/steam flow control. Initially, flows to these zones shall be changed at operator discretion from the control room. Changes in air and steam flows between the three grate zones are not recommended unless the operator can rely on indications of the location of the fixed-bed combustion zone, and unless the operator determines the combustion zone location must be moved or altered while in operation by modifying air and steam flows to the three grate zones.

Ash sources include mainly the gasifier bottom ash along with a minor source from the gasifier outlet cyclone. Gasifier bottom ash will be automatically conveyed via a steam inerted depressurization lock hopper (from 200 - 600 psig to 100 psig, @ 500° to 700°F) into a wet oxidation sulfation tank. Gasifier outlet cyclone solids will also be depressurized via a steam or nitrogen inerted depressurization lock hopper and discharged to a tote bin for either addition to the wet oxidation sulfation tank or return to Ft Martin's coal pile.

In anticipation that the ash may contain unsulfated forms of sulfur, it will be first automatically fed to a submerged combustion reactor to complete the sulfation reaction prior to automatic transfer to the temporary ash storage day-bin and subsequent disposal in the permitted Fort Martin existing coal ash landfill. The exhaust from this reactor shall be continuously vented to the fired HRSG for additional combustion. The treated ash is then automatically dewatered through mechanical filtration equipment, temporarily stored in the ash day-bin, and transported by truck to the existing ash landfill area of the Fort Martin power plant.

It is expected that there will remain approximately 15% to 25% free moisture in the GPIF solid waste. The anticipated properties include moist but dry handling granular solids, and the expectation is that conventional ash hauling trucks will be able to easily handle it. While the quantity of GPIF ash to be added to the existing ash landfill is extremely small relative to current fill rates, it is likely to contain some unreacted alkali from those tests which include excess limestone.

It is expected that the total solids collection from the above sources shall be in the range of 2000 lbs per hour. The 100 ton capacity temporary ash storage day-bin shall be utilized to accumulate ash and spent sorbent. This is about four days of ash at full load to accommodate weekends and holidays. Ash hauls are anticipated once or twice daily. Gasifier bottom ash handling from the wet oxidation system and process fines from the outlet of the hot cyclone shall be conveyed periodically on a timed basis into the 100 ton temporary ash storage day-bin.

The ash is removed from the temporary ash storage day-bin concrete slab into an ash disposal truck using the same 5 cubic yard front-end loader used for coal charging. Since each bucket's capacity will be approximately 3.5 to 5 tons of ash or coal, loading ash trucks or charging the coal hopper will likely not require more than about 15 minutes.

MAJOR PHILOSOPHY FOR SAFE OPERATION (HAZOPS CREDO)

1. The HRSG's primary purpose is as an incinerator of coal gas.
2. The most environmentally friendly way of consuming coal gas is in the HRSG.
3. Coal gas produced from the gasifier will normally flow to the HRSG.
4. Only in an emergency will coal gas be diverted to the flare.
5. The gasifier outlet rupture disk is the code compliant gas pressure relief safety.
6. The flare is an emergency shut-down operation for equipment & personnel protection.
7. Gasifier testing should only proceed if the HRSG is in service.
8. The coal preparation system shall be operated as a direct fired system per NFPA.
9. It is safer to start-up at or below 100 psi, and then raise system pressure.

NORMAL START-UP,
NORMAL SHUT-DOWN,
EMERGENCY SHUT-DOWN TO HRSG,
EMERGENCY SHUT-DOWN TO FLARE,
UNCONTROLLED EMERGENCY SHUTDOWN

The following reflects the conceptualized normal start-up procedure assuming "cold" start-up conditions. It should be anticipated that all safety related interlocks and permissives to include all fail-safe equipment design considerations will be integrated into this plan as the detailed design process continues.

NORMAL START-UP

(Verify all cooling water systems are filled and in operation)

1. START HRSG AND BRING TO OPERATING CONDITION

2. PROVE GASIFIER WATER JACKET COOLING CIRCULATION

3. NITROGEN PURGE THE GASIFIER INTO THE HRSG

4. START AIR COMPRESSOR AND BUILD PRESSURE (within mechanical stress limit constraints) TO START-UP PRESSURE
   (approximately 100 psi gas side pressure)
   (air flows into HRSG);
   PROVE HRSG COAL GAS FLAME SCANNER SEES STABILIZATION FLAME, AND EMERGENCY FLARE READY PERMISSIVE IS MET

5. PREHEAT PYROLYZER CONE WITH NATURAL GAS (Indirect Heater)
   (flow and rate of temperature rise per mechanical design requirements)
   UNTIL TEMPERATURE REACHES 1000°F (anticipate several hours)

6. ADJUST PYROLYZER AIR AND STEAM FLOW TO MINIMUM FLUIDIZATION FLOW RATE (at proper ratio for startup; air flow to reach set point pyrolyzer operating temperature and steam flow will be required in both the coal conveying and pyrolyzer fluidization streams)
   BYPASS BALANCE OF COMPRESSOR AIR TO ATMOSPHERE (if necessary)

7. ADD COKE OR LOW VOLATILE NON-CAKING COAL TO PYROLYZER AT MINIMUM FLOW RATE
   (approximately one tenth of maximum rotary feeder speed)

8 PRE-HEAT LOWER GASIFIER JACKET COOLING HEADER WITH STEAM
   (flow and rate of temperature rise per mechanical design requirements)
   WHEN GASIFIER DRUM TEMPERATURE EXCEEDS SATURATION, STEAM WILL VENT THROUGH THE GRATE

PREVENTING PREMATURE IGNITION OF FIXED-BED. MAINTAIN MINIMUM STEAM FLOW.

9. RAISE PYROLYZER TEMPERATURE TO SET POINT (approx. 1600°F), THEN SHUT DOWM INDIRECT HEATING (will likely take several minutes), AND BUILD SOLIDS BED IN PYROLYZER.

10. SWITCH TO TEST COAL WHEN PYROLYZER NUCLEAR LEVEL MONITOR INDICATES PYROLYZER SOLIDS OVERFLOW (prevents caking before bed can accept increased coal flow)

11. AS COAL RATE IS INCREASED, ADJUST PYROLYZER AIR FLOW TO MAINTAIN SET POINT TEMPERATURE, AND DECREASE STEAM FLOW WHILE MAINTAINING ABOVE MINIMUM FLUIDIZATION FLOW (may be automatically controlled)

12. WHEN NUCLEAR MONITOR INDICATES PROPER FIXED-BED SOLIDS LEVEL, TURN ON GRATE AIR AND INCREASE GRATE STEAM TO MAINTAIN SET POINT PEAK BED TEMPERATURE (approximately 2300°F; may be automatically or manually controlled)

13. GRATE ROTATION IS INITIATED WHEN NUCLEAR MONITOR INDICATES HIGH SOLIDS LEVEL

14 GRATE SPEED IS CONTROLLED BY ABOVE GRATE TEMPERATURE SET POINT (decreases speed as temperature increases, and the inverse)

15. HIGH INNER ANNULUS DELTA PRESSURE OVERRIDES TEMPERATURE CONTROL OF GRATE SPEED AND INCREASES GRATE SPEED UNTIL NUCLEAR MONITOR INDICATES LOSS OF BED LEVEL. HIGH ABOVE GRATE TEMPERATURE INCREASES GRATE STEAM FLOW.

NORMAL SHUT-DOWN

1. REDUCE COAL FEED TO MINUMUM FEED RATE (Approximately 10%).

2. REDUCE OPERATING PRESSURE TO 100 PSI.
(rate of temperature decline per mechanical design requirements)

3. STOP COAL FEED.

4. BURN OUT PYROLYZER INVENTORY; CONTROL PYROLYZER OPERATING TO 1500°F TO PREVENT AGGLOMERATION

5. START INDIRECT PRE-HEAT NATURAL GAS BURNER TO CONTROL RATE OF PYROLYZER CONE TEMPERATURE DECLINE IF NECESSARY
(rate of temperature decline per mechanical design requirements)

6. AS PYROLYZER TEMPERATURE DECREASES, REDUCE STEAM FLOW (may be automatic) AIR FLOW MAINTAINED AT ABOVE MINIMUM FLUIDIZATION LIMIT
(eventually, only air will be passing through pyrolyzer)

7. ALLOW FIXED-BED TO BURN-OUT CONTROLLING PEAK BED TEMPERATURE AT SETPOINT

8. REMOVE REMAINING SOLIDS FROM FIXED-BED WITH THE GRATE AND PRESSURE LOCKS

9. STOP ALL STEAM FLOW & INDIRECT HEATER & CONTINUE AIR FLOW THROUGH PYROLYZER UNTIL ITS TEMPERATURE IS CLOSE TO WATER JACKET (rate of temperature decline per mechanical design requirements); THEN STOP AIR FLOW

10. CONTINUE AIR FLOW THROUGH GRATE UNTIL ITS TEMPERATURE IS CLOSE TO WATER JACKET; THEN STOP AIR FLOW

11. WHEN COOL, AIR PURGE SYSTEM THROUGH THE HRSG

12. INERT WITH NITROGEN, AND ISOLATE WITH A NITROGEN BLANKET TO PROTECT AGAINST FIRES AND CORROSION
(important note: bypass this step if personnel expect to enter system within 2 days)

13. SHUT DOWN THE HRSG

14. SHUT DOWN ALL WATER COOLING CIRCUITS

15. NITROGEN BLANKET ALL WATER CIRCUITS TO PROTECT AGAINST CORROSION
(important note: bypass this step if personnel expect to enter system within 2 days)

CONTROLLED EMERGENCY SHUTDOWN TO HRSG

INITIATED AUTOMATICALLY OR BY OPERATOR

COVERS THE FOLLOWING CASES:

1. LOSS OF COAL FEED
2. WATER LEAK INTO SHELL
3. HIGH TEMPERATURE ALARM ON GASIFIER OUTLET

PROCEDURE:

1. STOP COAL AND AIR TO GASIFIER
2. DEPRESSURIZE SYSTEM TO HRSG AT A CONTROLLED RATE (rate of pressure decline per mechanical design requirements)
3. TRIP AIR COMPRESSOR
4. DRAIN PYROLYZER CHAR THROUGH ASH LOCK SYSTEM
5. INERT WITH NITROGEN (important note: bypass this step if personnel expect to enter system within 2 days)
6. CLOSE HRSG ISOLATION VALVE AND BOTTLE-UP SYSTEM WITH NITROGEN (important note: bypass this step if personnel expect to enter system within 2 days)
8. EITHER CONTINUE SHUT-DOWN FOLLOWING NORMAL SHUT-DOWN PROCEDURES, OR LEAVE SYSTEM BLANKETED UNTIL READY FOR RESTART (OPERATOR DECISION)

CONTROLLED EMERGENCY SHUTDOWN TO FLARE

INITIATED AUTOMATICALLY OR BY OPERATOR

COVERS THE FOLLOWING CASES:

1. LOSS OF ELECTRIC POWER
2. HRSG GOES DOWN
3. FORT MARTIN GOES DOWN

ITEMS IN THE PROCEDURE ARE LISTED SEQUENTIALLY, HOWEVER, EVENTS 1 THRU 4 ARE SIMULTANEOUS (by control system)

PROCEDURE:

1. TRIP AIR COMPRESSOR
2. STOP COAL AND AIR TO GASIFIER
3. CLOSE HRSG COAL GAS SHUT-OFF VALVE AND OPEN FLARE CONTROL VALVE AND DEPRESSURIZE SYSTEM TO FLARE AT A CONTROLLED RATE
   (rate of pressure decline per mechanical design requirements)
4. TRIP VENT SYSTEM
5. DRAIN PYROLYZER CHAR THROUGH ASH LOCK SYSTEM
6. INERT WITH NITROGEN
   (important note: bypass this step if personnel expect to enter system within 2 days)
7. CLOSE FLARE CONTROL VALVE AND LEAVE SYSTEM UNDER NITROGEN BLANKET
   (important note: bypass this step if personnel expect to enter system within 2 days)
8. EITHER CONTINUE SHUT-DOWN FOLLOWING NORMAL SHUT-DOWN PROCEDURES, OR LEAVE SYSTEM BLANKETED UNTIL READY FOR RESTART (OPERATOR DECISION)

UNCONTROLLED EMERGENCY SHUTDOWN

INITIATED AUTOMATICALLY

COVERS THE FOLLOWING CASES:

1. PRESSURE RELIEF THROUGH RUPTURE DISK

ITEMS IN THE PROCEDURE ARE LISTED SEQUENTIALLY, HOWEVER, EVENTS 1 THROUGH 6 ARE SIMULTANEOUS (by control system)

PROCEDURE:

1. TRIP AIR COMPRESSOR
2. STOP COAL AND AIR TO GASIFIER
3. CLOSE HRSG COAL GAS SHUT-OFF VALVE
4. INERT GASIFIER WITH STEAM
5. TRIP HRSG
6. INERT WITH NITROGEN
7. CONTINUE SHUT-DOWN FOLLOWING NORMAL SHUT-DOWN PROCEDURES

2.2.1.3 Operating Considerations of PyGas™

2.2.1.3.1 Eastern Bituminous Caking Coal Operation

Fixed-bed gasifiers traditionally have not successfully operated on Eastern bituminous caking coals. This acknowledgement appears in the DOE/METC RFP for this project which states:

"To attain the benefits of air-blown fixed-bed gasifiers, several process and control issues must be resolved. The most significant issues are: 1) processing high-swelling coals that comprise 87 % of all eastern U.S. coals; 2) significant fines and tar in the hot fuel gas; 3) production of ammonia in the hot fuel gas; and 4) production of ash clinkers.

To date, fixed-bed gasifier plants have avoided these coal and process issues by using low-caking coals or by incorporating subsystems that represent "engineered around" solutions (e.g., separate fines and briquette them for injection into the gasifier with the feedstock coal). These restrictions add cost and inefficiencies and may reduce the market penetration of simplified fixed-bed IGCC, especially in Eastern coal regions mining caking coals."

The primary reason for the historical shortcomings of conventional fixed-bed gasifiers utilizing caking coals is that the coal slowly heats up through the coal's plastic range (600°F to 900°F) which results in agglomeration, channeling, loss of capacity, and ultimately forced outages for clinker removal. In conventional fixed-bed gasifiers, this problem is aggravated when coal fines are introduced with lump coal.

For all the above reasons and more, PyGas™ is intentionally designed differently from conventional fixed-bed gasifiers.

It has been documented that caking bituminous coals can be successfully carbonized (DOE/METC contracts Nos. DE-AC21-78MC10484 and DE-AC21-86MC21023), and that gaseous tars can be destroyed in the process. Therefore, the operating problems (associated with tars in conventional fixed-bed gasifiers) can be avoided if the coal is rapidly pyrolyzed prior to entering the fixed-bed of the gasifier.

Therefore, PyGas™ since it incorporates a rapid pyrolysis tube similar in configuration to the Wormser, METC, and Foster Wheeler carbonizer tubes, will be designed to function similarly.

It is known that in conventional fixed-bed gasifiers, the sticky tars form on the surface of the coal during the slow coal heating process, acting like glue to fuse coal into incipient agglomerates. Once an agglomerate is formed, it is likely to cause channeling of the air/steam stream around it further aggravating the problem. This then is the primary reason why caking, tar containing coals, especially lump coal mixed with fines, do not gasify well in conventional fixed-bed gasifiers. Since PyGas™ rapidly devolatilizes the coal in its pyrolyzer prior to ever reaching the fixed-bed, caking coals will be stripped of their agglomerate causing tars, and per recent performance (DOE/METC contract No DE-AC21-86MC21023) in <u>completely eliminating this primary cause of poor fixed-bed gasifier performance.</u>

In this way, the greatest of operating problems typical of conventional fixed-bed gasifiers, agglomeration due to tars in caking coals can be avoided.

2.2.1.3.2 Fines Impact on PyGas™ vs. Conventional Fixed-bed Gasifiers

It is often erroneously assumed that while theory suggests coal fines feed to fixed-bed gasifiers should increase gasification rates and hence throughputs, historical operating experience nearly always results in drastic capacity reductions, or worse, total prohibition of the use of fines. Lurgi fixed-bed gasifier performance at Holten Plant on a variety of coals [12] showed the highest coal throughput (323 lb/sq ft-hr) of all coals tested was for a coal whose feed size was only 1 to 5 mm (0.04 to 0.2 inches), even though its ash fusion temperature was one of the lowest of all the coals tested. Could it be that fines have been mistakenly blamed for adverse fixed-bed gasifier performance all these years ? Is it possible that the inclusion of fines merely triggers some other capacity limiting condition like agglomeration, clinkering, segregation or localized overheating ? The results above clearly suggests fines may not be anything more than a symptom, and that the real capacity loss causes may be overcome by changes to the basic fixed-bed gasifier design along with perhaps modified gasifier operation.

When running well, conventional fixed-bed gasifiers' bottom ash typically consists of a large fraction of low carbon content fines. Therefore, "fines", per-se, do not of themselves cause channeling, agglomeration or clinkering. So long as the air and steam can react with the fines, gasification reactions can take place and coal fines can gasify more rapidly than lump coal.

The differences in coal combustion and gasification rates of fines vs. lump coal [13] is a likely significant reason why conventional fixed-bed gasifiers do not do well when both lump coal and fines are fed together. We know the fines react faster than the lump coal. Therefore, when grate air flow is increased to gasify the lump coal, the faster reacting fines can overheat, melt the fines ash, and cause incipient clinkers to form creating another potential channeling situation. Since the PyGas™ coal feed is more uniformly sized (no lump coal), it has a better chance to completely gasify its coal feed without overheating and without forming clinkers.

Another scenario for channeling in conventional fixed-bed gasifiers can result from the segregation of coal fines from lump coal. If coal size segregation occurs, the bed's void fraction (hence bed resistance to air/steam flow) can become unbalanced leading to channeling and poor fixed-bed gasifier performance.

Since the PyGas™ pyrolyzer tube is designed to operate in the "slug flow" region (5 ft per second superficial velocity), it is anticipated that the solids exiting the top of the pyrolyzer will remain heterogeniously mixed due to the randomness of the slugs issuing from its top. This randomness of solids flow could easily be seen in the plexiglas working air model videotape previously sent to METC. The symetry of the inner annulus to the pyrolyzer tube is designed to avoid solids segregation in the co-current flow zone of the PyGas™ gasifier thereby averting this additional cause of channeling common to conventional fixed-bed gasifiers. CRADA testing should be utilized to determine how much the pyrolyzer tube diameter should be widened at the top to minimize solids "spouting" without causing fines segregation.

2.2.1.3.3 PyGas™ System Conceptual Control Philosophy

Most conventional fixed-bed gasifiers do not have very sophisticated controls requirements, and PyGas™ is no exception. This is not to say we shouldn't develop instrumentation and controls consistent with modern day technological capabilities, however. The following PyGas™ conceptual controls philosophy is intended to provide insights into both rudimentary control and novel potentially improved monitoring and controlling techniques intended to make the operation of the PyGas™ gasifier simple, safe, and meaningful (details appear in Appendix K).

The likely progression of operation at the outset of testing will be to independently operate the pyrolyzer tube only, using the rotating grate for char conveying only. Once operation of the pyrolyzer tube is mastered, integration of the fixed-bed operation is the next logical step (initially without any top air introduction). When a sufficient operational comfort level is achieved for the combined pyrolyzer and fixed-bed, increasing the fixed-bed char inventory above the inner annulus and placing the top air/steam burner in service would then complete the integration of the hybrid PyGas™ gasifier maximizing the usefulness of its design features.

2.2.1.3.4 Coal Preparation and Feeding

Coal is dryed and crushed in the coal preparation area prior to being weighbelt fed into a surge bin and then pneumatically fed into the gasifier via pressure locks. Provisions have been made for the use of No. 2 fuel oil firing to dry the coal to levels comparable to conventional pulverized coal firing systems in order to avoid problems in feeding wet coal to the gasifier. A conventional hot and tempering air dampering and control arrangement is anticipated to evaporate coal surface moisture and pneumatically feed the coal to via pressure locks to the pyrolyzer section of PyGas™ at temperatures consistent with conventional coal delivery systems used in utility firing applications (approximately 150°F). A conventional ring and roll type crusher is contemplated for reducing the coal top-size to minus one quarter inch.

Safety considerations in the coal feed system include negative pressure filtering of coal dust from hopper charging and screening functions with the air being piped to the fired HRSG to preclude hydrocarbon release to the atmosphere.

The coal dryer burner will be equipped with flame scanner monitoring to prohibit unstable flame conditions via a conventional National Fire Protection Association (NFPA) approved fuel feed trip mechanism.

Locally mounted conveyor emergency shut-off buttons will also be furnished for all conveyors and belt feeders.

2.2.3.1.5 Limestone Feeding

Pre-sized limestone will be pneumatically delivered to a storage silo prior to being weigh belt fed into the pneumatic coal feed system upstream of the pressure locks.

2.2.1.3.6 Fixed-bed Air & Steam Flow Control

Like conventional fixed-bed gasifiers, PyGas™ fixed-bed control consists of the basic air and steam to coal ratios of grate air/steam flow necessary to consume available carbon rendering the gasifier bottom ash nearly void of carbon content. Therefore, air and steam flow to the grate will be controlled to proportions consistent with the combustion and gasification of available carbon in the char on the grate while not allowing the ash temperature to create undesirable clinkers. The method of determining when steam proportioning should be changed (unless fixed-bed peak temperatures can be accurately measured) will be the same as for conventional fixed-bed gasifiers, increase steam flow bias when bottom ash clinkers get to be fist sized. Therefore, steam to the grate is used to consume carbon and control peak bed temperatures.

2.2.1.3.7 Pyrolyzer Tube Temperature Control

Since PyGas™ will be designed with the ability to volatilize tars in its pyrolyzer tube, it will include a conventional set point temperature control loop. Air flow to the pyrolyzer tube will be controlled by proportioning it to the coal feed to maintain a fixed desired operating temperature. In addition, trimming will be accomplished using a temperature monitor (GASTEMP, thermocouple, optical pyrometer, or other suitable temperature indication device) which will be used to feed-back a signal to the pyrolyzer air flow controller to increase air flow trim when operating temperature dips below the temperature control set-point dead-band, or decrease when it increases above the set point control dead-band. This control method is quite standard throughout industry, is not considered complicated, and can be done either in manual or automatic modes.

2.2.1.3.8 Top Air (or Air/Steam) Control

The final trim device will be the top air input. The principle of the top air burner control is identical to the pyrolyzer tube temperature control and trim. A predetermined set-point top of gasifier operating temperature (determined prior to a given test) is set by proportioning top air flow to coal feed rate. As with the pyrolyzer operating temperature controller, a temperature feed-back trim controller is used to maintain the desired temperature. Air vs. steam biasing is done with prior intent for test purposes only. Normally, no steam flow is utilized with the top air feed.

2.2.1.3.9 Bed Solids Level

As is done in most conventional fixed-bed gasifier systems, bed level will be determined indirectly by measuring pressure differential upstream and downstream of the gasifier. The ability to accurately infer bed level based on pressure measurements may be simplified if the PyGas™ inner annulus produces significant pressure differential as some think it might, however, the likelihood of high inner annulus differential pressure is a matter of great conjecture at present, and it should not be assumed that this pressure differential will exceed 20 psig which would be ideal for bed level monitoring. Other devices such as gamma ray detection, sonic and optical density devices, etc., may be utilized in attempts to directly measure bed level, although none will be required for operation of the PyGas™ gasifier.

2.2.1.3.10 PyGas™ Grate Air/Steam Velocities vs. Conventional Fixed-bed Gasifiers

Conventional fixed-bed gasifiers force all their air and steam flow up through the grate. When channeling occurs due to either agglomeration or clinkering, this can lead to bed unbalances and fluidization of ash fines above the grate retarding the ash removal process. Conventional fixed-bed gasifiers can be limited in output by this phenomenon. PyGas™ has been designed to react most of the coal before it ever gets to the fixed-bed. As a result, much less air and steam flow is necessary through the grate to consume the remaining carbon, consequently grate air/steam velocities are much less than for conventional fixed-bed gasifiers so ash fines fluidization becomes less likely. In the "Foster Wheeler Best Case" carbonizer tube performance M-GAS kinetic model scenario applied to PyGas™, only 11% of the coal's carbon remains for the fixed-bed to consume, so through the grate velocities are an order of magnitude less than for conventional fixed-bed gasifiers.

2.2.1.4 PyGas™ Gasifier Design Criteria

All of the aforementioned operating requirements, considerations, and limits combine to generate the design criteria described in the following section. This design criteria was then reflected in the physical GPIF plant as detailed in Section 3 "Conceptual Design" herein. In general, the basic design of the gasifier must reflect the parameters listed below (Table 5) :

Table 5
Basic Design Criteria

Coal Feed Size Range:	1/4 inch minus
Limestone Feed Size Range :	1/8 inch minus
Operating Pressure Range :	200 to 600 psig
Pyrolyzer Operating Temperature Range :	1600°F to 1800°F
Top Gas Burner Temperature Range :	1800°F to 2300°F
Fixed-bed Oxidation Zone Range :	2300°F to 2500°F
Coal Throughput Range :	6,000 to 12,000 lb/hr
Air Input Range :	18,000 to 36,000 lb/hr
Steam Input Range :	5,000 to 10,000 lb/hr
Gasifier Vessel Height :	22 ft
Gasifier Vessel Diameter :	6.5 ft
Vessel Materials of Construction :	Carbon Steel (Water Cooled)
Pyrolyzer Tube Superficial Gas Velocity :	5 ft/sec
Grate Specific Throughput Range :	3 to 6 tons/hr
Anticipated Coal Gas HHV Range :	100 to 150 Btu/dscf

Pyrolyzer:
The pyrolyzer dimensions have been derived from previous carbonizer tube designs developed under DOE/METC contracts Nos. DE-AC21-78MC10484 and DE-AC21-86MC21023. Superficial velocity of the pyrolyzer was selected based on those previous carbonizer tube test results with a minor adjustment for operating pressure. Coal particle rate of heating was used to determine rapid devolatilization volume requirements. Therefore, the required pyrolyzer tube volume was determined based on operating temperature and coal particle heat transfer rate. It is expected that the pyrolyzer tube will rapidly devolatilize the coal mainly by combustion in air resulting in sufficiently high temperatures conducive to volatile matter liberation. Work performed under DE-AC21-78MC10484 showed constant coal weight loss during carbonization irrespective of coal feed rate over a wide range of feed rates. This is an indication that volatiles liberation is unlimited by carbonizer volume (at least over the range of feed rates tested). Observations made by Wormser under contract DE-AC21-78MC10484 were that the bulk of combustion and volatiles liberation were accomplished within the relatively small volume of the carbonizer cone. The relatively short duration peak temperature profile of the Foster Wheeler carbonizer under DE-AC21-86MC21023 appears to corroborate the confinement of combustion and the bulk of volatiles release to the highest solids mixing zone confined mainly to the cone.

Confirmation that reactor residence time (carbonizer volume) has only a small effect on volatiles release has previously been reported [14]. They also indicated the devolatilization reactions producing the hydrocarbon gases are essentially completed in approximately 50 msec. again illustrating a strong dependence on temperature and not volume. Perhaps even more importantly, Herman F. Feldmann identified temperature as the single most important parameter in avoiding agglomeration in a fluid bed at up to 1000 psig operating pressure [15]. Their work shows that coal can be rendered non-agglomerating in a fluidized bed whether or not all of its volatile matter is released from the char. This evidence confirms the likelihood of success in rendering coals non-agglomerating using the PyGas™ pyrolyzer even at 600 psig operating pressure. For PyGas™, the fate of any unreacted volatiles remaining in the char as it exits the top of the pyrolyzer tube and falls into the inner annulus should be obvious since the co-current and fixed-bed flow regimes add significantly to char residence time at elevated temperatures. Coal feed to the PyGas™ pyrolyzer will be on the order of 240 lb/cu ft-hr, so it is likely that, while the bulk of rapid devolatilization will occur in the conical zone, some volatiles liberation will be spread out over a greater volume extending upwardly through the pyrolyzer cylinder, and perhaps over into the co-current flow inner annulus zone.

Rapid devolatilization of coals is known to exhibit volatiles releases in excess of ASTM volatile content determinations, in some cases by 36% on Pittsburgh No. 8 coal whether externally heated in a vacuum [16], or heated by products of combustion in an entrained reactor where as much as 57% of coal with an ASTM volatile content of 34% was converted to gaseous products [14]. Perhaps more importantly, space time conversions as high as 408 lb carbon per cubic foot of reactor volume were achieved. While coal heated by combustion with air in a carbonizer tube also exhibited the same phenomenon of conversions in excess of ASTM volatile content (DE-AC21-86MC21023), the most relevant data corroborating the same conclusion comes from Wormser (DE-AC21-78MC10484) who consistently generated in excess of 50% coal conversion using air for heating by combustion in a carbonizer tube of very similar geometry to that expected to be applied in the PyGas™ gasifier. The effect of pressure on devolatilization appears to be insignificant over a range from 1000 psig to 2000 psig [17].

Further confirmation that caking coals can be rendered non-agglomerating and tar free was suggested by Wen referring to work by Squires [18] suggesting "practically no liquid and tar in the volatiles at temperatures above 900°C (1652°F) when gasification was done in a hydrogen partial pressure of 100 atm. and at a rapid rate".

Further evidence that rates of rapid devolatilization of carbonaceous solids are temperature controlled can be seen from ultrapyrolysis experiments [19] which produced only 28% gas yield at 650°C (1202°F) in 900 ms, but 83% gas yield at 850°C (1562°F) in only 200 ms.

It cannot be assumed that the size gradation of char produced in the pyrolyzer will be smaller than the coal feed size [20]. Depending on such parameters as swelling index, air/coal ratio, and char strength, it is possible to produce char with larger size fractions than the coal feed size. Gomez successfully carbonized several highly caking coals (FSI 6 to 7.50) without agglomeration in a carbonizer tube of very similar configuration to that of PyGas™. Even with substantially longer solids residence than planned for the PyGas™ pyrolyzer tube which should have created fines by attrition, the char size gradation exceeded that of the coal feed, in some cases the average char size gradation well exceeded the coal feed size range, and a significant (38.7%) fraction of char exceeded 16 mesh.

The lower pyrolyzer walls will be water cooled on the outside such that a cooled wall will be in contact with the fixed-bed combustion zone. The upper pyrolyzer tube will be of corrosion resistant (thin plasma ceramic coated) alloy material.

Shroud

The primary function of the internal shroud is to allow hot (2300°F) coal gas to endothermically react with carbon by forcing both to pass co-currently downward.

A careful balance between coal gas residence time, pressure drop, and physical gasifier dimensional practicality constraints had to be reached. The resulting configuration provides sufficient time (according to M-GAS rate equations) to allow the coal gas to approach its lower kinetic temperature limit. The upper shroud will be water cooled, and the lower shroud will also be fabricated of corrosion resistant (thin plasma ceramic coated) alloy material. M-GAS kinetics indicate the inner annulus should be approximately 18 cu ft. to provide sufficient residence time for gasification reactions to kinetically level off. The current inner annulus configuration has 19 cu ft not counting any additional volume around the bottom of the shroud and back up the outer annulus. This allows for varying the inner annulus bed height during testing while continuing to maximize kinetic benefits of lowered coal gas temperature. M-GAS kinetics predicts 1654°F exit from the co-current flow region, while past history suggests 1200°F may be potentially achievable [21] particularly in the presence of calcium or potassium and using high steam flow rates. Either result is acceptable since the GPIF will be designed to accommodate the higher exit temperatures according to M-GAS kinetic predictions.

Fixed-bed:
The design criteria for the fixed-bed section of the PyGas™ gasifier is based mainly on historical plan area carbon throughput rates for fixed-bed coke gasification since only fixed-carbon will remain to be oxidized and gasified in this section. A combination of very conservative throughput rates for coke fines was the primary selection factor, however, avoidance of minimum fluidization velocities through the grate also dictated conservative rate selections. As previously stated, the most significant parameter affecting the fixed-bed section of the gasifier is the effect of elevated pressures. Most gasification authorities place the capacity exponent with increasing operating pressure at between 0.5 and 0.7. The pressure parameter and rate of granular char gasification will have the greatest impacts on the ultimate capacity of the entire gasifier.

A potentially significant positive impact on the fixed-bed section of the PyGas™ gasifier may be particle size. It is known that the burning of char is the fastest of the char-gas reactions taking place in a gasifier [18]. For conventional lump coal fixed-bed gasifiers, this reaction takes place at the external surface of the char particle, and is controlled by ash-layer diffusion. Therefore, ash melting and the formation of incipient clinkers becomes a real concern. If temperature, and/or particle size decrease substantially, the reaction may proceed toward the chemical reaction control regime, and may take place uniformly throughout the internal pore surfaces of the particles. In this scenario, carbon burnout without ash melting is more likely. Wen also suggested that large particles favor CO_2 formation while smaller particles favor CO formation, implying better quality gas can be obtained from smaller particle sizes.

Other Components:
Rotating (and Reversing) Grate:
The rotating grate is three tiered with slotted pie shaped stainless steel grate bars configured at the same approximate angle as most fixed-bed gasifier grates. Underneath, the grate has plows configured above a peripheral ledge so as to push gasifier ash toward the center off the ledge and down into the ash hopper to the depressurization locks.

Pre-heater:
The preheat firing chamber is located underneath the rotating grate in the ash hopper. It is sized to be capable of preheating the pyrolyzer tube cone to

approximately 1000°F in order to initially carbonize, then sustain controlled rapid devolatilization reactions at normal pyrolyzer tube temperatures between 1300°F and 1800°F.

Gasifier Shell:
The PyGas™ gasifier's vertical wall shell and upper dome will be water cooled.

Top Air Admission Burner:
The CRS Sirrine Engineers, Inc. modified M-GAS kinetic model performance runs indicate better performance without steam admission to the top burner. Top air to total coal ratio of approximately 0.8 appears to produce the desired 2300°F top gas temperature. While the test gasifier may prove to perform best without top steam admission, it will be piped so as to allow testing with or without steam. For safety reasons, the top air admission burner will be equipped with a flame stabilizer and flame scanner which will cause it to subtend air flow on loss of stable flame. Conceptual gas velocities at various points within the gasifier appear in Table 6:

Table 6
Key Superficial Gas Velocities

Coal Feed Line Pickup Point:	60 fps
Coal Feed Line Entry to Pyrolyzer Tube:	60 fps
Pyrolyzer Mid Section:	5 fps
Pyrolyzer Exit:	1.7 fps
Inner Annulus Entrance:	3.5 fps
Inner Annulus Exit:	5 fps
Through the Grate:	0.10 fps
Two Feet Above Grate:	0.14 fps
Exit of Fixed-bed Gasifier:	0.10 fps

Comparison of Pyrolyzer Injection Velocities

Injection velocity of the coal/limestone/air into the pyrolyzer tube is intended to sufficiently high to promote mixing into the immediately previously devolatilized char bed to inhibit agglomeration. Previous carbonizer tube injection velocities are identified in Table 7:

Table 7
Comparison of Pyrolyzer Injection Velocities

Carbonizer Tube Operating Entity	Injection Operating Velocity (fps)	Nozzle Type	Vessel Operating Pressure (psig)
Denver Bureau of Mines	80-125	Open Ended	15
Grand Forks Bureau of Mines	120		15
Wormser Engineering	68	Open Ended	15
Foster Wheeler	40-60	Concentric	200
METC	40-120	Concentric	300
PETC	Free Fall	Open Ended	1000-2000
PyGas™	60	Concentric	600

2.2.2 Predicted Plant Emissions

Operation of the GPIF will result in solid, liquid, and gaseous emissions. A comprehensive detailed description of the anticipated emissions may be found in the "Environmental Report" issued under Task 1 of this project.

2.2.2.1 Gaseous Emissions

Emissions of criteria air pollutants (SO_2, NO_x, total particulate matter, PM-10, and CO) for the GPIF are based on conventional fixed-bed gasification experience. The following paragraphs summarize the expected emission of each pollutant from the package boiler prior to exhausting the flue gas into the stack at Fort Martin station.

2.2.2.1 SO_2 Emissions

It is expected that all of the coal sulfur will be converted to H_2S, COS, or CS_2 during the gasification process. H_2S is expected to constitute greater than 95% of the sulfur products. During tests when limestone was injected with the coal in pyrolyzer tube experiments, up to 95% sulfur retention of volatilized organic sulfur as CaS was achieved lending credence that PyGas™ gasifier may achieve similar reductions. It is therefore likely that greater than 50% of the H_2S will be captured and removed with the gasifier bottom ash. Therefore 10 to 100% of the coal's sulfur will be emitted as SO_2 from the package boiler. So long as the GPIF utilizes low sulfur coal, the combined Ft. Martin Station and GPIF facilities are expected to produce less SO2 emissions than the Ft. Martin Station currently does and normally will without the GPIF in service.

2.2.2.2 NO_x Emissions

The bound nitrogen contained in the coal is converted to molecular nitrogen, tar, ammonia, and cyanide during gasification. N_2 is the predominant product, but NH_3, HCN, and tar can total 10 to 40% of the coal nitrogen depending on gasifier temperature, steam/air ratio, pyrolysis conditions, and coal type.

Experience with the Riley-Morgan fixed-bed gasifier indicates that NH_3 (200 to 2000 ppm) is greater than HCN (~100 ppm) in the product gas. If tars are cracked in the upper gasifier, tar nitrogen will be converted to either N_2 or HCN. Therefore, the HCN content of the gas leaving the PyGas™ reactor may include more HCN then from previous fixed-bed gasifiers. Whether the fuel bound nitrogen is contained in the tar or cracked to HCN will have little impact on NOx emissions.

Table 8 shows measured conversion rates of fuel nitrogen to NH_3 in 2-ft diam Wellman-Galusha gasifier. High NH_3 concentrations corresponded to low gasifier outlet

Table 8. Conversion of Coal Nitrogen to Ammonia in a 2-ft Diam Wellman-Galusha Gasifier

Run	NH_3 Conc. (ppm)	lb Steam / Std. cu ft $(CO + H_2)$	Coal Nitrogen (wt%)	Molar Conversion of N to NH_3 (%)
1	1940	2.26	1.54	35.0
2	622	2.19	1.54	12.0
3	385	1.81	1.54	5.2
4	666	1.76	1.54	9.0
5	486	2.19	1.54	5.3
6	658	2.26	1.54	7.2
7	452	1.84	1.54	6.8
8*	1170	7.29	1.08	5.0
*Pure O_2 as the oxygen source.				

temperatures and high steam flows into the gasifier. Since the PyGas™ reactor will operate at higher outlet temperatures and minimize steam flows, these conversion rates are considered to be an upper bound.

Figure 8 shows the conversion of NH_3 to NO_x using a conventional swirl burner in a refractory-lined furnace. Note that the conversion rate decreases markedly as the NH_3 content of the gas increases, a common observance during oil combustion. The thermal NO_x contribution during these tests was about 100 ppm. The total NO_x emission ranged from 200 to 300 ppm, implying that the conversion of N to NO_x in a gasification or combustion process is less than 10%.

During cracking within the upper PyGas™ vessel, significant ammonia may be reduced to N2 and H2 further reducing NOx emissions potential.

Based on these data, we expect the NO_x emission from the package boiler to be less than 300 ppm (0.4 lb/MBtu). In contrast, the NO_x emission from the Fort Martin boilers are in the range of 525 to 900 ppm (0.7 to 1.2 lb/MBtu). Therefore, the combined Ft. Martin Station and GPIF facilities are expected to produce less NOx emissions than the Ft. Martin Station currently does and normally will without the GPIF in service.

2.2.2.3 CO Emissions

The fired HRSG will utilize a burner capable of burning low-Btu gas having a range of heating values between 80 to 170 Btu/SCF. During periods when poorer

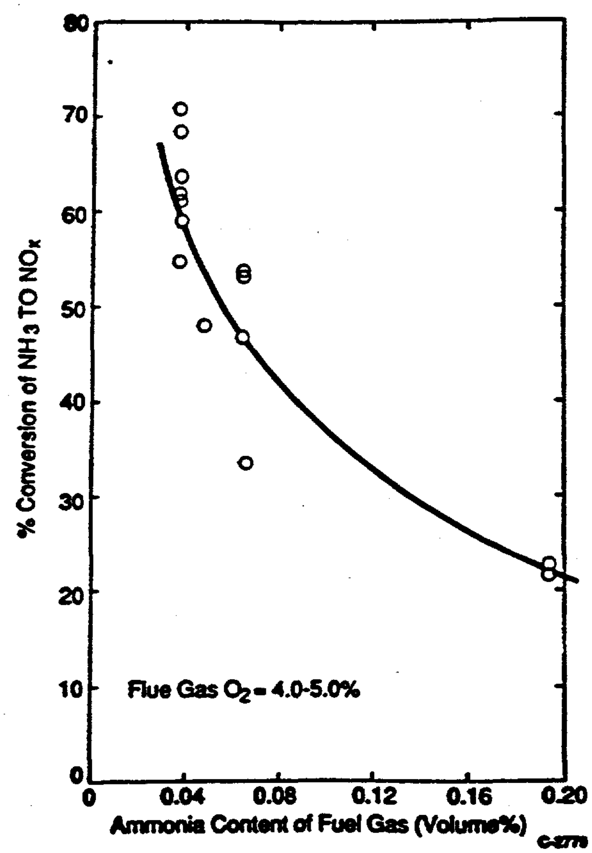


Figure 8
Conversion of Ammonia to NO_x in a Turbulent Diffusion Flame

quality gas is being produced, the facility will be fired with auxiliary #2 fuel oil (or natural gas) . Good combustion will be maintained for all conditions, thus maintaining CO emissions from the package boiler to less than 100 ppm.

Table 9 from the Task 1 Report (Table 14a) illustrates the normally expected trace metals emissions characteristics of the GPIF during testing operations. The first four columns present the flow rates into the hoppers and stack for the Fort Martin facility and the GPIF, both at maximum load. The next two columns are the combined flow rate assuming 12,000 lb/h of coal through the GPIF and a 610,000 lb/h through the Fort Martin Facility.

First, the flow rates through the GPIF can be seen to be small compared to the normal flow rates. Second, the distribution between hopper and stack is different for the GPIF. In the case of the GPIF, a larger fraction of the ash and trace metals go to the hoppers for disposal in the settling pond. When the combined flow in the stack is compared to the normal flow in the stack, there is a net decrease in every trace metal and overall flow

Table 9. Effect of GPIF Facility - Expected Case

Element	Comb. Hoppers Fort Martin Normal Operation (lb/h)	Stack Fort Martin Normal Operaton (lb/h)	GPIF Hopper s (lb/h)	Stack GPIF (lb/h)	Comb. Hoppers Fort Martin with GPIF (lb/h)	Comb. Stack with GPIF (lb/h)	Change Hopper s (%)	Ch'g Stack (%)
Antimony	0.74	0.004	0.03	0.000043	0.75	0.004	1.57	-0.91
Arsenic	14.67	0.26	0.29	0.001220	14.68	0.252	0.05	-1.45
Barium	105.36	0.38	2.04	0.000510	105.37	0.372	0.01	-1.79
Beryllium	1.36	0.006	0.03	0.000012	1.36	0.006	0.05	-1.74
Boron	27.23	3.05	0.62	0.008150	27.33	3.001	0.36	-1.66
Cadmium	0.29	0.002	0.006	0.000008	0.29	0.002	0.14	-1.51
Chromium	9.24	0.09	0.18	0.000204	9.24	0.088	0.03	-1.70
Cobalt	3.78	0.01	0.07	0.000020	3.78	0.013	0.03	-1.78
Copper	9.89	0.06	0.19	0.000114	9.90	0.057	0.02	-1.73
Lead	6.76	0.08	0.13	0.000237	6.76	0.082	0.05	-1.64
Manganese	26.63	0.12	0.55	0.000176	26.66	0.119	0.15	-1.78
Mercury	0.01	0.19	0.001	0.000901	0.01	0.184	6.87	-1.45
Molybdenum	2.03	0.02	0.05	0.000037	2.04	0.019	0.28	-1.74
Nickel	8.65	0.06	0.17	0.000128	8.65	0.056	0.01	-1.70
Selenium	1.56	0.35	0.03	0.000779	1.757	0.341	0.18	-1.71
Vanadium	13.6	0.09	0.27	0.000166	13.61	0.086	0.08	-1.74
Uranium	1.3	0.005	0.03	0.000005	1.30	0.005	0.15	-1.82
Thorium	1.98	0.007	0.04	0.000010	1.98	0.007	0.04	-1.79
Total Fly Ash	92964	336	2531	0.45	92972.5	330	0.009	-1.8

2.2.2.2 Liquid Discharges

Process Water Distribution System

The process water shall be distributed from the main process water line main near Monongahela Power's Unit No. 2 as shown on Exhibit 2 of the site tour of June 18, 1991.

A 2 inch main is included to supply this quantity of process water for the facility.

The cooling water distribution to the gasifier jacket, coal gas cooling and carbonizer tube cooling is estimated at 2,500 gpm. Cooling water from the GPIF will be returned to the existing Fort Martin Unit #2 cooling tower. There will not be a separate GPIF cooling tower.

Normally, there will not be waste water continuously discharged from the GPIF. A sump with 5 gpm pump will be furnished inside the GPIF to return water from washing and any potential spills within the GPIF back to the existing Ft. Martin waste water treatment system.
All water makeup to the auxiliary boiler and reactor cooling jacket shall be softened and injected with environmentally acceptable oxygen scavengers and corrosion inhibitor chemicals.

2.2.2.3 Solid Waste

Solid waste from the GPIF is anticipated to accumulate at a rate of approximately a ton per hour when limestone feed is introduced along with the coal.

Ash sources include mainly the gasifier bottom ash along with a minor source from the gasifier outlet cyclone. Gasifier bottom ash will be conveyed via a steam inerted depressurization lock hopper (from 200 - 600 psig to 100 psig, @ 500° to 700°F) into a wet oxidation sulfation tank. Gasifier outlet cyclone solids will also be depressurized via a nitrogen inerted depressurization lock hopper and discharged to a tote bin for Toxicity Characteristic Leaching Protocol (TCLP) testing and subsequent disposal.

Since the PyGas™ process provides an oxidation zone immediately above the rotating grate, it is expected that retained sulfur in the ash will be predominantly in the fully sulfated form.

However, in anticipation that the ash may contain unsulfated forms of sulfur, it will be first fed to a submerged combustion reactor to complete the sulfation reaction prior to transfer to the temporary ash storage day-bin and subsequent disposal in the permitted Fort Martin existing coal ash landfill. The exhaust from this reactor shall be vented to the auxiliary steam boiler for additional combustion. The treated ash is then dewatered through mechanical filtration equipment, temporarily stored in the ash day-bin, and transported by truck to the existing ash landfill area of the Fort Martin power plant.

Fort Martin has an air permeable dust screen at their landfill site. While some air can pass through it, it does provide a good buffer on windy days resulting in less particulate becoming air-borne.

It is expected that there will remain approximately 15% to 25% free moisture in the GPIF solid waste. The anticipated properties include moist but dry handling granular solids, and the expectation is that conventional ash hauling trucks will be able to easily handle it. While the quantity of GPIF ash to be added to the existing ash landfill is extremely small relative to current fill rates, it is likely to contain some unreacted alkali .

The ash is removed from the ash storage day-bin concrete slab into an ash disposal truck using the same 5 cubic yard front-end loader used for coal charging. Since each bucket's capacity will be approximately 3.5 to 5 tons of ash or coal, loading ash trucks or charging the coal hopper will likely not be very time consuming. Assuming a one minute per bucket dumping cycle, a day's worth of ash can be loaded on an ash truck in 15 minutes.

It appears that, based on the METC results from the 42 inch METC fixed-bed gasifier runs 106 and 107, and assuming 100% of the sulfur contained in the Fort Martin coal were captured and 100% of the gasifier ash became bottom ash, the available releasable sulfide levels in the ash would likely be an order of magnitude below RCRA hazardous waste limits.

To obtain significant sulfides in the ash, apparently a concentrated SO2 stream had to be bled into the gasifier, and the total ash sulfur content had to be an order of magnitude greater than is expected using PyGas™ at the GPIF site using Fort Martin coal.

Therefore, while previous METC testing has confirmed the presence of sulfides in the gasifier ash, the extent of conditions required to produce significant levels of releasable sulfides really cloud the issue more than provide any real cause for concern relative to the PyGas™ gasifier applied to the GPIF facility.

While sulfide hideout in the gasifier ash is not likely to be a problem for the GPIF facility, we continue to recommend the use of the wet oxidation process developed for this project.

Our hesitancy to utilize a dry ash storage and disposal system results from historical and current difficulties encountered in the fluidized-bed coal boiler industry. There have been numerous reports of (and personal experience with) caustic skin burns associated with dry ash systems designed very much like the current Fort Martin system. It should be pointed out that the Fort Martin system is perfectly suitable for their coal ash which does not contain calcined fluid-bed limestone.

The widely used process of dust suppression using water spray in the vicinity of the ash silo outlet feed conditioner results in the production of caustic vapor in systems which contain substantial free lime in the ash. As previously stated, this is most common in fluidized-bed systems using limestone sorbent. It has been demonstrated that such reactive ash can be easily neutralized by simply adding the ash to a tank of water. A side benefit of such wet oxidation is the mechanical separation of coal ash from and the potential to recover hydrated lime. Of course, care must be exercised to dissipate heat generated by the lime hydration (slaking) reaction. Since free lime will likely be produced by PyGas™ in the GPIF plant, wet oxidation will not only assure the complete sulfidation of sulfides, but also the stabilization of otherwise reactive ash constituents, and the potential recovery of hydrated lime, a useful byproduct for the additional reduction of sulfur emissions from coal fired plants via dry scrubbing techniques.

Both applications have sufficient calcined limestone (assuming normal Ca/S mole ratios) to produce excess lime which forms alkaline calcium hydroxide when sprayed.

The "Pulp and Paper" industry has successfully employed the use of strong black liquor wet oxidation to ensure 99% sulfide oxidation efficiency required to meet current boiler recovery odor release standards. Our GPIF application has, by no means, anywhere near the odor release likelihood of a recovery boiler. Nevertheless, we are conceptualizing a small, simple system to first fracture hot ash crystals by injection into water wherein the ash is mixed in an oxygenated circulation tank, pumped to a settling tank, and then dewatered in a vacuum filter to produce fully oxidized ash. This ash will not be subject to caustic vapor release as with dry ash systems, nor will it be dusty like dry ash systems. Both of these issues should be of significant concern to your NEPA and SARS programs. We anticipate it will be quite easily handled using the selected front end loader for loading into Ft. Martin's conventional ash dump trucks.

We anticipate that any excess hydrated lime produced when the GPIF happens to run testing with limestone injection with the coal will be of such a small quantity relative to the existing Ft. Martin ash inventory in its permitted landfill to be considered of diminimous impact.

With respect to expressed concerns of plugging the circulation tank vent, during the meeting I should have pointed out the demister in the tank sketch which is located so as to minimize solids carryover. Wet/dry zones of conventional limestone scrubbing systems in utility applications are normally dealt with in this manner.

2.2.3 Utility Requirements

The overwhelming logic to the location of this facility is its proximity to, and therefore, its ability to obtain utilities from Ft. Martin Generating Station.

2.2.3.1 Normal Utility Requirements

2.2.3.1.1 Process Water Distribution System

The process water shall be distributed from the main process water line main near Monongahela Power's Unit No. 2 as shown on Exhibit 2 of the site tour of June 18, 1991.

The normal total process water consumption (Table 10) at 70 psig is estimated as:

Table 10
Steam Generation, Process, and Cooling Water Consumption

1.	GPIF feed water for steam generation	300 gpm
2.	Coal gas cooling (service water)	5 gpm
3.	Ash conditioning	1 gpm
4.	Cooling water consumption	2,500 gpm
	Total	2,806 gpm

The steam generation, process and cooling water main lines must be sized to supply this quantity of feed-water, process and cooling water for the facility.

Cooling Water Distribution

The cooling water distribution to the intercoolers, gasifier jacket, coal gas cooling and possibly pyrolyzer tube cooling is estimated at 2,500 gpm. Cooling water from the GPIF will be returned to the existing Fort Martin Unit #2 cooling tower. There will not be a separate GPIF cooling tower.

Fired Heat Recovery Steam Generator (HRSG) & Induced Draft Fan

A No. 2 oil (or natural gas) ignited and stabilized coal gas fired HRSG followed by an induced draft fan shall provide the heat recovery system for returning the Btu's and the flue gas resulting from burning coal from the gasification of coal in the GPIF to the host utility. Required No. 2 oil (or natural gas) flows for gasifier preheat, flame stabilization, and coal drying are all shown in the "Feed Flow Rates" section of this report and on the "Mass & Energy Balance" located in the appendix section of this report.

Boiler Chemical Treatment

Cold reheat steam from the Ft Martin generating station will be used for startup. Therefore, all water makeup to the HRSG and PyGas™ reactor shall be previously treated at the Ft. Martin generating station prior to being pumped by the GPIF feed-water booster pump. At times, this may require the utilization of trailer mounted water purification equipment to treat the additional 10,000 lb/hr of steam which will be used up by the PyGas™ gasifier reactor in the gasification process.

2.2.3.1.2 Test Facility Motor Horsepower Consumption

Table 11 shows a list of motor and horsepowers associated with the test facility :

Table 11
Horsepower Consumption

Equipment Description	*Horsepower*	*K W*
Gasifier		
Rotary Coal Metering Drives (2)	10.0	7.45
Grate Drive	15.0	11.18
Cooling Water Pump	N/A	N/A
Air Compressor		
Centrifugal Compressor	1750.0	1305.0
Reciprocating Compressor (2)	700.0	522.2
Coal Receiving/Storage/Reclaim		
Pile Runoff Collection Sump Pump	1.0	0.74
Gravimetric Feeder Drive	3.0	2.24
Transfer Conveyor Drive	10.0	7.45
Vent Fan Drive(Pit Ventilation)	7.5	5.59
Sample Cutter Drive	1.0	0.74
Coal Crusher/Dryer Drive	20.0	14.90
Limestone Receiving/Storage/Reclaim		
Gravimetric Feeder Drive	3.0	2.24
Sample Cutter Drive	1.0	0.74
Coal Gas Combustion/Heat Recovery		
Forced Draft Fan Motor	125	93
Feedwater Pumps	10.0	7.5
Induced Draft Fan Motor	400	298
Wet Oxidation System		
Vacuum Filter Pump Motor	N/A	N/A
Transfer Pumps (2)	N/A	N/A
Oxidation Air Blower Motor	N/A	N/A
Ash Handling System		
Ash Blower	50.0	37.29
Totals:	2,857	2,131

Desulfurization

Provisions have been made for limestone feed to the proprietary PyGas™ coal gasifier. Based upon the results of other pyrolyzer tube testing, approximately 20% to 95% sulfur retention may be possible within the gasifier itself. This retained sulfur will be removed from the gasifier and disposed of in the Fort Martin Generating Station permitted coal ash landfill along with the gasifier bottom ash. It is expected that this solid waste product may contain some unsulfated alkali whenever testing included excess limestone. The expected range of calcium to sulfur mole ratios anticipated for testing is 1.0 to 3.0. Depending on sulfur content in the coal, this results in up to approximately a half ton of limestone per hour.

2.2.3.2 Special Utility Consumption

The CRADA arrangement between DOE/METC and APS will provide a special ability to procure coal for testing at costs which are reduced by the value of the steam produced by coal gasification testing and returned to Ft. Martin Generating Station. Therefore, the GPIF will conserve and reduce operating costs by recovering useful thermal energy during testing.

Under unique test operating conditions, variations in utility requirements may occur. Examples of such variations include high gas cooling water spray under extremely high gasification operating temperatures (ash fusion temperature range permitting), and high steam injection conditions should such operation be found to promote gasification within reasonable downstream operating conditions.

High coal gas cooling water flow requirements could double from the norm, and high steam injection requirements may triple from the norm. The GPIF shall be capable of producing these special utility provisions should testing demands require such flows.

2.2.4 Feed Flow Rates

Feed flow rates have been estimated under two operational scenarios, a conservative case based on C. Lowell, et al carbonizer tube performance data, and a best case based on recent Foster Wheeler carbonizer tube performance data. These flow rates can be found in the Mass & Energy Balances (Appendix A). The most significant flow rates appear on the following Tables 12 through 23 :

Table 12
Raw Coal From RFP Specifications to GPIF

Ultimate Analysis

Carbon	68.60%
Hydrogen	4.60%
Oxygen	4.70%
Nitrogen	1.20%
Sulfur	2.80%
Moisture	3.00%

Table 13
AIR COMPRESSOR SIZING :

Based on Wormser Data :
5500 scfm

Based on Foster Wheeler Data :
6762 scfm

Table 14
Fuel Oil Requirements

Coal Dryer	288 lb/hr
Burner Support	1,294 lb/hr
Pyrolyzer Preheat	1,294 lb/hr
Start-up Steam	512 lb/hr
Total at Startup	3,387 lb/hr
Total at Startup	8.1 GPM

Table 15
Low Pressure Air Requirements

Coal Dryer, Classifier & Dust Collector Exh	17,776 lb/hr
Air for HRSG Combustion	182,077 lb/hr
Total Air	199,853 lb/hr

Table 16
Pyrolyzer High Pressure Air (from Appendix A-8)

Dense Phase Feed	7,373 lb/hr
Outer Annulus Air	27,069 lb/hr
Total Pyrolyzer Feed	34,440 lb/hr (design)
Pyrolyzer Air/Coal	2.87
Pyrolyzer % Theo Air	37.1%
Gasifier Top (Cracking)Air	0 lb/hr
Undergrate Air	17,065 lb/hr
Pyrolyzer Feed	34,440 lb/hr
Total Air	51,505 lb/hr
Overall Air/Coal	4.15 lb/hr

Table 17
Steam Utilization (Model Optimum)

Pyrolyzer Feed	0 lb/hr
Gasifier Top (Cracking)	0 lb/hr
Undergrate	3,865 lb/hr
Ash Lock	192 lb/hr
Total Steam Use	4,056 lb/hr
Available for Gasification	10,000 lb/hr
Grate Steam/Air	0.23
Overall Steam/Air	0.08
Overall Steam/Coal	0.32

2.2.5 Product Flow Rates

Table 18 reflects the throughputs anticipated for one typical test condition. Appendix A contains more complete product flow rates for several potential test cases based on the CRSS gasification model.

Table 18
Product Flow Rates (Anticipated)

Products of Pyrolysis	23,824 lb/hr
Carbon Monoxide	4,515 lb/hr
Hydrogen	323 lb/hr
Carbon Remaining	5,553 lb/hr
Carbon Remaining	65 %
Gases Exiting Down-flow	33,851 lb/hr
Carbon Monoxide	8,748 lb/hr
Hydrogen	391 lb/hr
Carbon Remaining	4,189 lb/hr
Carbon Remaining	49 %
Fixed-bed Gasification	25,034 lb/hr
Carbon Monoxide	7,722 lb/hr
Hydrogen	264 lb/hr
Carbon Remaining in Ash	8 lb/hr
Carbon Remaining in Ash	0.1 %
Combined Hot Raw Gas Flows	58,885 lb/hr
Carbon Monoxide	16,470 lb/hr
Hydrogen	655 lb/hr
Combined Hot Raw Exit Gases	64,206 lb/hr
Carbon Monoxide	20.90 % vol
Hydrogen	11.55 % vol
Coal Gas Production	54 to 86 scf/lb
Range of HHV	88 to 144 Btu/scf
Coal Gasification Rate	400 to 435 lb/sq ft

2.2.6 Process Mass & Energy Balances

Tables 19 & 20 illustrate typical mass & energy balances for the GPIF done to sufficient levels of accuracy for conceptual design flow determinations. Appendix A contains more complete product flow rates for several potential test cases based on the CRSS gasification model.

Table 19
Mass Balance Overview

RFP Specification Raw Coal to GPIF
Proximate Analysis

Volatile Matter	30.00%
Fixed Carbon	52.00%
Moisture	3.00%
Ash	15.00%
HHV	12,500 Btu/lb
LHV	12,495 Btu/lb
Firing Rate	150-million Btu/hr
Feed Rate	6 Tons/hr

Table 20
Energy Balance Overview

Coal Firing Rate	150-million Btu/hr
Compressed Air Sensible Heat	1.56-million Btu/hr
Raw Coal Gas Chemical Heat	101-million Btu/hr
Raw Coal Gas Sensible Heat	29-million Btu/hr
Raw Coal Gas Latent Heat	3-million Btu/hr
HRSG Support Flame Heat	15-million Btu/hr
Steam (Heat Added) to Ft Martin	95-million Btu/hr

Table 21
Permitting Status

Permit Type	Existing Ft. Martin Permit
Boilout & Acid Cleaning	NPDES
Ash Disposal	NPDES
Water Discharge	NPDES
Wetlands	NPDES
Wildlife Management	NPDES
Emissions Monitoring Certification	AIR
Calibration of CEM Inspection	AIR

Note: Of the 66 identified potential requirements, 41 are either not applicable or not required.

Table 22
Permit List

Permits, Certificates, Inspections 10/12/93

Potential Permits/Certificates Identification	Normal Authority Level	Person to Initially Contact
Prevention of Significant Deterioration (PSD)	Federal, Regional, State	Part of Existing APS Air Permit
Resource Conservation and Recovery Act (RCRA)	Federal, State	No Hazardous Waste (no permit)
Site Survey	CRSS for APS/DOE Only	no permit
Spill Prevention Plan	State	CRSS to submit to APS for their SARA Title 3
Stream Encroachment (Underground Storm Drain Pipe)	State, Local	Cross existing storm drain above ground (no permit)
Building (Local Siting Authority)	Not Applic.on APS Property	no permit
Building Inspection	Not Applic.on APS Property	no permit
Bulk Materials	Not Applic.on APS Property	no permit
Certificate of Occupancy	Not Applic.on APS Property	no permit
Contractor's Site Building	Not Applic.on APS Property	no permit
Electrical Code Inspection	Not Applic.on APS Property	no permit
Explosion Relief Venting	NFPA	CRSS to comply (no permit)
Explosives	State	Local Governing Jurisdictional Staff Member
Fencing	per APS Standards	CRSS to comply
Fire Protection (NFPA, OSHA, State)	State Fire Marshall Inspect.	CRSS to design to codes (no permit)
Fire Suppression (NFPA, OSHA, State)	State Fire Marshall Inspect.	CRSS to design to codes (no permit)
Noise Abatement	Local	CRSS to advise APS of flare noise estimate
Obstructional (Building Height)	Local but Not Applicable	no permit
Odor	Local	Local Governing Jurisdictional Staff Member
Operating Certification	Local but Not Applicable	not required
Plant/Boiler Operation	Local but Not Applicable	not required
Plumbing Code Inspection	Local but Not Applicable	not required
Potable Water	State	Line flush & State Health Dept. test
Sewage	Local but Not Applicable	Holding tank & truck away (no permit)
Steam Blows	Local but Not Applicable	Advise APS only
Temporary Sewage Disposal	Local	General Contractor
Visual (Aesthetics) & Zoning	Local but Not Applicable	APS & DOE only
National Environmental Policy Act (NEPA)	Federal	DOE to handle
NationalPollutionDischargeEliminationSystem(NPDES)	Federal & Regional	Under existing APS permit (no permit)
Water Discharge	Under Existing APS NPDES	design for 25 year rain capacity (no permit)
Water Diversion (Intake Structures)	APS Property	Fire protection water from lagoon (no permit)
Wet Lands, Wildlife Management (Fish & Game)	Under Existing APS NPDES	no permit
Highway Access (Curb Cut)	APS	APS Property (no permit)

Table 23
Permit List

Permits, Certificates, ...spections 10/12/93

Potential Permits/Certificates Identification	Anticipated Authority Level	Resolution
Boilout & Acid Cleaning	Existing NPDES Permit	APS to notify NPDES only (no permit)
Calibration of Utility Metering	APS	Certification between APS & DOE only (no permit)
Coal/Ash Vehicles	Hauler to have permit	Local truck hauler contract (no permit)
Emissions Monitoring Certification	Under Existing APS Permit	APS has CEM on stack (no permit)
Energy Facility Siting Board (EFSB)	None	no permit
Public Utility Regulatory Policy Act (PURPA)	Federal but Not Applicable	not applicable
Railroad Crossing (lease incl. inspec. & maint.)	Conrail Lease to DOE	Tariff monthly (no permit)
Utility Connect/Disconnect	APS Interfaces	no permit
Federal Aviation Administration (FAA)	Federal but Existing Stack	existing stack (no permit)
Federal Energy Regulatory Commission (FERC)	Federal but Not Applicable	not applicable
Concrete Testing	Certificate to meet codes	General Contractor
Construction Waste	Part of APS Agreement	Dumpsters to permitted landfill
Gas Fitting Inspection (Nitrogen)	Local Certification	General Contractor
Handicapped Persons Access	Federal, State, Local	General Contractor
Hydrostatic Test	ASME & State Codes	General Contractor
Lube Oil Flushing	Local	General Contractor
Non-distructive Testing (NDT)	Fereral, State Code Cert.	General Contractor
Occupational Safety & Health Act (OSHA) Inspection	Federal	General Contractor
Pressure Vessel Code Fabrication Stamp	ASME & State	General Contractor
Pressure Vessel Code Inspection	ASME & State	General Contractor
Pressure Vessel Code Installation Stamp	ASME & State	General Contractor
Soils Testing (Boring, Resistivity, Compaction)	APS	General Contractor
Structural Stamp	BOCA Bldg. Codes, State	General Contractor
System Flushing	Under Existing APS Permit	General Contractor
Welding Tests	ASME & State	General Contractor
Air Emissions	Under Existing APS Permit	no permit
Appellation Club	APS Property	no permit
Ash Disposal	Under Existing APS NPDES	no permit
Calibration of CEM Inspection	State but Not Applicable	APS has Stack Monitors (no permit)
Environmental Impact Statement (EIS)	Federal & State	Environmental Assessment only (no permit)
Erosion Control (Terrain Alteration)	State	Best Mgt Practice Plan by CRSS to APS
Friends of the Earth	Not Applic.on APS Property	Governor's Environmental Assistant Staff Member
Historical/Archaeological	Federal, Regional & State	Done by DOE/METC

Premises and strategies involved in the development of a satisfactory NEPA document for the GPIF are summarized in the following Tables 24 through 26 :

Table 24
Environmental Impact
Air Emissions

Air Emissions Premise :
No net increase in criteria air emissions

Strategies:

• SO2	-	Low Sulfur Coal
• NOx	-	Ammonia Cracking Cyanide Cracking Low Btu Gas Combustion
• Particulates	-	Gasifier Bottom Ash Existing Elect Precip
• Trace Metals	-	Net Decrease

Table 25
Environmental Impact
Solid Waste Emissions

Solid Waste Emissions Premise :
A slight increase in solid waste generation

Strategies:

• Trace Metals	-	Net Increase (Decrease in Air Emissions)
• Sorbents	-	Calcium based solid waste helps ash pile Metal oxide sorbents collected (Phase II)

Table 26
Environmental Impact
Effluent Treatment

Effluent Treatment Premises :

- Wastewater is not continuously produced.
- Periodic process wastewater pumped to existing Ft Martin treatment system.
- Stormwater from coal & ash pumped to existing Ft Martin treatment system.
- Sanitary waste removed by truck.

2.2.7 Major Operating Parameters

The most significant operating parameter which has been isolated to date is the solids to gaseous conversion which can be accomplished in the pyrolyzer section of the PyGas™ gasification process. This issue has long been the subject of much conjecture, and should be one of the first testing objectives of the PyGas™ gasifier being installed under the GPIF program. The consensus has been that it would be advantageous to maximize solids conversion in the pyrolyzer tube to minimize throughput limitations in the fixed-bed gasifier section. Figure 9 serves to illustrate how far the technology has progressed during the past three years. Figure 9 superimposes significant recent carbonizer tube performance data shown in Figure 10 (DE-AC21-86MC21023) over previous data originally presented three years ago to support the suggestion that in excess of 50% coal to gas conversion may be possible within the pyrolyzer tube section of the PyGas™ process. It shows that test data with increasing pilot plant coal loading generally followed the projected relationship (fc Pitts = 0.0232(%stoich)-10^4(1-Lc)^2) between stiochiometric air and fractional carbon conversion for Pittsburgh #8 coal. This is very significant in that it indicates that caking coal concerns can be eliminated via rapid devolatilization in a fluidized-bed, and in excess of 50% carbon conversion can be attained as well.

Table 27 illustrates two potential operating conditions for testing the PyGas™ gasifier. Both have been developed using the CRS Sirrine Engineers, Inc. in-house model.

The first represents anticipated operating conditions and predicted results based on previous operation of a carbonizer tube [22] which resulted in approximately 50% coal conversion into gaseous fuel within the confines of the carbonizer tube. This may be referred to as the "conservative case" since more recent test data confirms that greater conversion efficiencies will be possible.

The second operating scenario represents the best carbonizer conversion produced by Foster Wheeler (DOE/METC Contract DE-AC21-86MC21023). This may be referred to as the "best case" operating condition until actual testing can either confirm or change this presumption.

Table 27 then, represents the range of test expectations. Appendix A-8 was generated to provide a single set of realistic design conditions which more clearly define the expected optimum operating conditions.

Table 27

PyGas Operating Conditions

Parameter	Conservative Case (Appendix A-5)	Best Case (Appendix A-1)
Pyrolyzer Devolatilization	35%	69%
Inner Annulus Gasification	0%	20%
Fixed-Bed Gasification	65%	11%
Tar Cracking Steam	S/C=0.4	S/C=0
Fuel Nitrogen Destruction	0%	90%
Volatilized Alkali Reduction	0%	90%

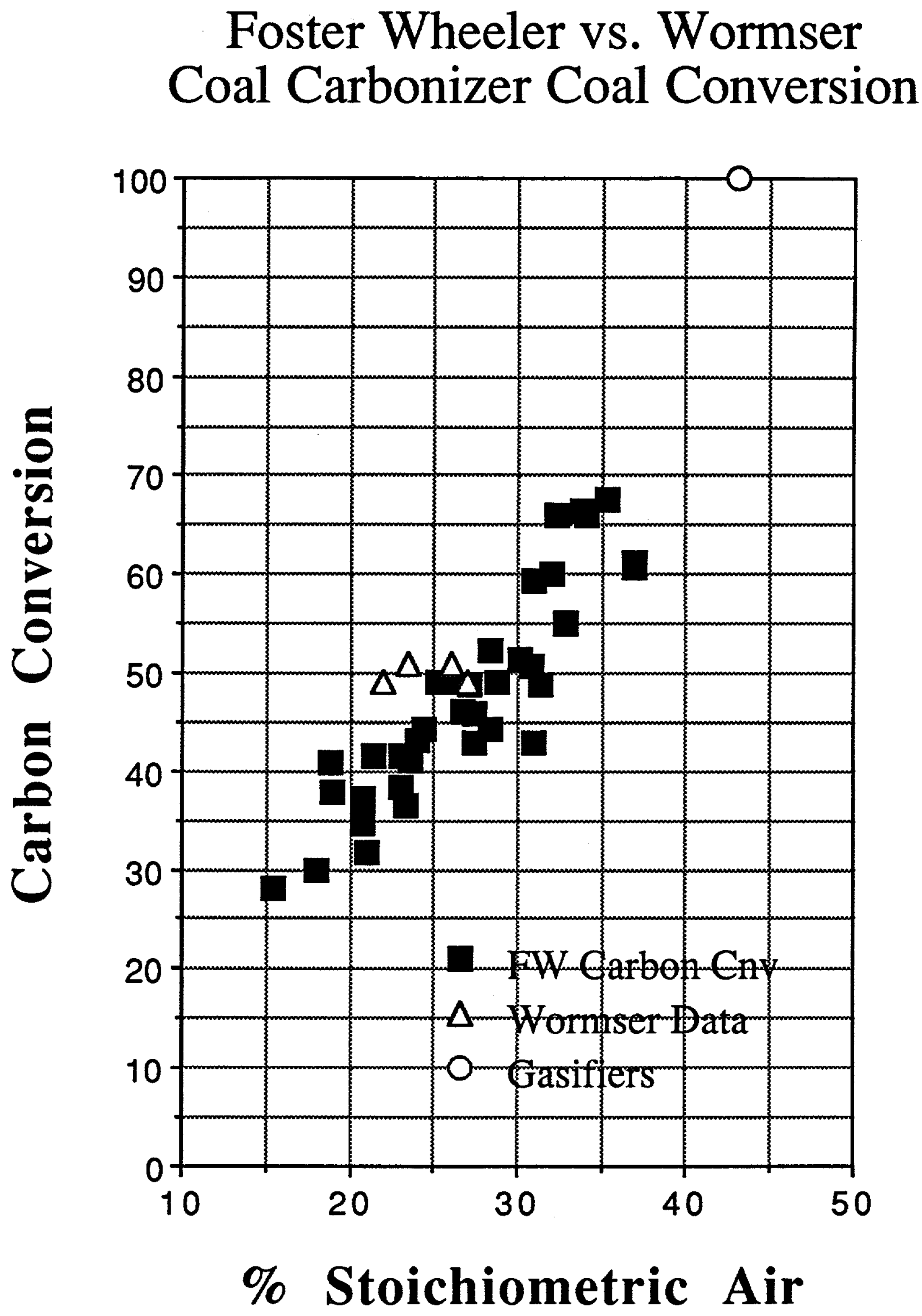


Figure 9 : Anticipated Pyrolyzer Tube Performance

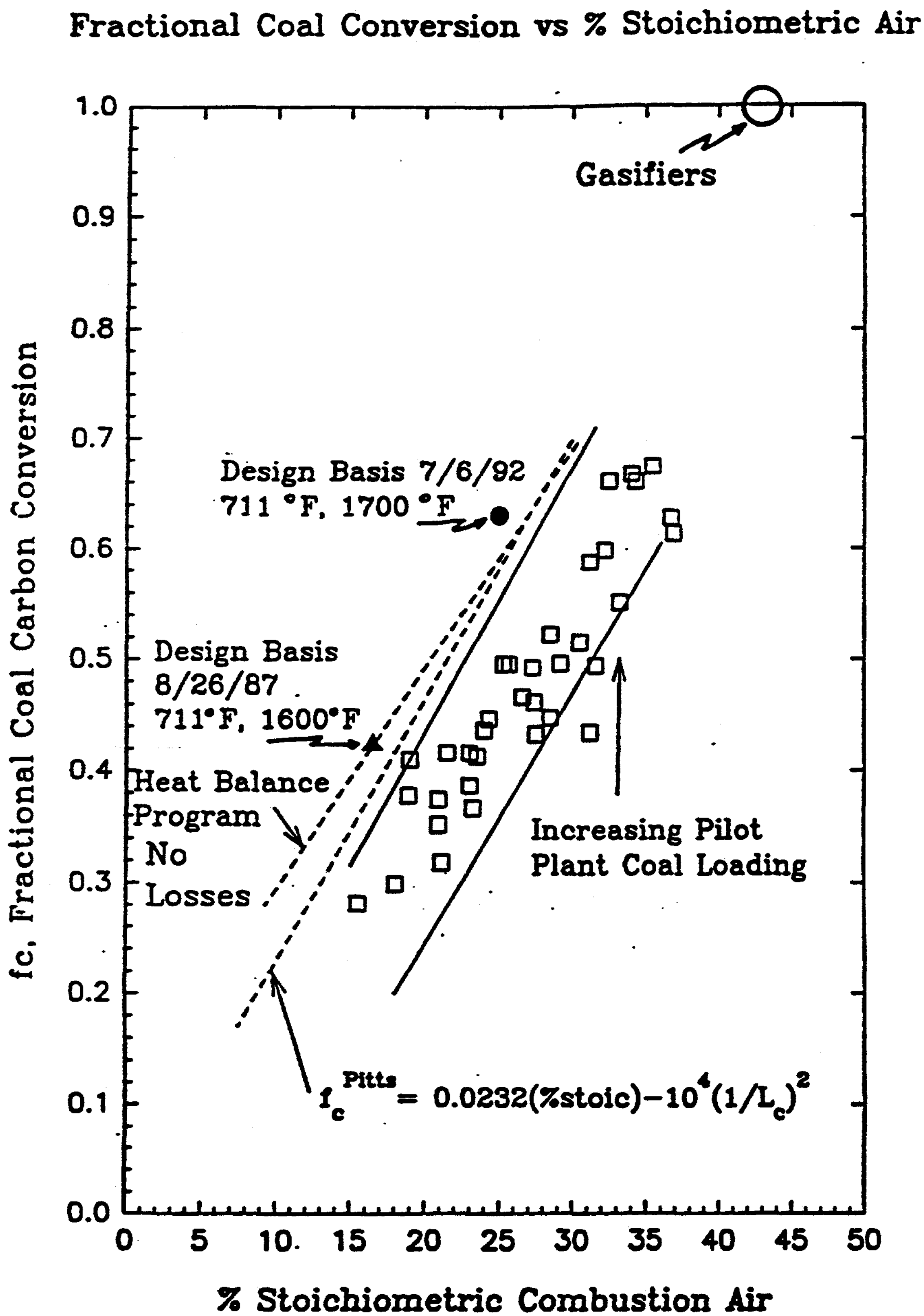


Figure 10
FW Fractional Coal Conversion vs. % Stiochiometric Air

Section 3 Conceptual Design of the GPIF

3.1 Plant Description

The GPIF consists of four major structures and several sub-systems necessary to effect an operational coal gasification test facility (see following General Arrangement Exterior Elevation and Plan drawings, Figures 11 & 12).

The first of the four structures is a three sided concrete reinforced enclosure to house the gasifier and related Phase II Hot Gas Cleanup Unit (HGCU) vessels, thereby providing for personnel protection from potential explosive conditions where they are most likely to occur. This area may be referred to as the "containment bay".

Adjacent to the gasifier containment bay on both sides are the compressed air and ash treatment bay, and the Heat Recovery Steam Generator (HRSG) bay.

Behind the facility are an outdoor coal and sorbent receiving, temporary storage, processing, and conveying sub-systems.

Finally, in front of the facility is the administration building which houses the office, control room, laboratory/presentation room, communications room, uninterruptable power supply room, input-output room behind the control room panel, and mens' and womens' locker and lavatory facilities.

3.2 Coal Preparation and Feed System

Coal is received via dump truck to the coal receiving hopper and elevated to temporary storage bin by bucket elevator. The coal then flows by gravity down through the storage bin (Figure 13), through the active bin discharge and onto a weigh-belt feeder. The coal sampler is located at the weigh-feeder discharge. The coal then falls into a dryer and on through a crusher prior to being pneumatically delivered to a screen type separator. The properly sized coal is then admitted into a surge bin, then on to a pressure charge hopper and transfer hopper pressure lock before being pneumatically delivered to the PyGas™ pyrolyzer inlet.

In similar manner, limestone is received pre-sized by pneumatic truck, conveyed into a temporary storage silo, fed by gravity into a weigh-belt feeder, and then blended into the coal surge bin (Figure 14).

3.3 Compressors and Air Handling System

3.3.1 Compressor

The air compressor is a multi-stage interstage water cooled centrifugal type unit. The unit is sized to delivered a maximum of 8770 scfm at a pressure of 700 psig The driver for this machine will be an electric motor with a present estimated power capacity of 3000 hp. The air compressor unit will provide sufficient air for gasification, pneumatic conveying of solids feed to

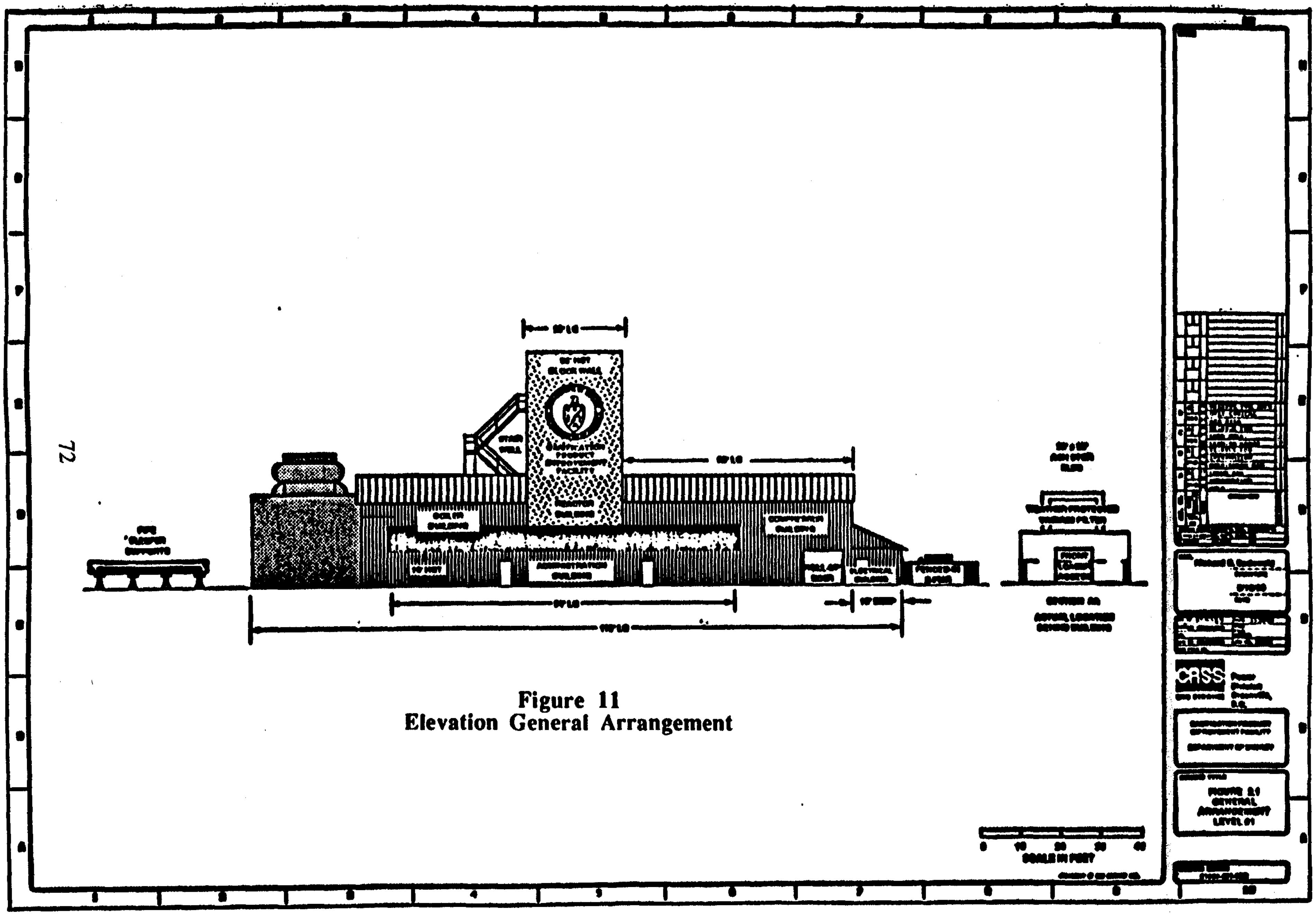


Figure 11
Elevation General Arrangement

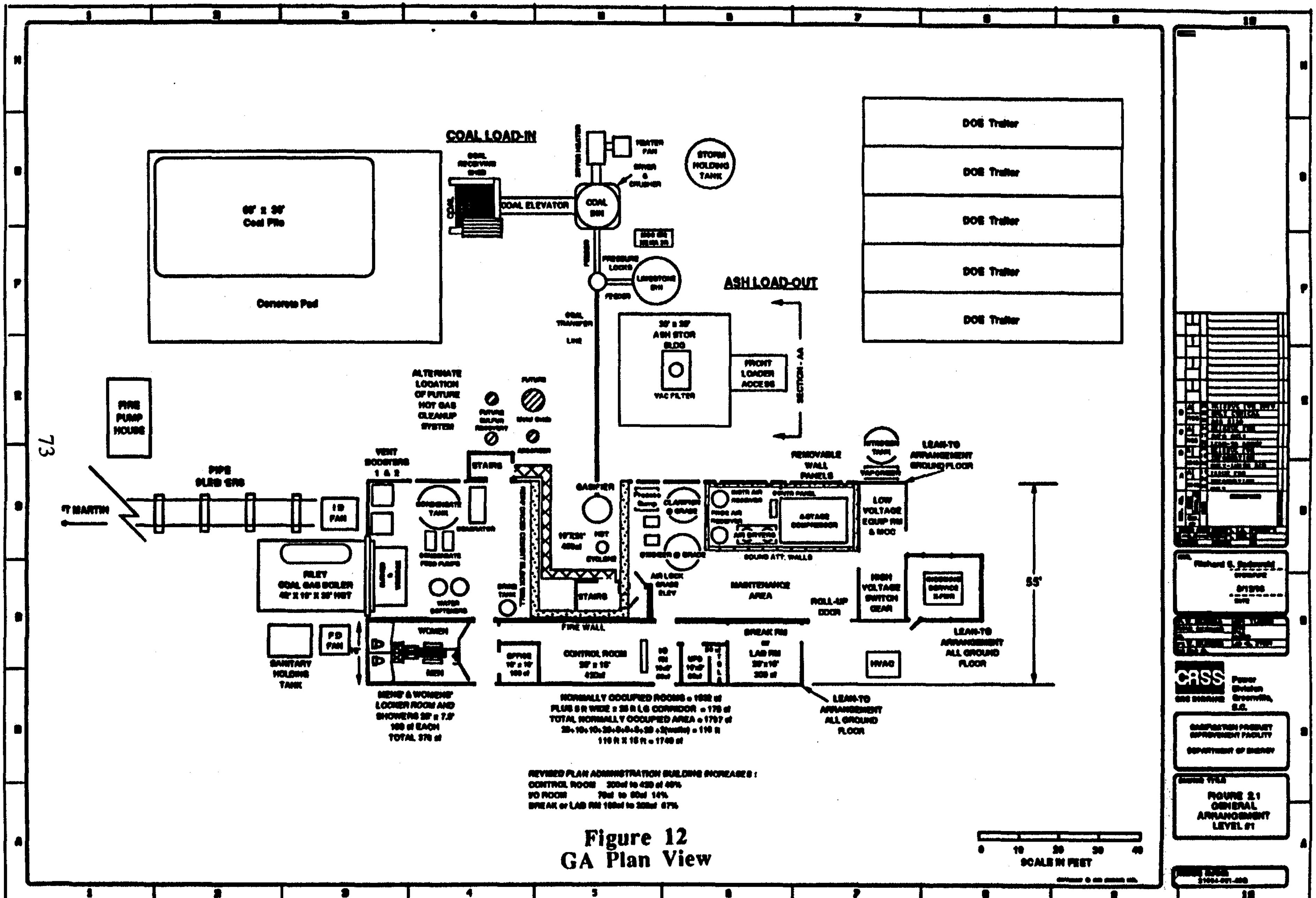
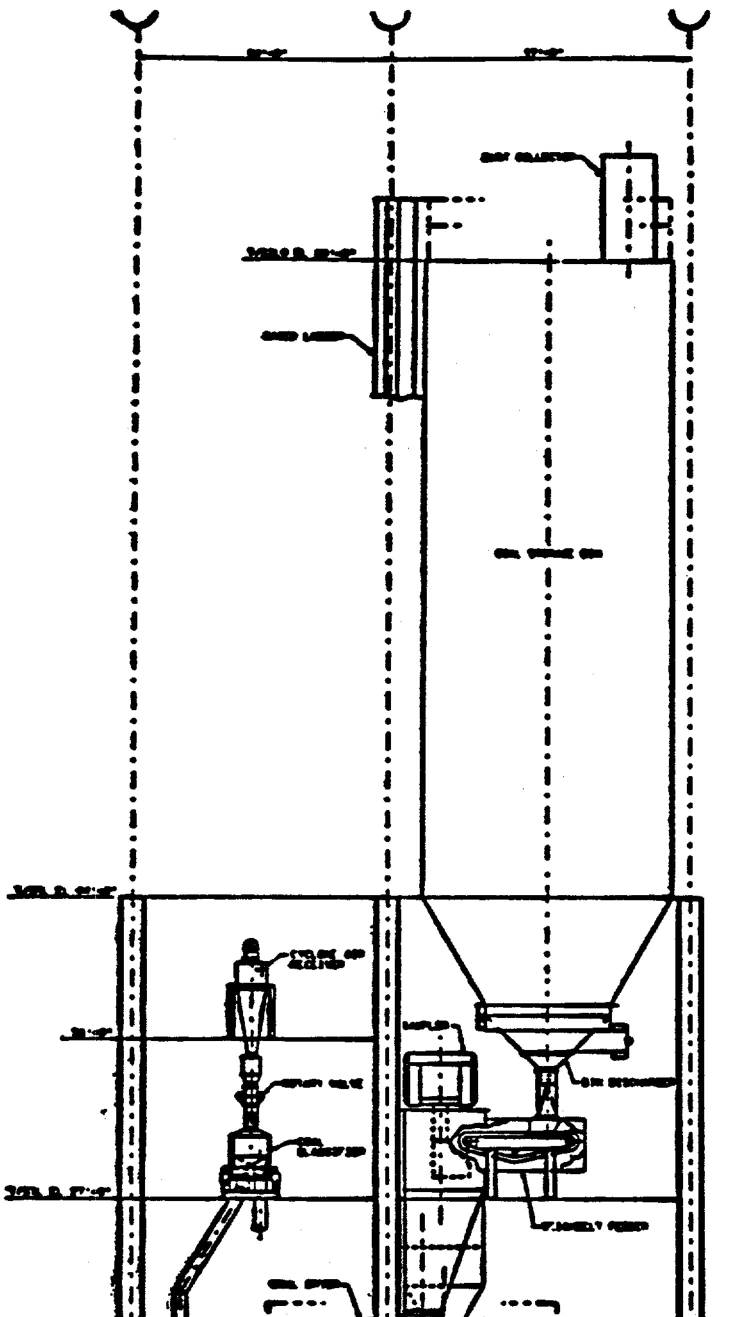


Figure 12
GA Plan View



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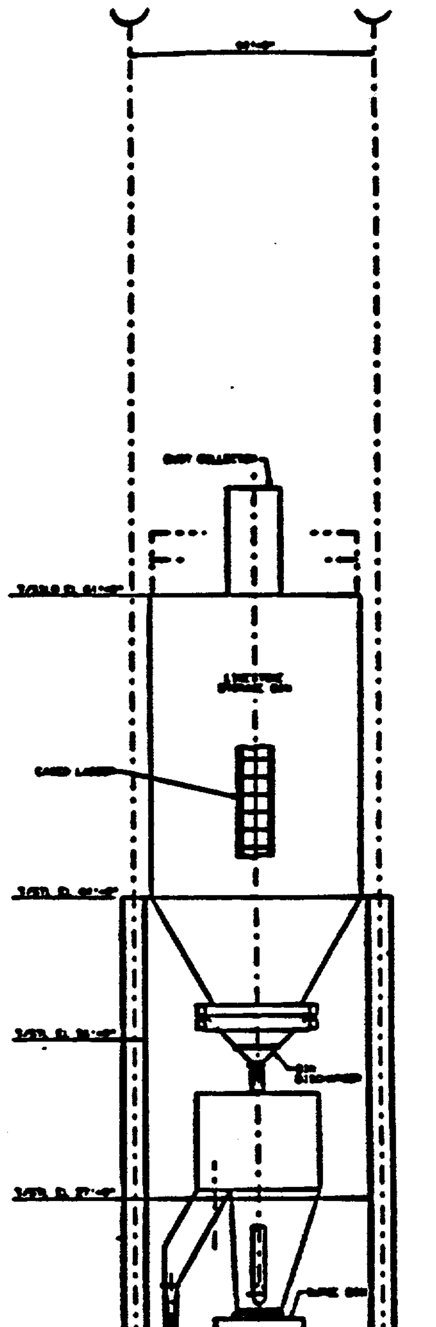

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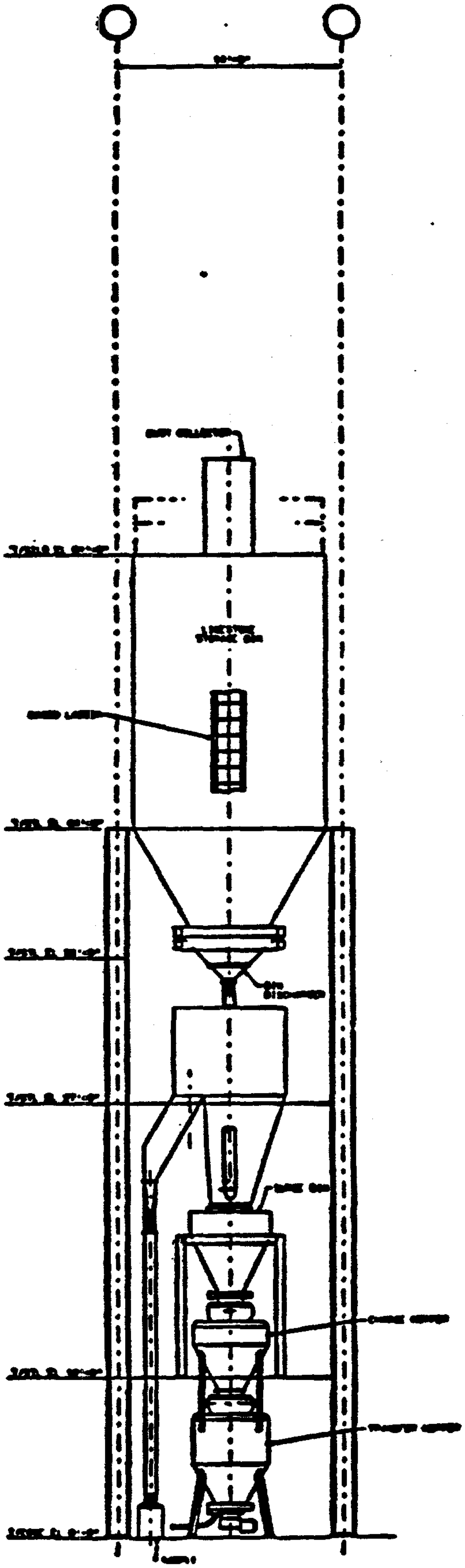
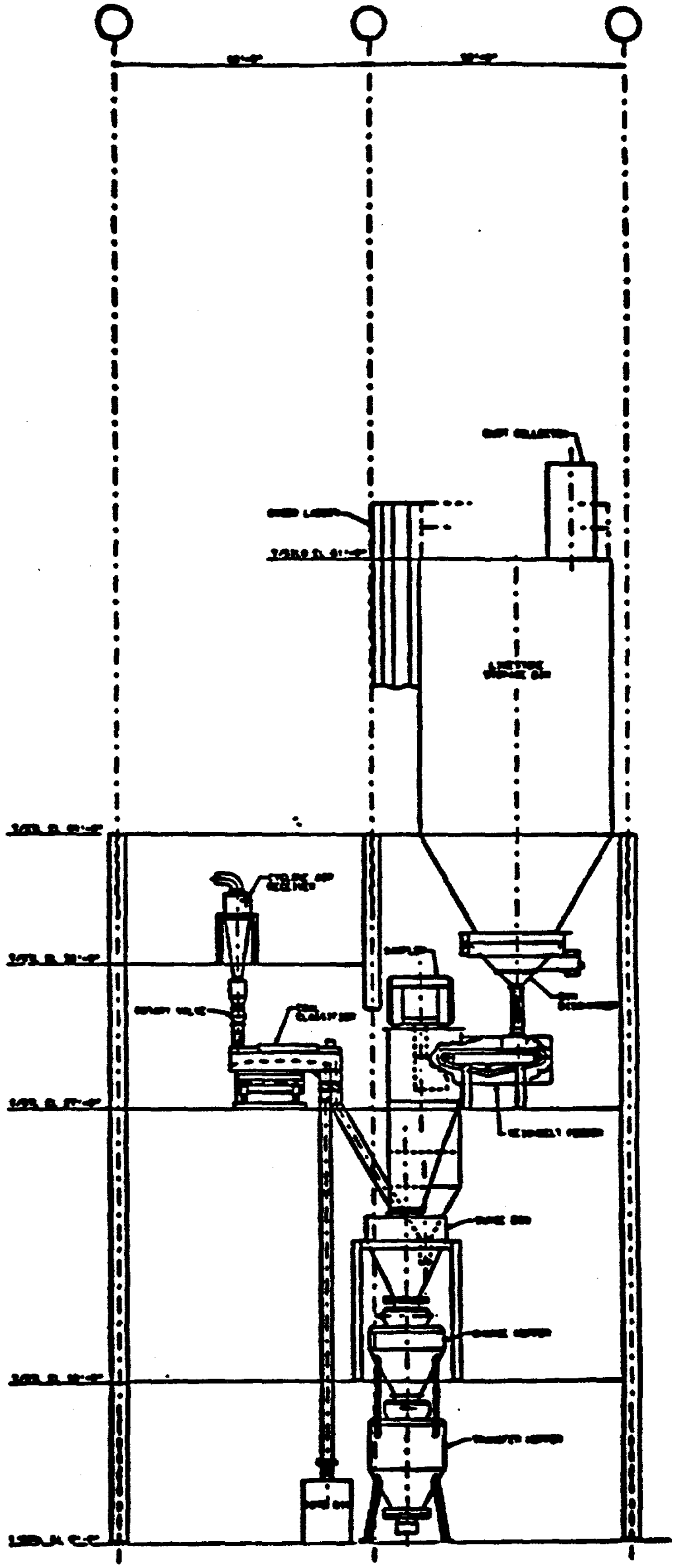


SECTION 82-S-001-2



SECTION 82-S-001-3

the gasifier, and instrument air. The unit will be skid mounted for simplified installation. The compressor unit will have its own control panel, and will have display signals and on/off commands at the plant's DCS.

3.3.2 Air Dryer

An air dryer system will be installed to provide instrument quality air at a rate of 100 scfm at 200 psig. The system will include: a dual heatless type air drier with associated control valves and filters; and an ASME coded carbon steel receiver with reliefs valves and instrumentation.

3.4 PyGas™ Gasifier, Ash Handling, Fines Control

The PyGas™ gasifier and fines control cyclone are located within the three sided reinforced concrete walled "containment bay".

Gasifier bottom ash is pneumatically conveyed to the wet oxidation tank. Air is sparge piped into the oxidation tank to assure chemical reaction of any CaS which may be trapped within the ash particles to $CaSO_4$. The fully sulfated ash is then pumped into a settling tank, and the densified solids are pumped to a vacuum filter for de-watering. Separated water is all pumped back into the wet oxidation circulation tank. Make-up water is introduced into the wet oxidation tank as demister spray.

3.5 Steam Generation, Water Treatment

3.5.1 HEAT RECOVERY STEAM GENERATOR (HRSG)

The HRSG will combust the coal gas and supplemental No. 2 fuel oil (or natural gas) to produce up to 110,000 lbs/hr of steam, and will be configured as shown in Figure 15. The unit will be of the water tube type, and be capable of producing steam at a pressure of 900 psig and 700 deg. F. The use of supplemental fuel is intended only to stabilize the combustion flame of the coal gas.

The HRSG package will also include a CBD flash tank, a Blow-off tank, a Dearator, a supplementary combustion air fan (40,000 scfm @ 4" W.G), and standard boiler operating instruments and controls. All boiler critical instruments will be monitored and controlled from the DCS.

3.5.2 Water Treatment

Water treatment in the GPIF will be limited only to "internal water treatment" (condensate treatment, and steam drum water).. Boiler make-up water as condensate will be provided directly by the Ft. Martin Station. Chemical feed systems will be provided to inject an oxygen scavenger, a phosphate, and a neutralizing amine into the boiler feed water. The chemical feed systems will be composed of high-pressure microfeed pumps and the associated controls. The chemicals will be provided in ready mixed tote bins by water treatment chemical suppliers (e.g. Nalco, Betz, Drew, etc.)

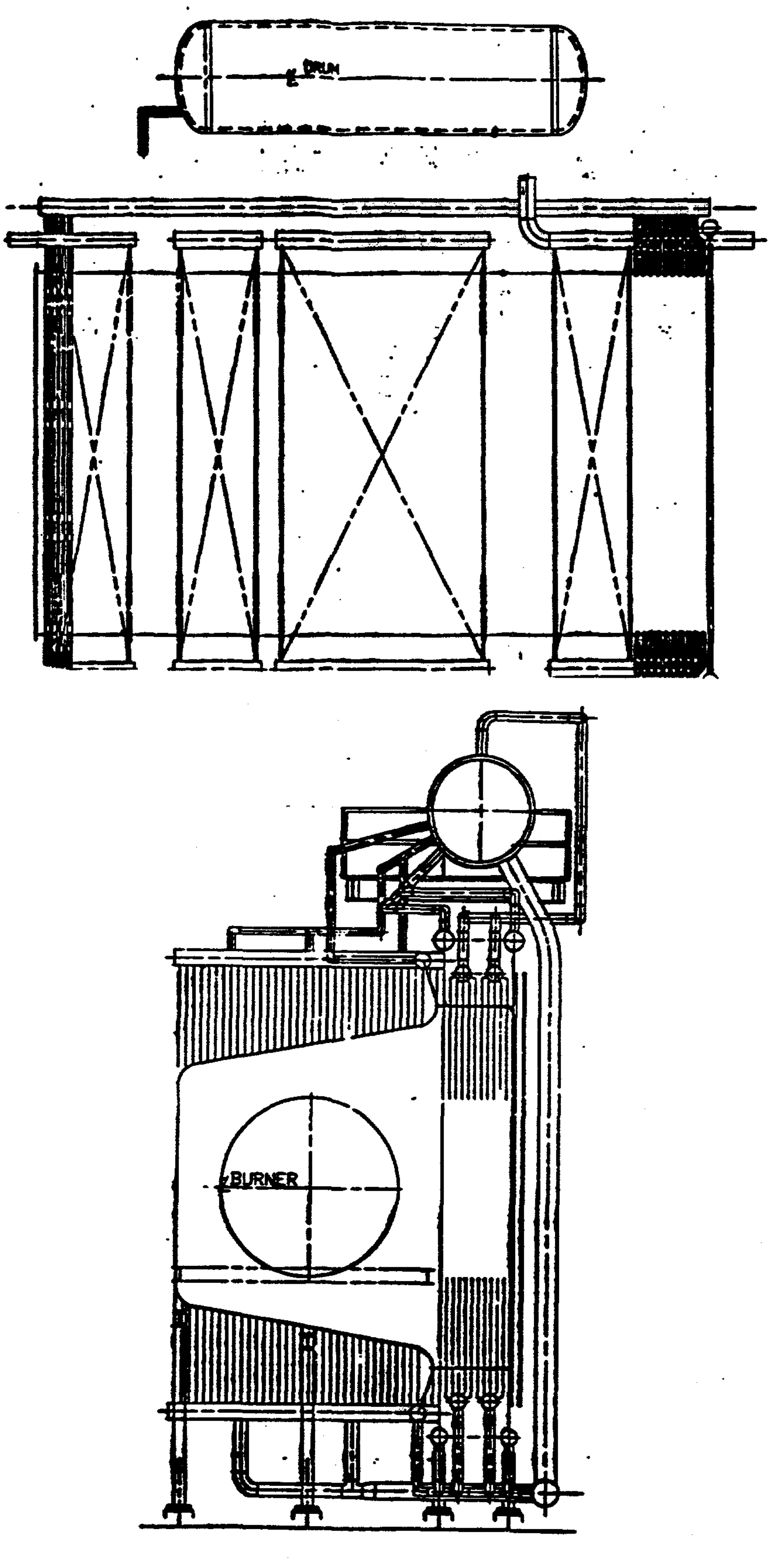


Figure 15
Riley HRSG Sketch