TECHNICAL PROGRESS REPORT NUMBER 40972R14
FOR QUARTER: April-June 30, 2004

Development of Pressurized Circulating Fluidized Bed

Partial Gasification Module (PGM)

DOE Contract No: DE-FC26-00NT40972

Issued: July 1, 2004

Foster Wheeler Development Corporation
12 Peach Tree Hill Road
Livingston, NJ 07039

Disclaimer

Abstract

Foster Wheeler Power Group, Inc. is working under US Department of Energy Contract No. DE-FC26-00NT40972 to develop a partial gasification module (PGM) that represents a critical element of several potential coal-fired Vision 21 plants. When utilized for electrical power generation, these plants will operate with efficiencies greater than 60% and produce near zero emissions of traditional stack gas pollutants.

The new process partially gasifies coal at elevated pressure producing a coal-derived syngas and a char residue. The syngas can be used to fuel the most advanced power producing equipment such as solid oxide fuel cells or gas turbines, or processed to produce clean liquid fuels or chemicals for industrial users. The char residue is not wasted; it can also be used to generate electricity by fueling boilers that drive the most advanced ultra-supercritical pressure steam turbines.

The amount of syngas and char produced by the PGM can be tailored to fit the production objectives of the overall plant, i.e., power generation, clean liquid fuel production, chemicals production, etc. Hence, PGM is a robust building bock that offers all the advantages of coal gasification but in a more user-friendly form; it is also fuel flexible in that it can use alternative fuels such as biomass, sewerage sludge, etc.

Under this contract a series of pilot plant tests are being conducted to ascertain PGM performance with a variety of fuels. The performance and economics of a PGM based plant designed for the co-production of hydrogen and electricity will also be determined. This report describes the work performed during the April-June 30, 2004 time period.

Table of Contents

1.0 Introduction ... 1
2.0 Executive Summary ... 3
3.0 Proposed Program ... 3
4.0 Experimental ... 5
5.0 Results and Discussion ... 5
6.0 Conclusions ... 10
7.0 References ... 10
8.0 Bibliography ... 10
9.0 Acronyms and Abbreviations ... 10

List of Graphical Materials

Figures

1 Vision 21 Modules – Enabling Technologies ... 3
2 Partial Gasifier Module Experimental Test Unit ... 4
3 Entrained Flow Co-production Plant Block Diagram (Single Gasification Train) ... 7
4 PGM Co-production Plant Block Diagram ... 7
5 Dual Train Entrained Flow Co-production Plant Block Diagram ... 8

Tables

1 Comparison of Co-production Plant Performance ... 9

1.0 Introduction

Foster Wheeler Development Corporation is working under DOE Contract No. DE-FC26-00NT40972 to develop a partial gasification module (PGM) that represents a critical element of several potential coal-fired Vision 21 plants. When utilized for electrical power generation, these plants will operate with efficiencies greater than 60% while producing near zero emissions of traditional stack gas pollutants.

The new process partially gasifies coal at elevated pressure producing a coal-derived syngas and a char residue. The syngas can be used to fuel the most advanced power producing equipment such as solid oxide fuel cells or gas turbines or processed to produce clean liquid fuels or chemicals for industrial users. The char residue is not wasted; it can also be used to generate electricity by fueling boilers that drive the most advanced ultra-supercritical pressure steam turbines.

The unique aspect of the process is that it utilizes a pressurized circulating fluidized bed partial gasifier and does not attempt to consume the coal in a single step. To convert all the coal to syngas in a single step requires extremely high temperatures (~2500 to 2800F) that melt and vaporize the coal and essentially drive all coal ash contaminants into the syngas. Since these contaminants can be corrosive to power generating equipment, the syngas must be cooled to near room temperature to enable a series of chemical processes to clean the syngas. Foster Wheeler's process operates at much lower temperatures that control/minimize the release of contaminants; this eliminates/ minimizes the need for the expensive, complicated syngas heat exchangers and chemical cleanup systems typical of high temperature gasification. By performing the gasification in a circulating bed, a significant amount of syngas can still be produced despite the reduced temperature and the circulating bed allows easy scale up to large size plants. Rather than air, it can also operate with oxygen to facilitate sequestration of stack gas carbon dioxide for a reduction in greenhouse gas emissions.

The amount of syngas and char produced by the PGM can be tailored to fit the production objectives of the overall plant, i.e., power generation, clean liquid fuel production, chemicals production, etc. Hence, PGM is a robust building block that offers all the advantages of coal gasification but in a more user-friendly form; it is also fuel flexible in that it can use alternative fuels such as biomass, sewerage sludge, etc.

The PGM consists of a pressurized circulating fluidized bed (PCFB) reactor together with a recycle cyclone and a particulate removing barrier filter. Coal, air, steam, and possibly sand are fed to the bottom of the PCFB reactor and establish a relatively dense bed of coal/char in the bottom section. As these constituents react, a hot syngas is produced which conveys the solids residue vertically up through the reactor and into the recycle cyclone. Solids elutriated from the dense bed and contained in the syngas are collected in the cyclone and drain via a dipleg back to the dense bed at the bottom of the PCFB reactor. This recycle loop of hot solids acts as a thermal flywheel and promotes efficient solid-gas chemical reaction.

Left untreated the syngas will contain tar/oil vapors, alkali vapors, and hydrogen sulfide at levels dependent on PGM operating conditions and fuels. The downstream users of the syngas will dictate a tolerance level for each of these gas constituents. If the users can tolerate both tar vapors and hydrogen sulfide, the syngas can be cooled to a level that condenses the alkali vapors on the particulate being removed by the barrier filter. Although this is a simple solution to an alkali problem, syngas cooling typically lowers the plant efficiency. When efficiency is to be maximized, as in the case of Vision 21 plants, the clean up can be done hot/without syngas cooling. In this case, lime based sorbents instead of sand can be fed to the PCFB reactor along with the coal to catalytically enhance tar cracking and react with the hydrogen sulfide to capture the sulfur as calcium sulfide. Depending upon sorbent feed rates and gas residence times, the hydrogen sulfide can be reduced to near equilibrium levels, which for high sulfur fuels (>3% sulfur) amounts to 95 to 98% sulfur capture. Alkali levels can be brought to gas turbine acceptable levels by injecting finely ground getter material such as emathlite or bauxite into the syngas downstream of the recycle cyclone. The fine particulate that escapes the recycle cyclone together with the injected alkali getter material are carried into the barrier filter by the syngas. As the syngas flows through the porous filter elements, the particulate collects on the outside of the elements and forms a permeable dust cake that ensuing syngas must pass through. The getter absorbs the alkali vapors as the syngas flows to the filter and passes through the filter dust cake. As the dust cake thickness increases, the filter pressure drop increases. Upon reaching a predetermined pressure drop, the dust cake is blown off the element by a back pulse of a clean high-pressure gas such as nitrogen injected into the clean side of the element. The dislodged dust cake falls to the bottom of the filter vessel and drains from the unit. If even higher sulfur capture efficiencies are desired, a second more reactive sorbent can be injected into the syngas for enhanced filter cake sulfur capture. Although the barrier filter is provided to reduce syngas particulate loadings to less than 1 ppm, it can also serve as a reactor in that its filter cake can be used for alkali vapor removal and sulfur capture. The char-sorbent-getter residue generated in the PGM drains continuously from the filter along with an intermittent PCFB reactor bed drain for transfer to the char combustor.

The proposed partial gasifier module (PGM) represents a building block of the Vision 21 program, which can be connected with a variety of additional modules to form complete Vision 21 plants (Figure 1). The PGM represents an “enabling” technology within the Vision 21 framework in that it can serve as a central processing unit for converting the raw fuel (coal, coke, biomass, or other opportunity fuels) into useful by-products (electricity, steam, chemicals, or transportation fuels).

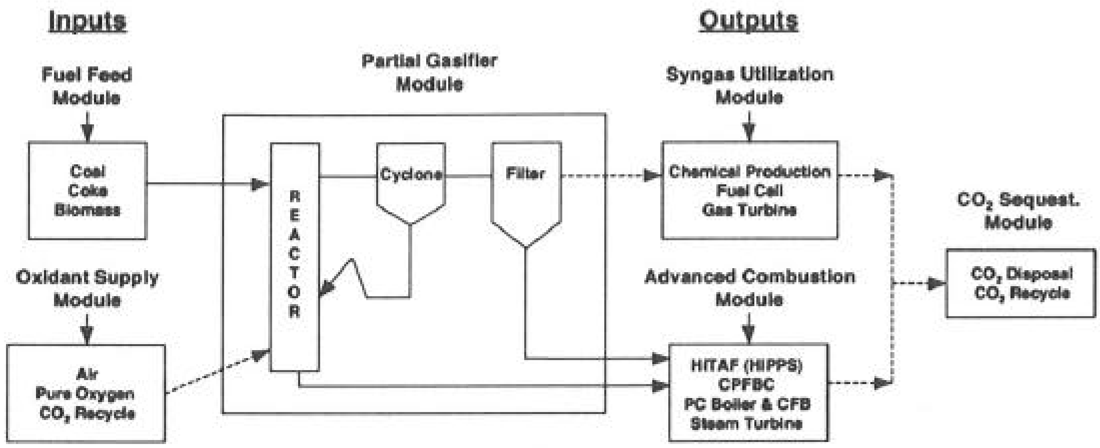

Fig. 1 Vision 21 Modules – Enabling Technologies

2.0 Executive Summary

FW's partial gasification tests in an air blown pressurized circulating fluidized bed gasifier pilot plant have been successfully completed. Under this test program, five different coals, petroleum coke, and sawdust were gasified and the effects of oxygen and CO_2 enrichment of the fluidizing air studied via 22 test points.

A draft test report documenting the program was submitted for DOE approval on May 27, 2004.

In the previous reporting period a study was begun to determine the economics of using PGM technology to co-produce hydrogen and electricity. The PGM based plant is to be compared to a comparable plant that incorporates an alternative technology and which was conceptually designed and cost estimated for the DOE by Parsons Infrastructure and Technology Group Inc. (Parsons). To assure a consistent comparison of the technologies, Parsons is to participate in the study. Although paper work requesting/authorizing Parsons' participation was initiated in the previous quarter, a delay in the approval process brought all study work to a stop. The study is expected to resume in the third quarter of 2004.

3.0 Proposed Program

FW possesses a coal-fired PCFB pilot plant at its John Blizard Research Center in Livingston, NJ. The facility can be operated in either a combustion or gasification mode with a gross heat input of up to 12 million Btu/hr. To support the Vision 21 program, the facility will be operated in the gasification mode with the focal point being the PCFB reactor with its recycle cyclone dipleg and loop seal and a barrier filter. These three components form the PGM shown in Fig. 2 and a syngas cooler can be installed to control the filter inlet temperature.

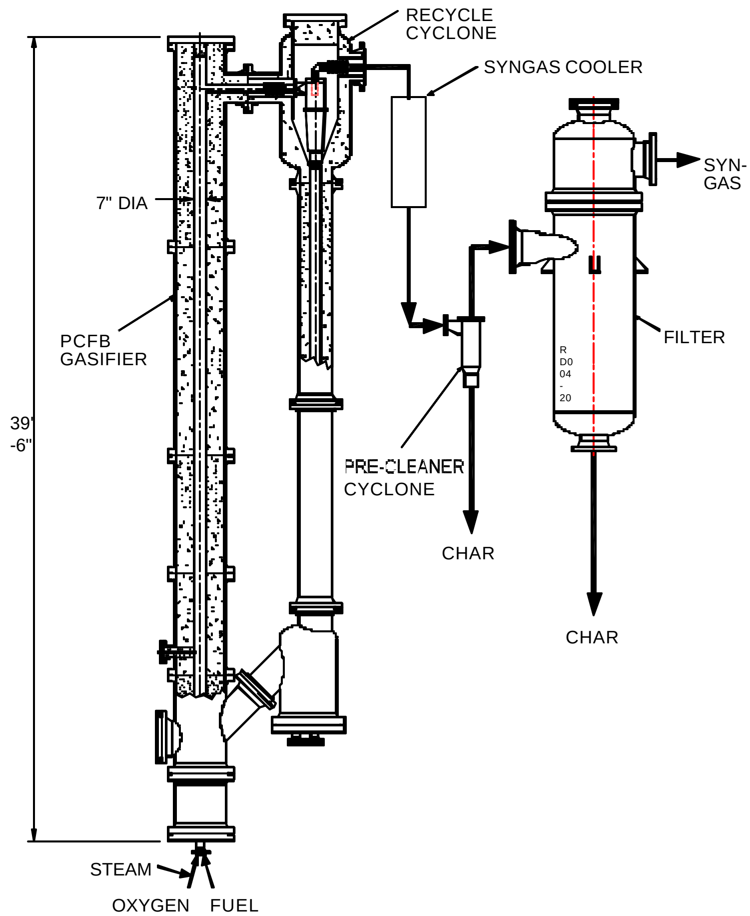

Fig. 2 Partial Gasifier Module Experimental Test Unit

The PCFB reactor is a 30" OD x 39'-6" tall vessel that is refractory lined to a 7" ID. Two lock hopper feed trains operating in parallel bring coal and sorbent to process pressure and feed the materials into a common line that injects the material into the reactor. The coal and sorbent are blown into the unit by air via a vertical 1" Sch 80 pipe located on the centerline and at the base of the unit. A 1½" pipe concentric with the feed pipe admits the balance of the process air together with steam. A relatively dense bed of coal, char, and sorbent form at the base of the unit. Syngas, together with entrained bed particulate matter, flow vertically up the unit at velocities ranging from 12 to 15 ft/sec and exit via a 4" ID radial nozzle 34'-10" above the top of the feed pipe. A recycle cyclone removes larger size particles from the syngas and returns them to the base of the unit via a dipleg and loop seal. The partially cleaned syngas passes through a cooler, a second stage cyclone, and enters a barrier filter vessel for removal of the remaining particulate. The filter can contain up to twenty-two 2 3/8" OD x 60" long candles all hung at one elevation from a metallic horizontal tube sheet. The syngas cooler is designed to yield filter inlet temperatures ranging from 650 to 800EF to allow operation with porous metal iron aluminide candles. The char-sorbent residue generated in the PGM is drained from the bottom of the PCFB reactor via a 2½" wide annulus around the 1½" air supply pipe. The draining material enters a holding section where counter flowing nitrogen cools the material as a packed bed to approximately 500EF. A lock hopper provided under the PCFB reactor and under the filter collects and depressures the material in batches for disposal.

Under the Vision 21 hydrogen-electricity co-production study a PGM based co-production plant will be conceptually designed and its performance and economics determined. The plant will then be compared to a comparable entrained flow gasifier based co-production plant to identify the merits of PGM co-production technology. The co-production study is divided into the following five tasks:

Task 1 – Cycle Analyses: Full load heat and material balances will be prepared for the PGM and entrained flow gasifier based hydrogen-electricity co-production plants. To permit a consistent comparison, the plants will be designed for similar hydrogen and electricity production rates estimated to be approximately 313 tons per day and 250 to 300 MWe respectively.

Task 2 – PCFB Gasifier and CFB Char Boiler Design and Cost Estimating: The PCFB gasifier and char burning CFB boiler required by the PGM co-production plant will be conceptually designed and cost estimated.

Task 3 – Balance of Plant Design and Cost Estimating: PGM "balance of plant" components will be conceptually sized and the costs of both plants estimated.

Task 4 – Performance and Economic Analyses: The costs, net power output, effective thermal efficiency, and hydrogen sell price will be determined for both plants. The performance and economics of the two co-production plants will be compared.

Task 5 – Project Management: All activities needed to insure that project objectives are met on time and within budget will be conducted under this task including the preparation/submittal of cost and progress reports and a report documenting study results.

4.0 Experimental

Testing was completed January 2002.

5.0 Results and Discussion

Progress for April-June 30, 2004 Time Period

In addition to generating electrical power, the PGM can be used to co-produce clean fuels or chemicals. In January 2004 Foster Wheeler began a study aimed at identifying the performance and economics of co-producing hydrogen (H_2) and electricity with PGM technology, the intent being to determine its competitiveness vis a vis other coal fueled technologies.

Working under DOE contracts, Parsons Infrastructure and Technology Group Inc. (Parsons) has conceptually designed and determined the performance and economics of several Destec (now E-Gas) entrained flow type IGCC plants. These studies have included plants designed for electrical power generation as well as a plant designed for the co-production of hydrogen and electricity [1]. To minimize the cost of the PGM co-production plant study, the PGM plant is being designed for the same hydrogen production rate and fuel used in [1]; this will allow reuse of much of the balance of plant design and costing work done in that study and facilitate a comparison of PCFB gasification versus entrained flow gasification technologies. To insure that both plants are on a consistent basis, Parsons will assist Foster Wheeler in the determination of PGM plant costs and a comparison of the performance and economics of the two plants.

The entrained flow type IGCC co-production plant was fueled with Pittsburgh No. 8 coal fed as a 65 per cent coal/35 percent water slurry to an oxygen blown, Destec/E-Gas type, two stage, entrained flow gasifier. Figure 3 is a simplified process block diagram of the plant. As discussed in the previous progress report the plant produced/sold 38 MWe of power to the grid and was calculated to have a levelized hydrogen production cost of $5.71 per million Btu or $1.86 per thousand standard cubic feet.

A "first cut" heat and material balance was prepared for the PGM based co-production plant shown in Figure 4 and results are presented in Table 1 along with data for the entrained flow gasifier plant from [1]. Several items are entered as question marks as the data was not published in [1] and or must be obtained/determined by Parsons. Although both plants produce the same amount of H_2 and are expected to have similar PSA tail gas flows, the PGM plant, being based on a partial gasifier, produces much more electrical power because of its char combustion. Several studies, such as [2], have shown that the sale of electrical power creates a revenue stream that reduces the required H_2 sell price and in [2] two gasification trains were utilized, one to produce H_2 and the other to produce electricity. To put the plants on a consistent basis it will also be necessary to match the plant electrical outputs as well as their H_2 production rates. As a result, a second gasification train will be added to the entrained flow plant to fuel a General Electric 7 FA gas turbine yielding the Figure 5 plant arrangement. Parsons' input is needed to resize the entrained flow plant and identify its new net electrical output. Once this is known, coal can be fed along with char to increase the size of the CFB boiler/steam turbine to match plant electrical outputs. Expecting that the required output will be in the 250 to 300 MWe range, coal was added to the CFB yielding the plant performance also tabulated in Table 1.

Although paper work requesting/authorizing Parsons' participation was initiated in the previous quarter, a delay in the approval process brought all study work to a stop. The co-production study is expected to resume in the third quarter of 2004.

Entrained Flow Gasifier Based H_2-Electricity Co-production Plant

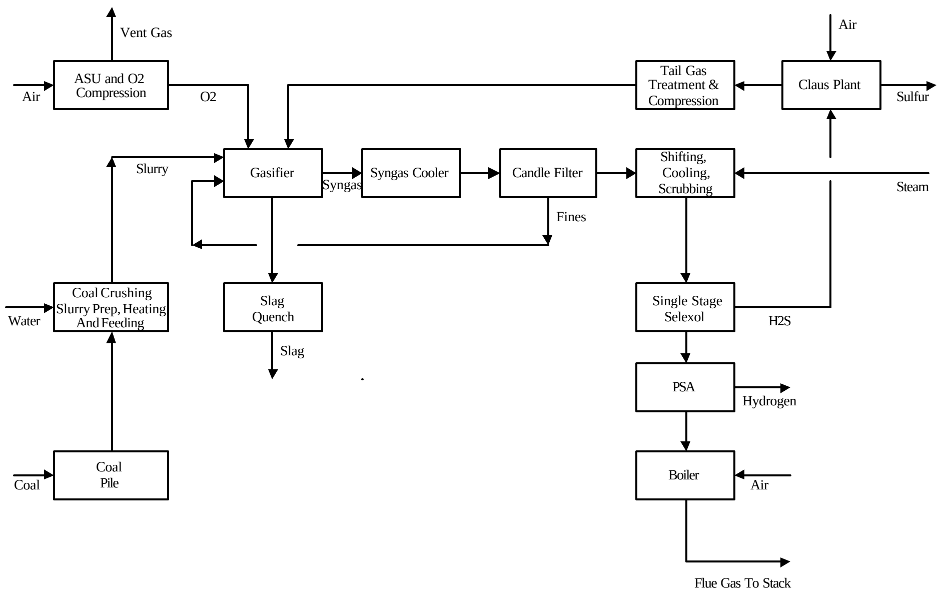

Figure 3 Entrained Flow Co-production Plant Block Diagram (Single Gasification Train)

PCFB Gasifier Based H_2-Electricity Co-production Plant

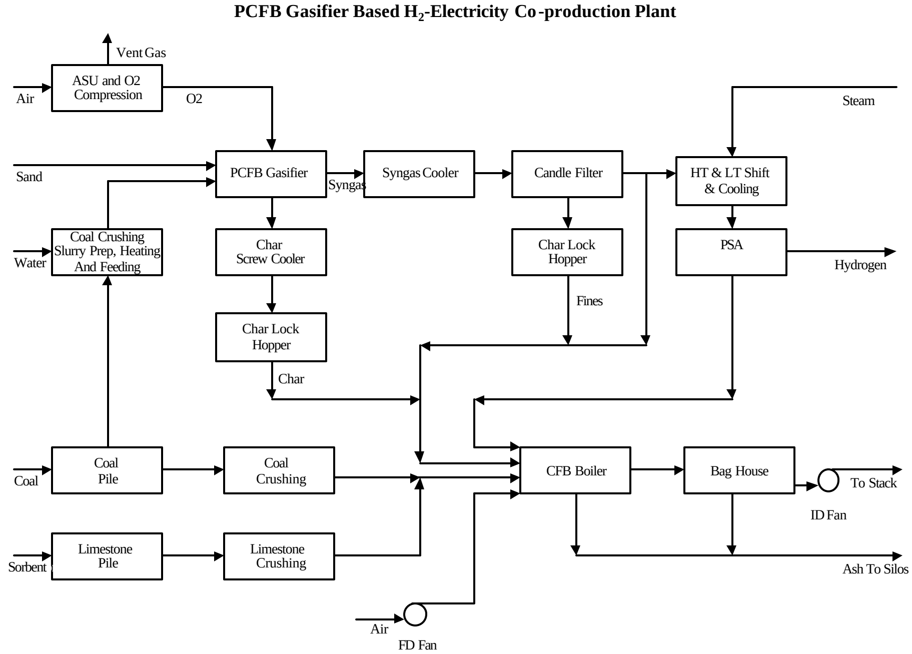

Figure 4 PGM Co-production Plant Block Diagram

Entrained Flow Gasifier Based H_2-Electricity Co-production Plant

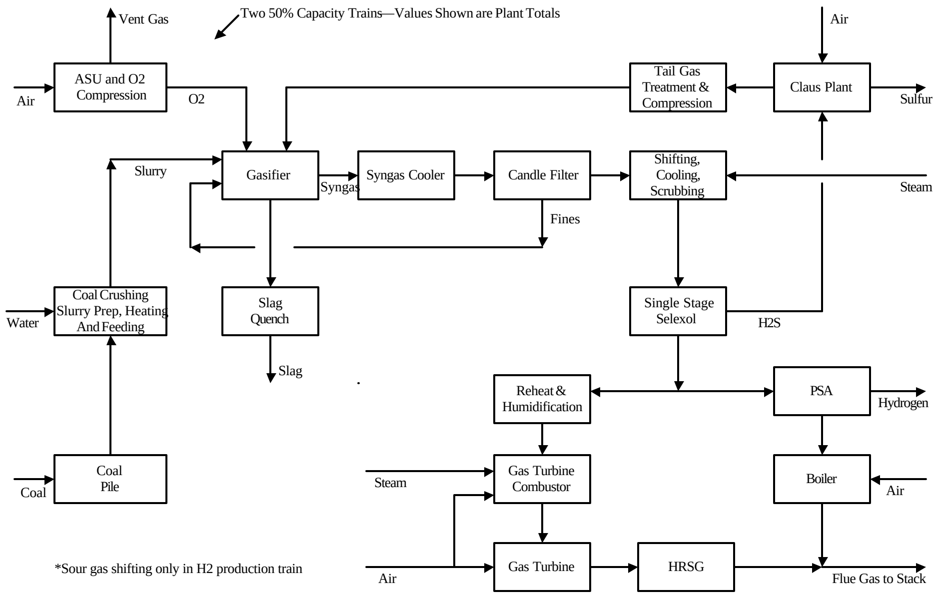

Figure 5 Dual Train Entrained Flow Co-production Plant Block Diagram

Table 1 Comparison of Co-Production Plant Performance

Type of Gasifier	***Entrained Flow***	***PGM***	***Entrained Flow***	***PGM***
# of Gasifier Trains	1	1	2	1
H2 Production Rate				
Tons/Day	312.6	312.6	312.6	312.6
MM SCFD	112	112	112	112
Net				
Power, MWe	38	?	?	?
Effective Efficiency*	?	?	?	?
Gross Power, MWe				
7 FA Gas Turbine	NA	NA	?	NA
Steam Turbine	?	181	?	260
Parasitic Power, MWe	?	?	?	?
Plant Flow Rates, Klb/hr				
Coal (As Received)				
To Gasifier #1	208.3	271.0	?	271.0
To Gasifier #2	NA	NA	?	NA
To CFB Boiler	NA	0.0	NA	49.0
Total	208.3	271.0	?	320.0
Char to CFB Boiler				
Oxygen				
To Gasifier #1	?	188.0	?	188.0
To Gasifier #2	NA	NA	?	NA
Total				
Water, Klb/hr				
To Slurry	?	133.0	?	133.0
Other to Process	?	73.0	?	73.0
Cooling Tower	?	?	?	?
Total	?	?	?	?
Sand to PCFB Gasifier	NA	5.0	NA	5.0
Limestone to CFB	NA	64.0	NA	76.0
Waste Water	?	?	?	?
Slag	?	NA	?	NA
Sulfuric Acid	19,167	NA	?	NA
Ash	NA	87.0	NA	102.0
Stack Flue Gas	?	1,812.00	?	2,407.0
Steam Turbine Conditions				
Turbine #1				
Steam Flow, lb/hr	?	780.0	?	1,300.0
psia/F/F/inches of Hg.	?	3852/1040/1050/2	?	3852/1040/1050/2
Turbine #2				
Steam Flow, lb/hr	NA	NA	?	NA
psia/F/F/inches of Hg.	NA	NA	?	NA

*(H2 Heating Value+Electrical Btu Equivalent)/Fuel Heating Value all on HHV basis

6.0 Conclusions

A preliminary heat and material balance was prepared by Foster Wheeler in the first quarter of 2004 for a PGM based IGCC H_2-electricity co-production plant. The plant was designed to match the H_2 production rate of an entrained flow type IGCC co-production plant conceptually designed and cost estimated by Parsons. By designing the PGM based co-production plant for the same conditions, its costs can be estimated with a minimal of effort and a direct comparison made of the two differing gasification technologies. Initial results showed that the PGM based plant produced much more electrical power which would give it a significant cost advantage. As a result, a second gasification train aimed at electrical power generation is to be added to the entrained flow plant so that H_2 and electricity production rates are matched. Parsons' input is needed to redefine the entrained flow plant electrical output and estimate the costs of both plants. Although paper work requesting/authorizing Parsons' participation was initiated in the previous quarter, a delay in the approval prevented study work from proceeding. The study is expected to resume in the third quarter of 2004.

7.0 References

1. Rutkowski, M., et. al., "Hydrogen Production Facilities Plant Performance and Comparisons" NETL Contract No DE-AM26-99FT40465, March 2002.
2. Gray, D and Tomlinson, G., "Hydrogen from Coal" NETL Contract No DE-AM26-99FT40465, Mitretek Technical Paper MTR 2002-31, July 2002.

8.0 Bibliography

N/A

9.0 Acronyms and Abbreviations

ACFB/CFB	Atmospheric Pressure Circulating Fluidized Bed
ATS	Advanced Turbine System
D50	Mass Mean Particle Size in Microns
DOE	U.S. Department of Energy
FW	Foster Wheeler Power Group, Inc
H_2	Hydrogen.
HITAF	High-Temperature Air Heater
IGCC	Integrated Gasification Combined Cycle
NETL	National Energy Technology Laboratory
PCFB	Pressurized Circulating Fluidized Bed
PGM	Partial Gasification Module
PSA	Pressure Swing Absorption
SNCR	Selective Non Catalytic Reduction
SOFC	Solid Oxide Fuel Cell