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Development of Pressurized Circulating Fluidized Bed Partial Gasification Module (PGM)

DOE Contract No: DE-FC26-00NT40972

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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 gases for a 100% 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 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).

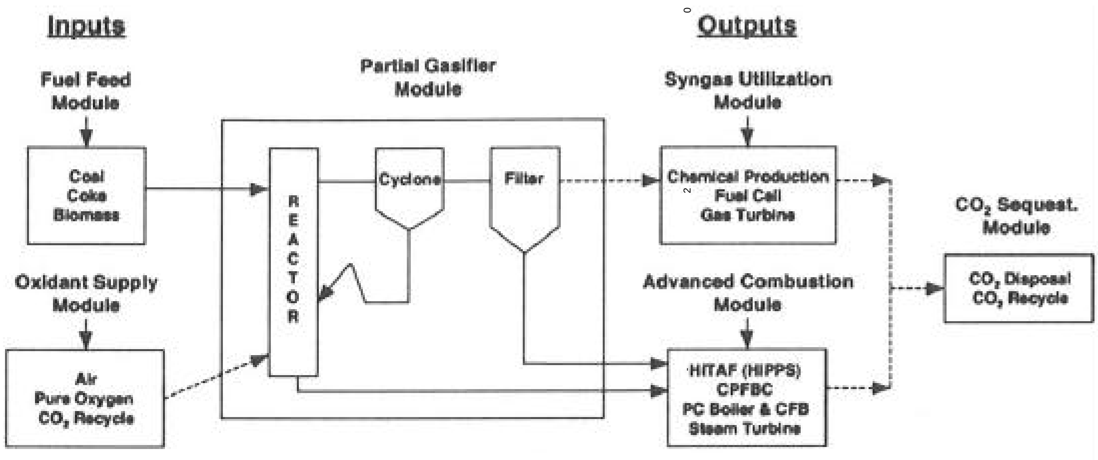

Fig. 1 Vision 21 Modules – Enabling Technologies

Proposed Program

FW possess 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.

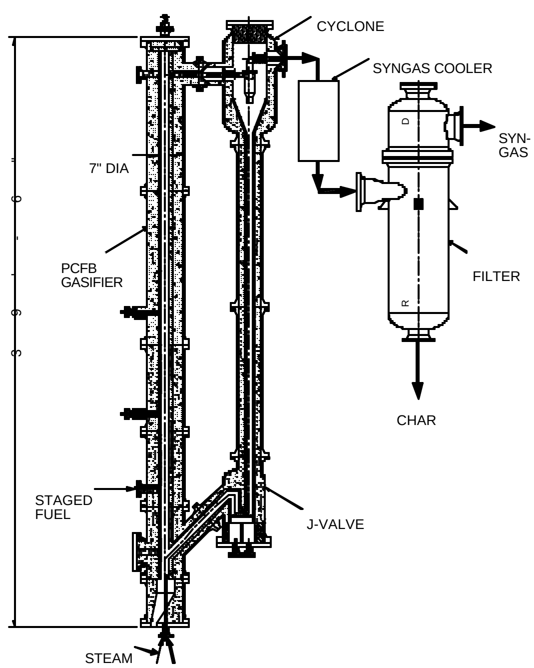

Fig. 2 Partial Gasifier Module Experimental Test Unit

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 program, the PGM will be operated at varying conditions to determine syngas and char yields, heating values, and compositions when operating with:

1. alternative fuels, e.g., coke and coal-biomass cofiring
2. oxygen-enriched air

In addition to process investigations limited equipment evaluations will be conducted involving use of:

3. a Stamet pump to feed material to the PCFB reactor
4. ceramic honeycomb elements rather than candles in the barrier filter.

The Vision 21 effort is divided into the following five tasks:

Task 1 – Research and Development – Included in this effort are characterization of feedstocks to be tested, material evaluations to determine process induced corrosion rates, computer modeling of the PGM, and updates of possible Vision 21 plant configurations.

Task 2 – Engineering Design – Included in this task is the design of all modifications that must be made to and the procurement of materials that must be incorporated in the existing pilot plant to facilitate the Vision 21 test program.

Task 3 – Construction – This task covers the construction of all Task 2 changes/ modifications.

Task 4 – Testing – Included in this effort are parametric tests and data analyses dealing with alternate feedstocks and oxygen-enriched air plus evaluations of Stamet feed pump and filter performance.

Task 5 – Project Management – Conduct all activities needed to insure that project objectives are met on time and within budget; issue all cost and progress reports and a final report documenting the results of all test activities.

<u>Progress for January – March, 2002, Time Period</u>

<u>Task 4 – Testing</u>

The fifth and final partial gasification test run was conducted in the Livingston PCFB pilot plant during the week of January 14th. During this run a total of 9 test points were completed using three different fuels/feed stocks. Seven test points were completed with petroleum coke; of these, one used air enriched with carbon dioxide and two used air enriched with oxygen, the first with air oxygen level increased by 25% the second with it increased by 50%. Test points 8 and 9 were conducted with highly caking Dilworth coal, the first with coal alone and the second point with sawdust added/co-fired with the Dilworth coal in the mass ratio of 26% sawdust to 74% coal. After completing the nine test points and running continuously for 73 hours the unit was voluntarily shutdown.

The test run was very successful; it demonstrated that the PCFB can partially gasify petroleum coke as well as biomass-coal mixtures with either air or air enriched mixtures without the formation of agglomerates or sticky ash/tar conditions.

The typical compositions of the petroleum coke, Dilworth coal, and sawdust used during the test run are shown in Table 1. As would be expected the petroleum coke was low in volatile content, only about 11% compared with 33% for the Dilworth coal, which would tend to make it difficult to gasify. The Dilworth coal had a high free swelling index which indicates a tendency to form sticky agglomerates that could lead to a loss of fluidization. The sawdust with its high alkali content would also tend to form agglomerates. The carbon dioxide and oxygen were supplied by the vaporizer tanker trucks shown in Fig 3 and they entered the air and steam supply line to the gasifier via the nozzle arrangement shown in Fig 4. The use of oxygen enrichment would tend to form a localized hot spot in the gasifier that could melt the above fuels. Despite the tendency of these fuels and oxygen enrichment to cause agglomerating conditions, the turbulence and excellent mixing of the circulating bed prevented agglomerates from forming.

With the exception of test points 8 and 9, all previous points were performed with the coal/coke injected at the base of the unit via a 1-inch vertical nozzle encircled by an air or air-steam jet. The air jet tends to form a localized hot spot and injecting the coal into it rapidly heats the coal through the caking temperature range while tending to consume tar and oil vapors released from the coal. The rapid heating reduces risks of agglomeration and destruction of tar/oil vapors reduces risks that they will condense and foul downstream equipment. Although this is desirable, it is done at a loss in syngas heating value as a portion of the coal volatile matter will be consumed by the oxygen in the surrounding air jet. In test points 8 and 9 the coal injection point was moved from the base of the unit to a side feed nozzle located approximately 86 inches above the point of air injection. The unit operated without any agglomeration problems until it was voluntarily shut down 16 hours later. Switching to side feed resulted in an increase in filter pulse cleaning as the time interval between cleanings went from about 38 minutes to 18 minutes without a significant change in baseline pressure drop. A very preliminary analysis of syngas compositions indicates that side feeding may have increased the gas heating value by about 25%.

Table 1 Typical Composition of Fuels Tested

Mine Location	Eagle Butte WY	West Elk CO	Jones Fork KY	Dilworth PA	Buchanan PA	---	---
Fuel	Subbitum.	Bitum.	Bitum.	Bitum.	Bitum.	Pet Coke	Sawdust
Proximate, Wt % AR							
Moisture	23.57	3.55	6.83	7.50	7.12	1.84	4.28
Volatiles	31.50	37.11	35.74	33.41	19.05	11.14	76.79
Fixed Carbon	39.23	51.53	49.77	51.63	67.93	84.12	16.55
Ash	5.70	7.81	7.66	7.46	5.90	2.90	2.38
Ultimate, Wt % AR							
Carbon	54.09	73.22	70.93	72.96	79.44	88.03	47.64
Hydrogen	3.45	5.16	4.65	4.67	3.85	3.73	5.42
Nitrogen	0.72	1.51	1.44	1.45	1.08	1.28	0.44
Chlorine	0.00	0.05	0.14	0.12	0.17	0.00	0.00
Sulfur	0.29	0.64	1.06	1.41	0.74	2.16	0.03
Ash	5.70	7.81	7.66	7.46	5.90	2.90	2.38
Moisture	23.57	3.55	6.83	7.50	7.13	1.84	4.28
Oxygen	12.18	8.06	7.29	4.43	1.69	0.06	39.81
HHV, Btu/lb	9070	12899	12798	12977	13760	14793	8238
FSI	---	1 1/2	3 1/2	8	8	---	---

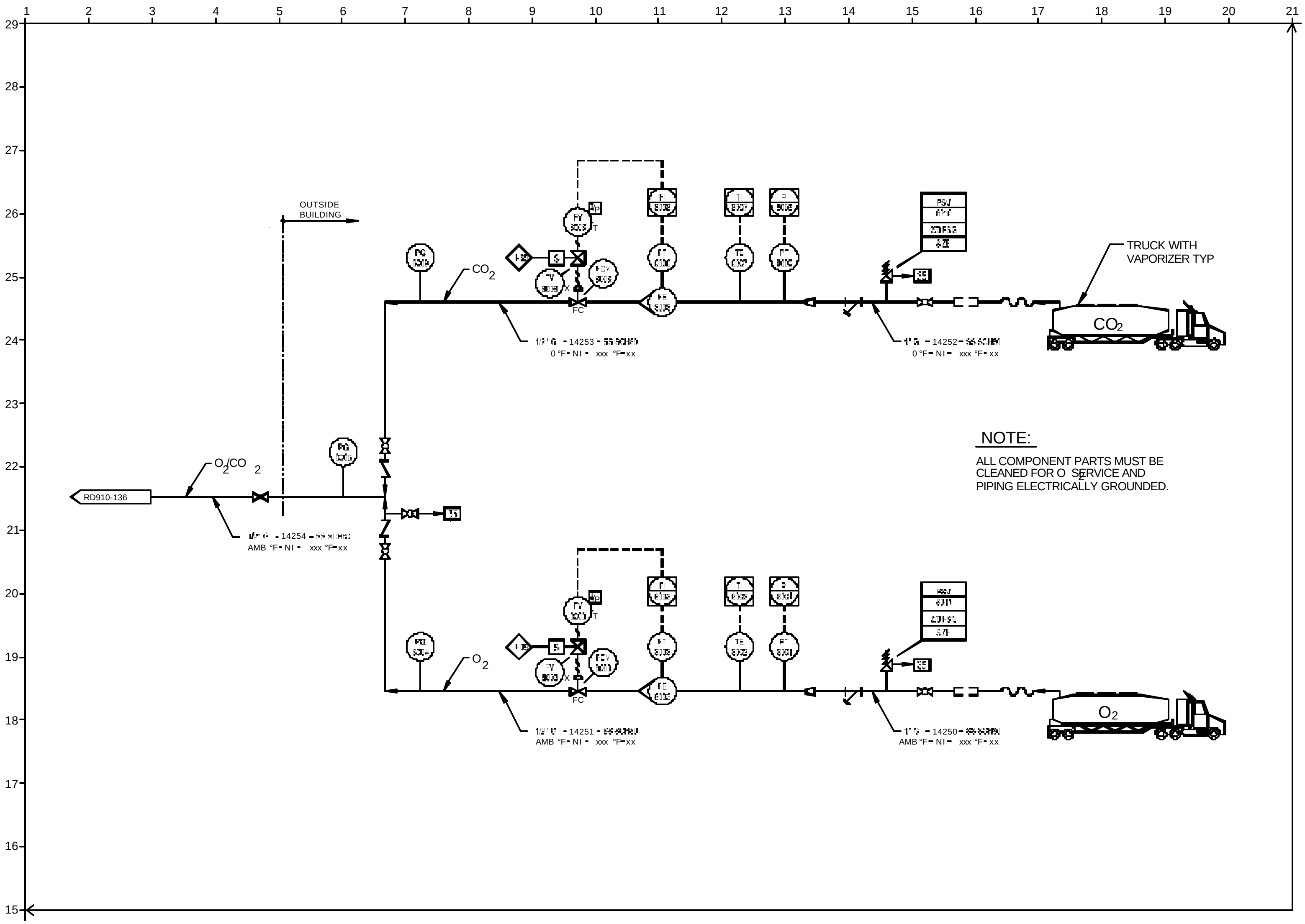

Figure 3 Pilot Plant Oxygen & Carbon Dioxide Injection System P&ID

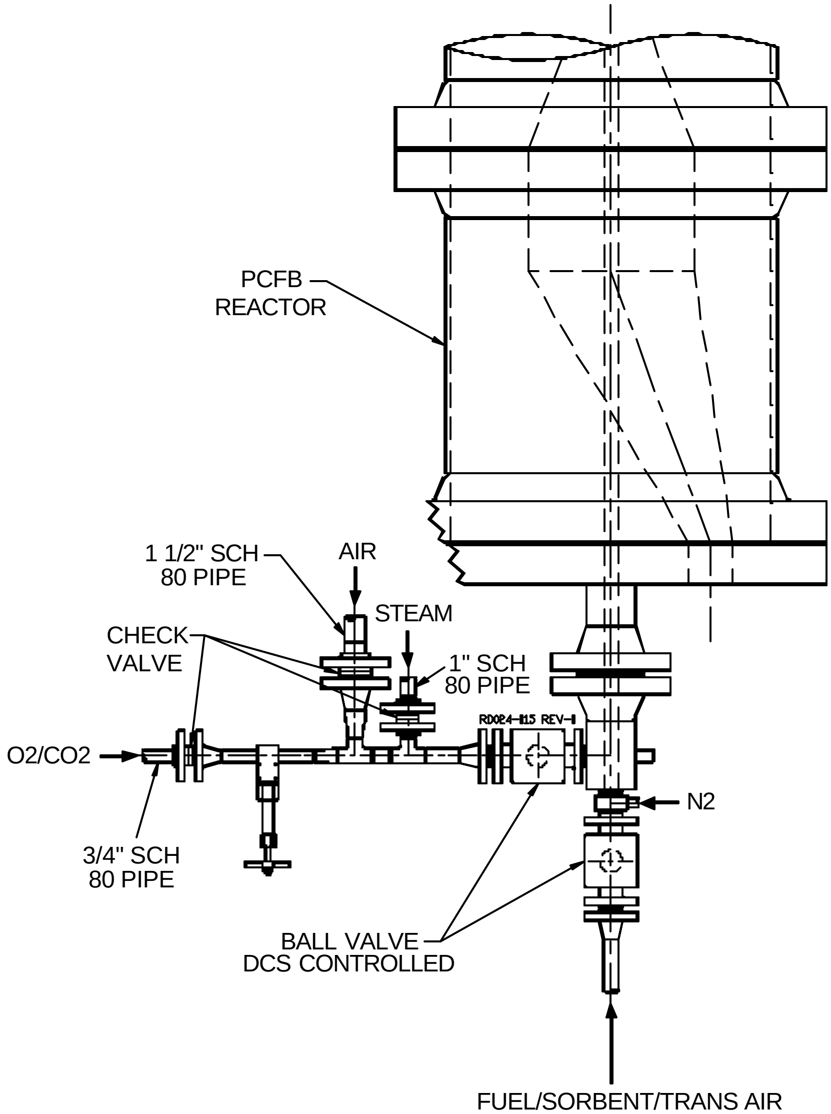

Figure 4 Vision 21 Pilot Plant O_2/CO_2, Steam & Air Injection Points

Data Analysis

Since our project funding authorization is limited to only ¾ of our contract value and since 16 people are required to operate the pilot plant, downtime between test runs has been kept to a minimum. As a result, laboratory analyses of solid samples have not kept up with data acquisition, thus preventing preparation of test point heat and material balances and cross checking of carbon conversion levels determined from solids versus those determined from gas analyses. With testing now ended, laboratory analyses are catching up and detailed analyses are expected to begin next quarter. Based on preliminary analyses of syngas compositions reported by the mass spectrometer, which sampled the gas downstream of the porous metal filter, the PCFB partial gasifier yielded the following ranges of carbon conversions:

Subbituminous coal:	95 to 98%
Bituminous coals:	48 to 75%
Petroleum coke:	55 to 59%

FW has a proprietary gasification computer model for predicting syngas yields, compositions, heating values, etc. The above conversions are in agreement with predictions made by this model and are consistent with Vision 21 plant predictions. As a result, our Vision 21 test program has been very successful in that:

a. it has confirmed commercial plant predictions;

b. it has demonstrated that a PCFB can gasify a wide variety of fuels ;

c. it can handle highly caking coals without agglomeration problems;

d. it can operate in a co-firing biomass-coal mode;

e. it can operate with oxygen and carbon dioxide enriched air;

f. porous metal filters can be used to filter particulate without tar/oil blinding;

g. the char residue produced by the PCFB can be easily handled.

Plant Shut Down

Because of funding limitations (see Project Management Section below), completion of Test Run 5 also marked the completion of the Vision 21 test program. With reductions in staff scheduled to take effect January 31st the pilot plant went into a shutdown mode during which:

1. the char residues from the various test runs were transported to and combusted in FW's burner test facility in Dansville, NY;

2. the carbon dioxide and oxygen tanker trucks along with the liquid nitrogen storage tank and vaporizers were removed from the site/returned to renter;

3. remaining feedstocks and empty drums previously used for material storage were returned to their suppliers for disposal or reconditioning;

4. test floor materials were gathered up, moved to storage trailers, and locked up.

Task 5 – Project Management

The project is slightly ahead of the schedule shown in Fig. 5 with testing having begun in October.

DOE funding authorizations currently limit FW to approximately ¾ of the amount proposed for the Vision 21 program. As a result, FW has delayed the start of activities not deemed critical to testing. (FW did not release any of its team members.) By conserving funds in this manner, we have been able to complete most of the planned test investigations and will be able to issue a test report with the remaining funds available.

A paper entitled, "Vision 21 Partial Gasification Module Pilot Plant Testing" was presented at the 27th International Conference on Coal Utilization and Fuel Systems on March 5.

Preliminary results of the pilot plant test program were presented to NETL in a project review meeting held in Livingston, NJ, on March 21.

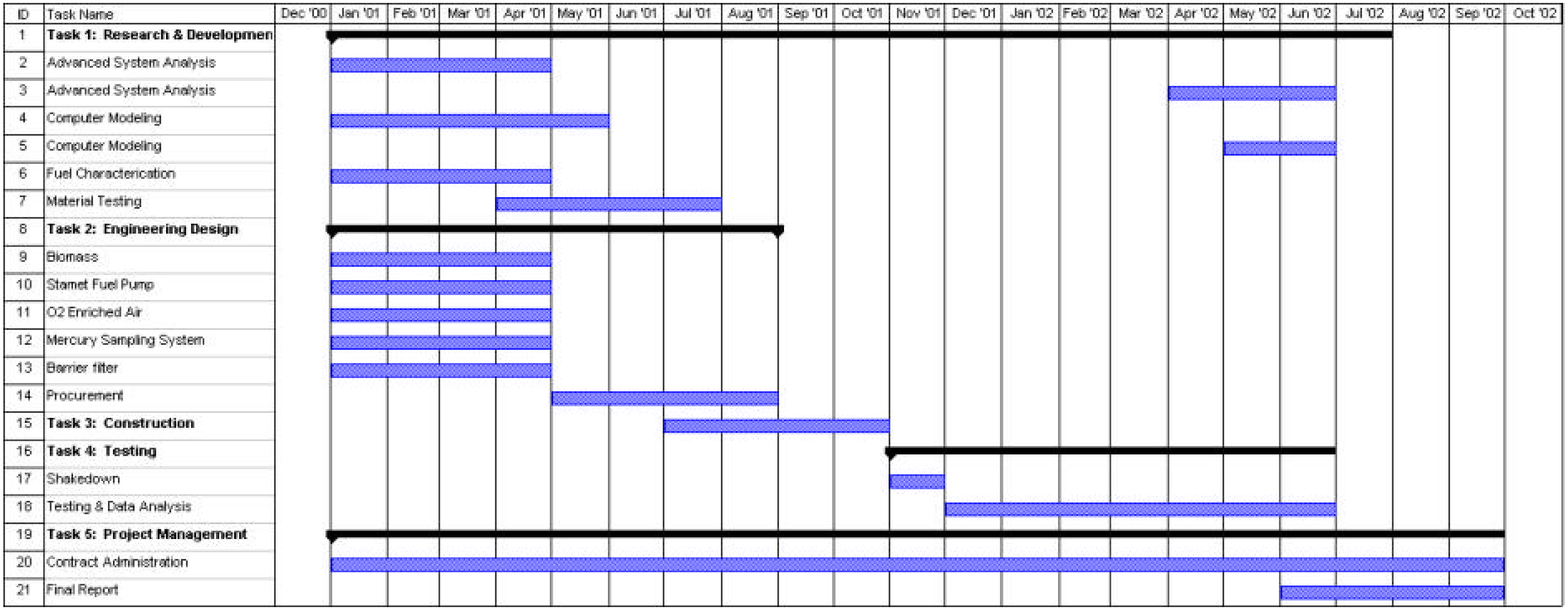

Fig. 5 Vision 21 Partial Gasification Module Schedule