Development of Foster Wheeler's Vision 21 Partial Gasification Module

A. Robertson, Foster Wheeler Development Corporation

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Foster Wheeler Development Corporation
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ABSTRACT

The US Department of Energy (DOE) has awarded Foster Wheeler Development Corporation a contract 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.

This paper describes the test program and pilot plant that will be used to develop the PGM.

INTRODUCTION

Vision 21 is a cost-shared partnership between the U.S. Government and industry. One of its objectives is to develop the design basis for coal-fueled electric generating plants that operate with efficiencies greater than 60% while producing near zero emissions of traditional stack gas pollutants. The cost of electricity generated by these new plants should be comparable to, if not less than, that of present plants and ideally should be amenable to sequestration of stack carbon dioxide gases.

The objectives of the Vision 21 program can be met via many different pathways. One of these is the coal gasification route, utilizing a combined cycle to achieve the high efficiency targeted in the Vision 21 program. Current gasification systems (especially the entrained flow type) must operate at high temperatures, well above 2500EF, to achieve high carbon conversion efficiency. These high temperatures essentially release all of the coal's contaminants to the syngas, and chemical-type cleaning systems must be provided to remove the contaminants. Present cleaning systems operate at about 100EF and large, expensive heat exchangers or gas quench systems must be provided to cool the syngas. Because the hot syngas contaminants can be extremely corrosive, the heat exchanger tubes must be kept at relatively low temperatures; and, with gas turbine discharge temperatures limited to 1100 to 1200EF, these technologies cannot easily accommodate advanced steam temperatures (≈1300EF). An alternate route proposed by Foster Wheeler is a partial gasifier module (PGM); it operates at lower temperatures that minimize the release of coal contaminants and enable the syngas to be fired hot. The PGM can operate with air, enriched air, or pure oxygen. The admission of pure oxygen requires that the flue gas be recycled or water added to control PGM temperature. The utilization of pure oxygen eliminates all nitrogen from the flue gas and provides a suitable exhaust stream for direct CO_2 sequestration. Because of the lower temperature, a char is produced along with the syngas, and the former is combusted in an Atmospheric or Pressurized Circulating Fluid Bed Combustor (ACFBC or PCFBC) or a High-Temperature Air Furnace (HITAF). The syngas and char generated in the PGM allow the use of high efficiency gas turbines together with the most advanced steam cycles.

In addition to generating electric power, a portion of the syngas could be used to co-produce valuable by-products such as liquid fuels and/or chemicals. Since FW's proposed plant utilizes char combustion to achieve steam temperatures of 1300EF, PGM carbon conversion efficiencies need only be in the 80% range or even lower. These conversion levels can be easily achieved with a fluidized bed reactor operating at about 1800EF. Hence the plant will not be restricted to reactive coals; it can handle less reactive coals as well as alternative fuels such as petroleum coke.

Coal-fired atmospheric fluidized bed boilers were originally marketed as bubbling bed units. As the technology advanced and moved to larger sized units, the bubbling bed was replaced by the circulating bed because the latter gave, among other things, superior performance with hard to burn fuels, was more compact, required fewer feed points, and was more easily scalable to large size units. Based on this experience, we have selected a circulating bed configuration for the PGM. The PGM will provide excellent feedstock and operating flexibility, will be amenable to system scale up, and the compact nature of the module will allow the use of shop fabrication and barge transportation, resulting in reduced installation, erection, and overall capital cost. These advantages constitute impressive gains over the present state of the technology and are a major step toward achieving Vision 21 goals.

PARTIAL GASIFIER MODULE

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 an intermediate level that only 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).

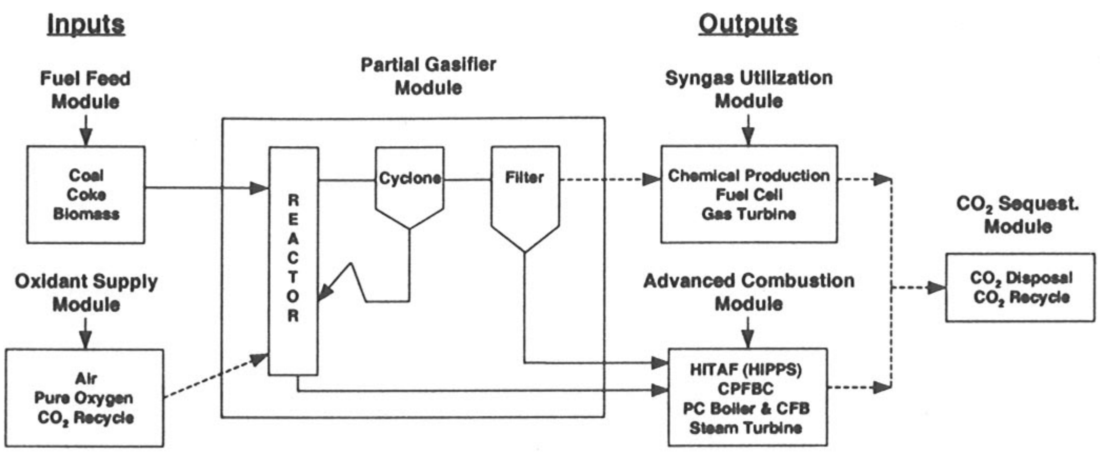

Figure 1 Vision 21 Modules – Enabling Technologies

VISION 21 PLANT ARRANGEMENT

An example of a high-efficiency plant incorporating an air blown PGM is illustrated in Figure 2. The overall plant schematic highlights the integration of all the modules forming the fundamental building blocks of the Vision 21 plant. The PGM serves as the initial fuel processing unit, converting the fuel feedstock into both a syngas and a solid limestone-char residue. The high temperature barrier filter functions to remove particulate and other contaminants from the gas stream, thus assuring a "clean" syngas exiting the PGM. The main components of the air blown, partial gasifier syngas are CO_2, N_2, CO, H_2, CH_4, and H_2O.

In the Figure 2 plant arrangement, the syngas is split into two separate streams. One stream is cooled to 1200EF, after which it is introduced into a desulfurization unit for further H_2S removal prior to entering a solid oxide fuel cell (SOFC). Presently, efforts are underway to develop high temperature (≈1000EF) sulfur removal systems for IGCC plants. The Vision 21 program requires development of even more advanced gas stream purification systems that are suitable for synthesis gas conversion, and fuel cell applications. Gas stream purification is also a critical module in the development of Vision 21 plants, and advancements in this area can directly benefit the proposed plant.

Once all of the sulfur species are removed from the syngas, it is admitted into the fuel cell. The SOFC technology is best suited for this cycle because of the high operating temperatures of the air and the syngas. The SOFC is outfitted with all solid-state ceramic components and may be enhanced to operate at temperatures up to 2300EF. The syngas generated in the partial gasifier module is well suited for fuel cell operation since hydrogen is one of the main chemical components. The methane component in the syngas can also be readily converted through a steam reforming process to produce additional hydrogen. For the purposes of defining overall plant efficiency, the fuel cell utilization is assumed to be 50%. The fuel cell represents one of the essential enabling technologies defined in the Vision 21 program, and the PGM is poised to take full advantage of all improvements in this technology.

The solid char that is generated in the PGM can be fired either in an ACFBC, PCFBC, or HITAF. The selection of the combustion technology will depend upon the characteristics of the fuel feedstock to be used. The HITAF is designed to operate at atmospheric pressure and to "indirectly" heat pure air supplied to the topping combustor, whereas the PCFBC operates at elevated pressure and provides vitiated air "directly" to the topping combustor. It should be noted that both of these combustion technologies are included as enabling technologies within the Vision 21 advanced combustion systems program. An ACFBC can also be incorporated into a Vision 21 plant using the PGM. The combustion system, in conjunction with the gas turbine heat recovery unit/HRSG, will provide the necessary thermal duty for the steam cycle. The proposed Vision 21 plant arrangement employs a double reheat steam cycle operating at 6000 psi/1300EF/1300EF/1300EF.

The back end of the Figure 2 plant incorporates advanced FGD and SCR systems to achieve near zero emissions of NOx and SOx. Although economic trade-offs will need to be made between pollutant capture within the process versus post-process pollutant removal, back-end exhaust cleanup is a sure necessity to meet the minimum emission requirements of Vision 21 plants. Hence, advanced back-end cleanup systems are also critical Vision 21 plant modules.

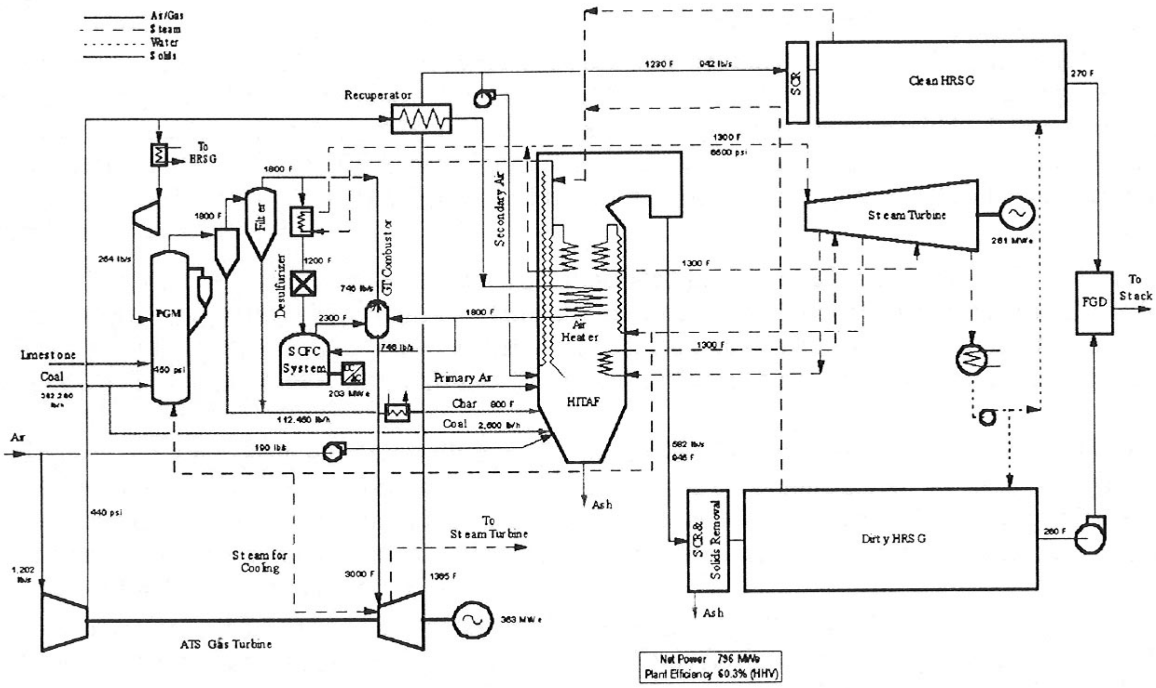

Figure 2 Advanced Air-Blown Vision 21 Plant Arrangement

- Although the Vision 21 plant arrangement illustrated in Figure 2 utilizes air as the oxidant, the system is also amenable to oxygen-rich firing to make it suitable for CO_2 sequestration. The four oxidant consuming reactors, the partial gasifier, fuel cell, topping combustor, and advanced combustion system will need to incorporate oxygen firing.

Although the proposed cycle is optimized for electrical power generation, the syngas can also be used in the production of liquid transportation fuels, such as methanol and ethanol, as well as the production of ammonia. Depending upon the prevailing market price for these chemical products, it may be economical, under certain conditions, to switch from the generation of electrical power to the production of marketable co-products.

Pilot Plant for PGM Development/Testing

Foster Wheeler possesses a coal-fired PCFB pilot plant at its John Blizard Research Center in Livingston, NJ. The pilot plant has a maximum heat input rating of 12 million Btu per hour, and its PCFB reactor can be operated either as a partial gasifier or a combustor. Figures 3 and 4 depict the PGM test module and pilot plant. The plant typically operates with coal, and limestone or dolomite can be injected with the coal to serve as sulfur capturing sorbents. The coal and sorbent are delivered to the plant, dried, crushed and screened to size in either 2000 lb. super-sacks or in pneumatic transport tanker trucks. Coal, sorbent, and sand can be fed to the process via dry, lock hopper type pneumatic transport feed systems or mixed with water and pumped in as a nitrogen atomized paste.

When the coal and limestone are delivered to the site in separate supersacks, they are loaded into separate 10-ton silos located behind/outside the back wall of the laboratory. A series of bucket elevators, vibrating feeders, belt conveyors, etc., load and transfer these materials into the building into separate lock hopper systems. Side loading chutes not shown in Fig. 4 allow materials to be manually loaded into the conveyors without having to pass through the silos. If dry feeding is selected, the lock hoppers are pressurized with 70EF nitrogen, vented to atmosphere, and then repressurized to match the pressure of the feed hoppers located beneath them. After matching pressures, the lock hoppers transfer their materials by gravity to their feed hoppers. Pressurized feeders at the bottom of each hopper withdraw the coal or limestone and discharge them to a common pipe for pneumatic transport to the PCFB reactor. Sand can also be gravity fed into the reactor via a lock hopper provided above the unit.

The reactor is a 30 in. OD x 39.5 ft. tall pressure vessel refractory lined to a 7 in. ID. Air, coal, and lime-based sorbent are injected into the unit through a central, vertical, stainless steel feed pipe at the bottom. Low-Btu syngas generated in the unit leaves through a 4 in. ID radial nozzle at the top. Spent bed material and char are drained from the bottom via an annulus that surrounds the feed pipe. The annulus leads to a nitrogen aerated packed bed where the draining material is cooled to 300EF before leaving through a 4 in. drain. The draining material is withdrawn in batches and depressured in a lock hopper provided under the PCFB reactor.

The syngas exiting from the top of the unit passes through a stainless steel primary stage cyclone located within an adjoining refractory lined pressure vessel. Particulate (hot char, sorbent, and sand) captured by the primary cyclone drains through a vertical dipleg and returns to the base of the PCFB reactor to permit the continuous circulation of hot material through the unit. As the char is consumed and ground up by its continuous recirculation through the system, the finer fraction eventually escapes the primary cyclone. This fine material together with the syngas are cooled to 650EF by a tubular heat exchanger and ultimately passed through a barrier type candle filter for the removal of all remaining particulate. The filter utilizes 2-3/8 in. OD by 60 in. long porous metal candles made of iron aluminide. Particulate collects on the outside of the candles; and as a dust cake forms, the pressure drop across the candle filter increases. Upon reaching a predetermined pressure differential, the dust cake is removed/blown off the candles by a back pulse of nitrogen gas. The dust cake falls to the bottom and drains by gravity to surge and lock hoppers provided under the filter for depressuring and removal. The higher the syngas dust loading and the higher the gas velocity through the candles, the more rapidly the filter pressure drop builds up and the more frequently it has to be pulse cleaned. To reduce the size and hence cost of the filter, a precleaning cyclone has been provided upstream of the filter.

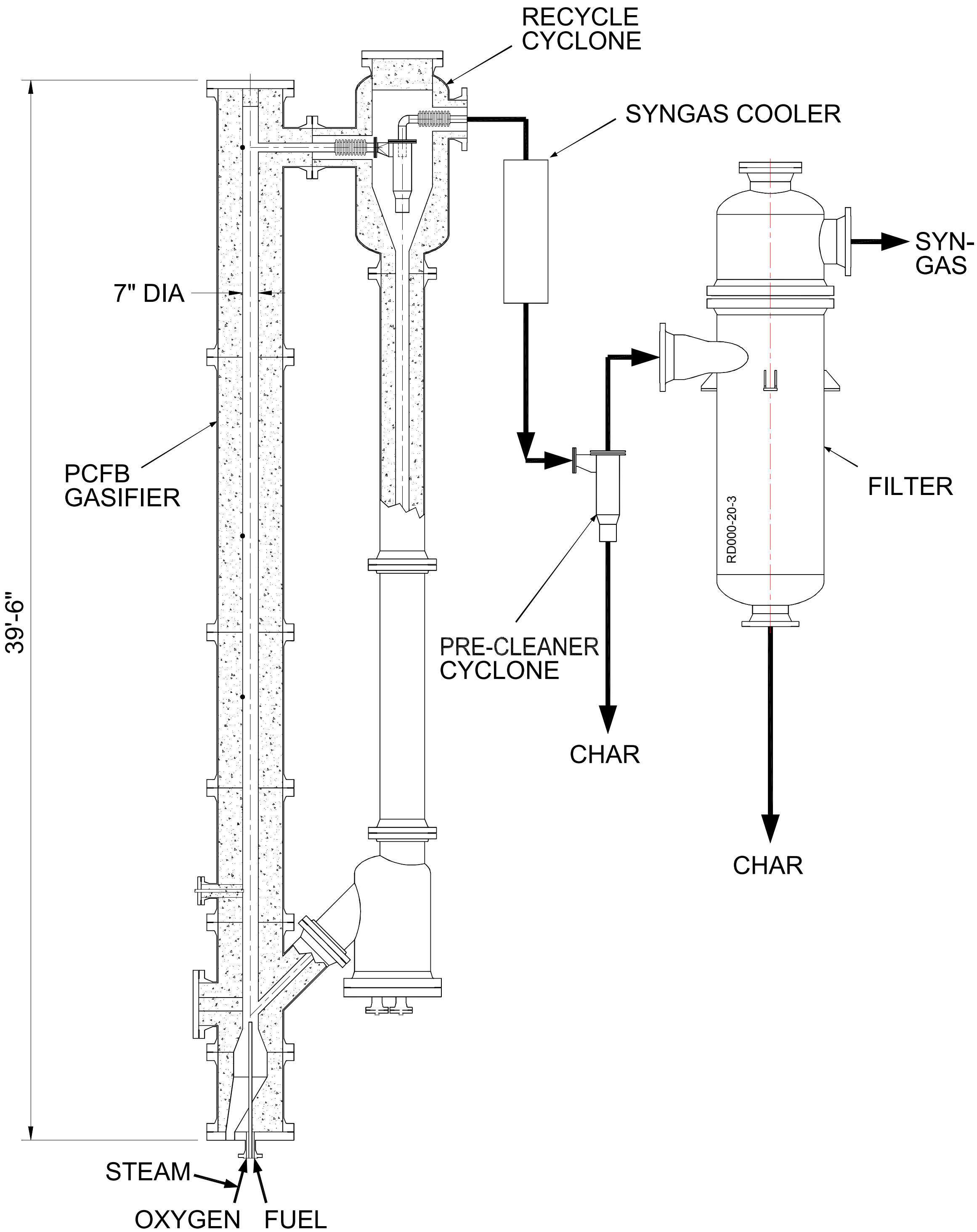

FIG 3. PARTIAL GASIFIER TEST MODULE

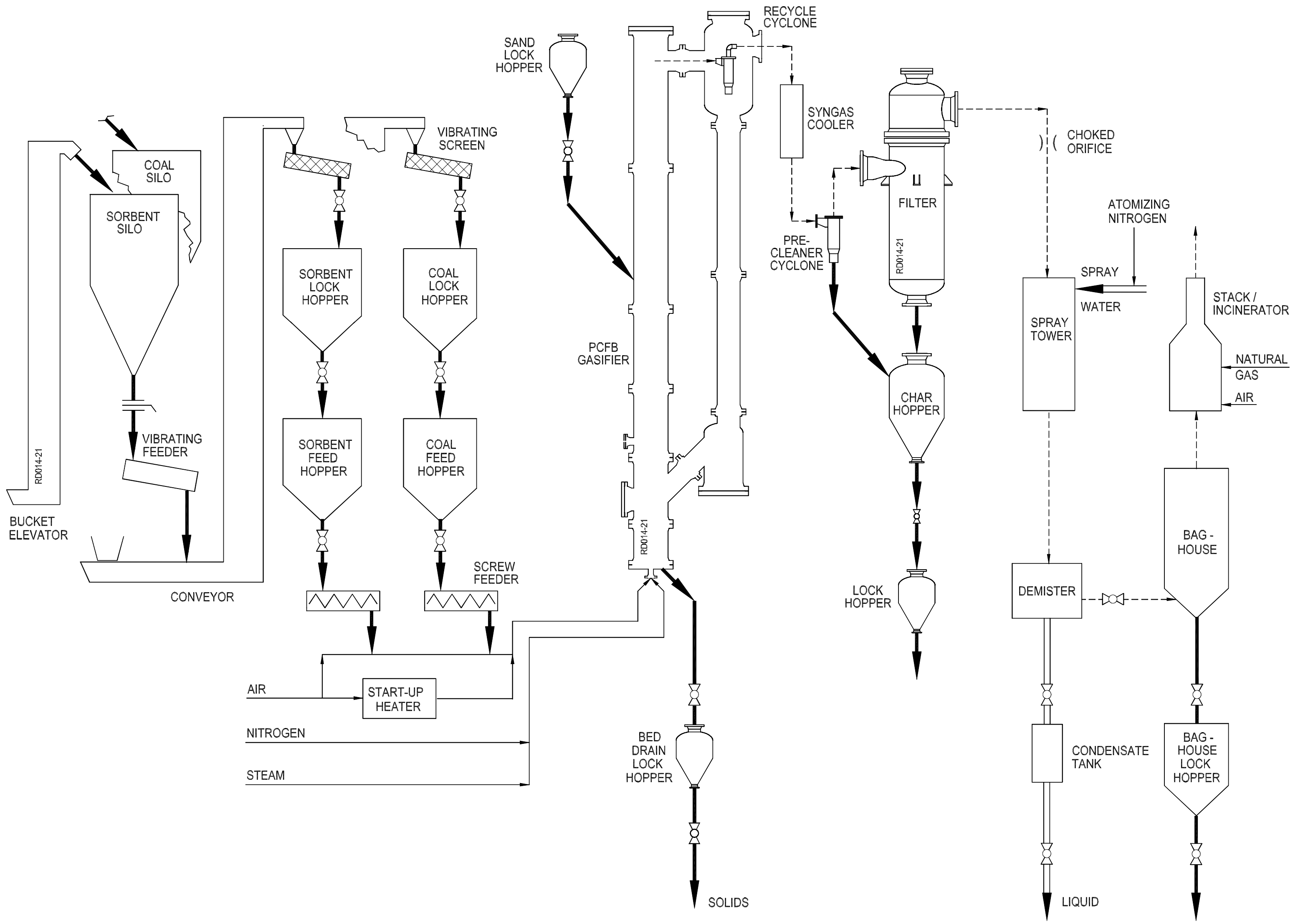

Fig. 4 Schematic of VISION 21 Pilot Plant

After passing through the filter, the syngas is depressured to ambient via a choked flow orifice and a water spray used to cool the gas to approximately 300EF. To satisfy NJ air permitting requirements, the cooled syngas is passed through a baghouse filter and then burned in an enclosed flare.

Test Program

To support the PGM development effort, a series of test runs will be conducted in the PCFB pilot plant. The tests will identify syngas yields, heating values, and compositions when processing both non-caking and highly caking bituminous coals as well as petroleum coke; in addition, sawdust will be cofired with the coke and the effects of enriching the air with oxygen will be studied. Testing is expected to begin in October, 2001, and end in the spring of 2002.