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OPERATION OF THE TRANSPORT GASIFIER™ AT THE PSDF

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ABSTRACT

The Power Systems Development Facility (PSDF) is an engineering scale demonstration of advanced coal-fired power systems and high-temperature, high-pressure gas filtration systems. The PSDF was designed at sufficient scale so that advanced power system components and the Department of Energy's Clean Coal Roadmap program elements could be tested in an integrated fashion to provide data for commercial scale-up. The PSDF is funded by the U. S. Department of Energy (DOE), the Electric Power Research Institute, Southern Company, Kellogg Brown & Root, Inc. (KBR), Siemens Power Generation, Inc. (SPG), Peabody Energy, Lignite Energy Council, and Burlington Northern Santa Fe Corporation (BNSF).

Currently, the primary focus of the PSDF is research and advancement of the gasification process, with focus also on particulate removal and syngas cleanup systems. Gasification at the PSDF is based on the KBR Transport Gasifier™, which is an advanced circulating fluidized bed reactor designed to operate at considerably higher circulation rates, velocities, and riser densities than a conventional circulating bed. These conditions result in higher throughput, better mixing, and higher mass and heat transfer rates.

The Transport Gasifier began operation in September 1999, and through March 2006 has achieved about 8,300 hours of gasification. A total of 6,841 hours of gasification were using Powder River Basin, while additional hours were devoted to North Dakota lignite

and bituminous coals from Utah, Illinois, Indiana, and Alabama. Approximately 5,100 hours of testing have occurred in air-blown gasification with the remaining hours in oxygen-blown operation. The gasifier typically operates at temperatures between 1,600 and 1,800°F, pressures up to 275 psig, and coal rates between 2,500 and 5,500 pounds per hour. These conditions yield carbon conversions up to 97 percent and produce commercially projected syngas lower heating values up to 145 Btu/SCF in air-blown gasification and 300 Btu/SCF in oxygen-blown gasification. The technology being demonstrated at the PSDF is also the basis for an advanced 285-megawatt coal gasification project located in Orlando, Florida, which was selected by DOE under its Clean Coal Power Initiative (CCPI). This paper discusses the performance of the Transport Gasifier during recent testing in air-blown and oxygen-blown mode as well as future plans of the PSDF and the Orlando Gasification Project (OGP).

INTRODUCTION

The PSDF is an engineering scale demonstration of advanced coal-fired power systems with high-temperature, high-pressure gas filtration. The PSDF was designed at a scale sufficient to test advanced power system components and Clean Coal Technology Roadmap program elements in an integrated fashion to provide data for commercial scale-up. Clean coal research at the PSDF focuses on testing the Transport Gasifier, a particulate control device (PCD, a high temperature, high pressure gas filter), and a number of auxiliary systems essential for any gasification process.

The Transport Gasifier is an advanced pressurized circulating fluidized bed system designed to operate in air or oxygen-blown modes using a variety of fuels such as subbituminous, bituminous and lignite coals and biomass. Syngas produced by the Transport Gasifier can be used as fuel for a combustion gas turbine or a fuel cell, or can be used for processing into chemicals such as methanol or transportation fuels. The gasifier operates at considerably higher circulation rates, velocities, and riser densities than a conventional circulating bed, resulting in higher throughput, better mixing, and higher mass and heat transfer rates.

PROCESS DESCRIPTION

Figure 1 illustrates the general flow diagram used for testing the Transport Gasifier and PCD at the PSDF. A series of lock hoppers feed coal to the Transport Gasifier, while a separate set of lock hoppers feed sorbent, if necessary, to capture sulfur in the coal as calcium sulfide. The gasifier also has feed lines so air and steam can be fed as reactants, along with nitrogen and recycle gas for fluidizing the system.

The syngas exiting the Transport Gasifier cyclone is sent through a primary gas cooler, where the temperature is reduced to around 800°F before entering the PCD for final particulate cleanup. In the PCD, virtually all of the particulates remaining in the syngas are removed using filter elements. After exiting the PCD, the syngas may be sent to gas cleanup, a piloted syngas burner and combustion turbine, or the secondary gas cooler. Most of the syngas is typically sent to the secondary gas cooler and is later depressurized to around 2 psig using a pressure control valve. Next, the gas is sent to an atmospheric syngas combustor where it is combusted and all reduced sulfur compounds (H_2S, COS, CS_2) and reduced nitrogen compounds (NH_3, HCN) are oxidized. Upon leaving the combustor, the oxidized syngas, or flue gas, flows through a heat recovery boiler to cool the gas and produce steam. The gas then travels through a baghouse, and out the stack.

The Transport Gasifier produces both fine and coarse ash. Fine ash, which is collected by the PCD, is cooled and removed via a continuous fine ash depressurization (CFAD) system. Coarse ash accumulates in the standpipe and is removed via a continuous coarse ash depressurization (CCAD) system. Both the fine and coarse ash streams are pneumatically conveyed into an ash silo for disposal.

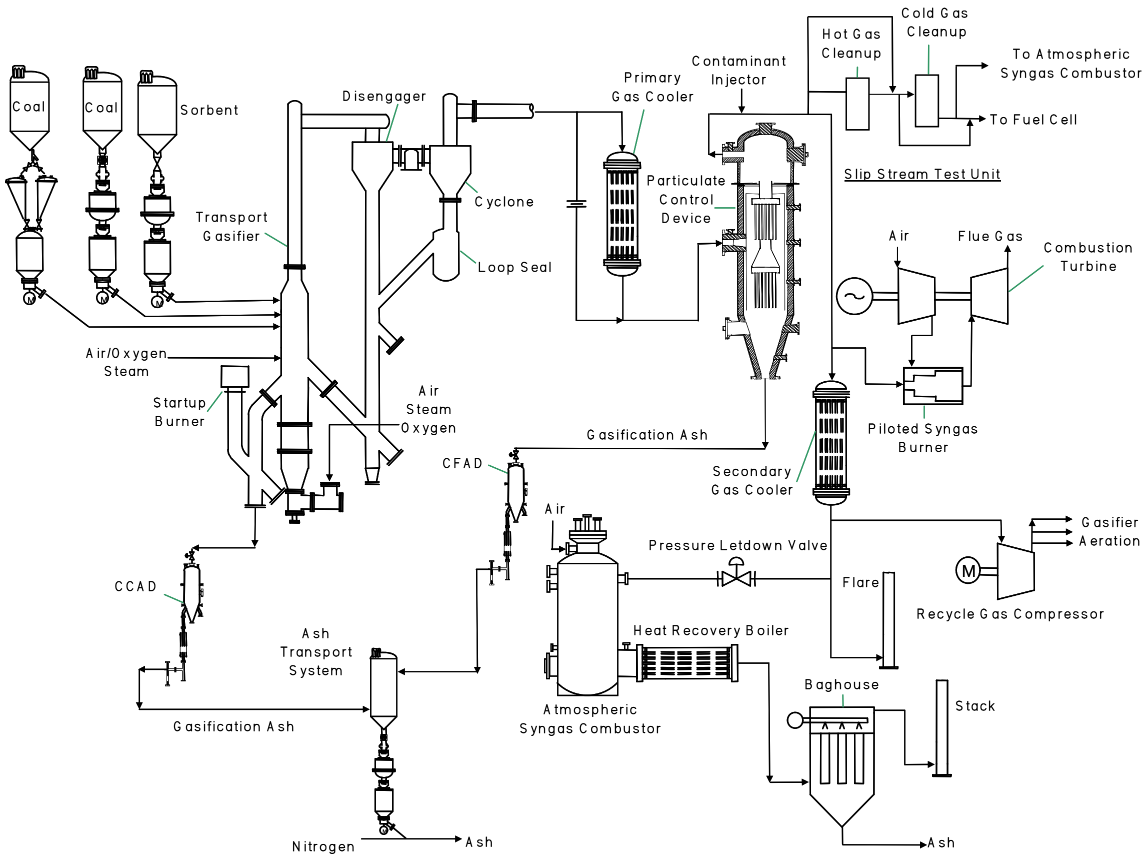

Figure 1: Flow Diagram of the PSDF Transport Gasifier Train

As mentioned earlier, syngas is produced in the Transport Gasifier using fuel and reactants. As shown in Figure 2, the Transport Gasifier consists of the following parts: mixing zone, riser, disengager, cyclone, loopseal, standpipe, and J-leg. During gasification operations, the top portion of the mixing zone serves as the entry point for the fuel and sorbent, if necessary. The oxygen, steam, and air are routed separately and mixed for injection into the mixing zone both above and below the J-leg. Hot solids containing unreacted carbon return from the standpipe through the J-leg to the mixing zone. Air or oxygen fed to the lower or upper mixing zone combusts the carbon in the circulating solids and provides the energy necessary for the devolatilization and gasification of the fuel.

The resulting gas and solids mixture continue to react as they move up the riser, which is a vertical section of smaller diameter pipe than the mixing zone. The larger solid particles in the syngas are removed by the disengager, a gravity separator that forces the largest particles into the standpipe, while the syngas, along with the remaining smaller solid particles, proceed to the primary cyclone. Most of the remaining particles are removed in the primary cyclone, returned to the standpipe via a loop seal, mixed with the larger, previously removed particles, and circulated back to the gasifier mixing zone.

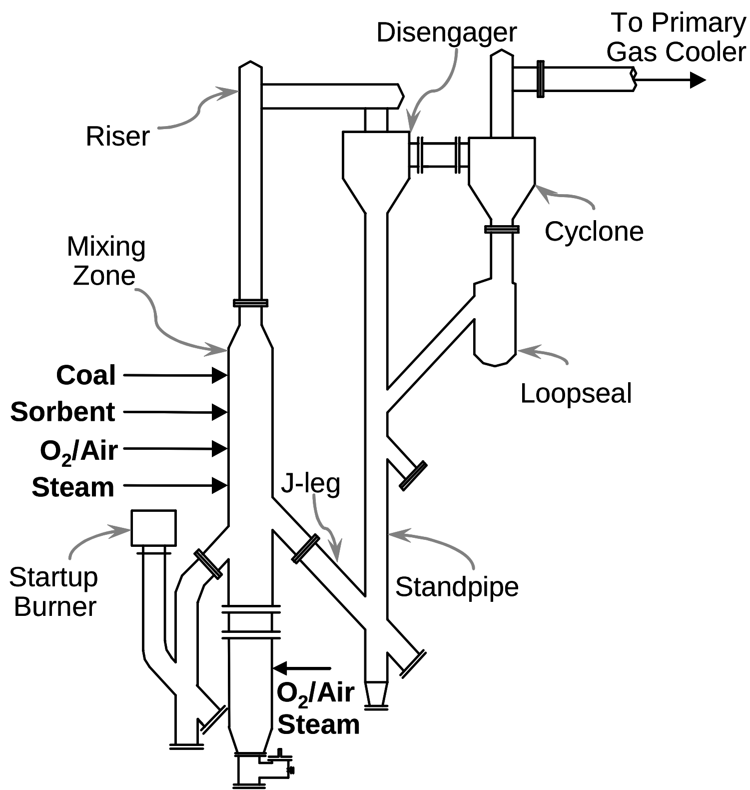

Figure 2: Transport Gasifier Flow

The nominal Transport Gasifier operating temperature is between 1600 and 1,800°F. The gasifier is designed to have a maximum operating pressure of 294 psig in air-blown mode and 220 psig in oxygen-blown operation. The thermal input capacity is approximately 50 million Btu/hr.

OPERATION

The Transport Gasifier began operating in September 1999. Currently, the Transport Gasifier has achieved about 8,300 hours of gasification, with a total of 1,722 hours in oxygen-blown operation using Powder River Basin, Indiana bituminous, Utah Hiawatha seam bituminous, Alabama Calumet mine bituminous, Illinois #6 bituminous, and North Dakota Falkirk and Freedom mine Lignite. Table 1 further summarizes previous gasification testing for the Transport Gasifier.

Table 1: Gasification Testing for the Transport Gasifier

Test Run	Fuel	Mode	Dates	Hours
GCT1	PRB, Alabama Calumet mine bituminous, Illinois #6	Air	September – December 1999	233
GCT2	PRB	Air	April 2000	217
GCT3	PRB	Air	January 2001	184
GCT4	PRB	Air	March 2001	242
TC6	PRB	Air	July – September 2001	1025
TC7	PRB, Alabama Calumet mine bituminous	Air	January – April 2002	442
TC8	PRB	Air, oxygen	June 2002	365
TC9	Utah Hiawatha bituminous	Air, oxygen	September 2002	309
TC10	PRB	Air, oxygen	November – December 2002	416
TC11	North Dakota Falkirk lignite	Air, oxygen	April 2003	192
TC12	PRB	Air, oxygen	May – July 2003	733
TC13	PRB, North Dakota Freedom lignite	Air, oxygen	October – November 2003	501
TC14	PRB	Air, oxygen	February 2004	214
TC15	PRB	Air, oxygen	April 2004	200
TC16	PRB, North Dakota Freedom lignite	Air, oxygen	July – August 2004	835
TC17	PRB, Indiana bituminous	Air	October – November 2004	313
TC18	PRB	Air	June – August 2005	1342
TC19	PRB	Air	November – December 2005	519

TRANSPORT GASIFIER PERFORMANCE

Developing a process for low ranked coals and predicting commercial gasifier performance are primary goals at the Power Systems Development Facility. Commercial gas turbine manufacturers have suggested that a lower heating value (LHV) of greater than 100 Btu/SCF is necessary to operate an Integrated Gasification Combined Cycle (IGCC) unit. The Transport Gasifier has successfully demonstrated that it is capable of producing projected lower heating values greater than 100 Btu/SCF using low ranked fuels such as PRB and lignite.

The actual lower heating value of the syngas produced by the Transport Gasifier is lower than that of a commercial facility for several reasons. In air-blown operation, approximately 50 percent of the nitrogen in the syngas produced enters the process through instrument and equipment purges, fluidization lines, and coal and sorbent conveying lines, while the remaining syngas nitrogen enters with the process air. In a commercial facility, a recycle gas compressor would supply syngas for aeration, as opposed to nitrogen. Therefore, the amount of nitrogen per standard cubic foot of syngas produced would be less than at the PSDF. Nitrogen would remain the source of the equipment purges; however, this percentage of flow would be insignificant compared to the total percentage of syngas produced in the gasifier. In addition, the gasifier heat loss per pound of coal fed in a commercial facility would be minimal due to the lower surface area to volume ratio in a commercial unit. As a result, the raw syngas lower heating value is corrected for a minimum amount of nitrogen in the syngas and heat loss when predicting the commercially projected syngas LHV. The projected lower heating value also increases due to the presence of a cold syngas cleanup unit. This unit enriches the syngas quality by cleaning the syngas and decreasing the moisture content to approximately 1 percent.

Figure 3 shows ranges of the projected lower heating values for both air-blown and oxygen-blown mode based on fuel type. The large range of projected lower heating values can be attributed to variations in the tests performed over time. The projected lower heating values for both PRB and Freedom Lignite were consistently above the commercial gas turbine specification. As shown below, the syngas quality using Powder River Basin coal was higher than that of other coals in both air and oxygen modes. However, conditions can be optimized for all of the fuels used to achieve over 100 Btu/SCF. Also, the syngas quality produced was always greater in oxygen-blown mode than in air-blown mode. The increase in quality can be attributed to less nitrogen dilution, since air nitrogen is absent.

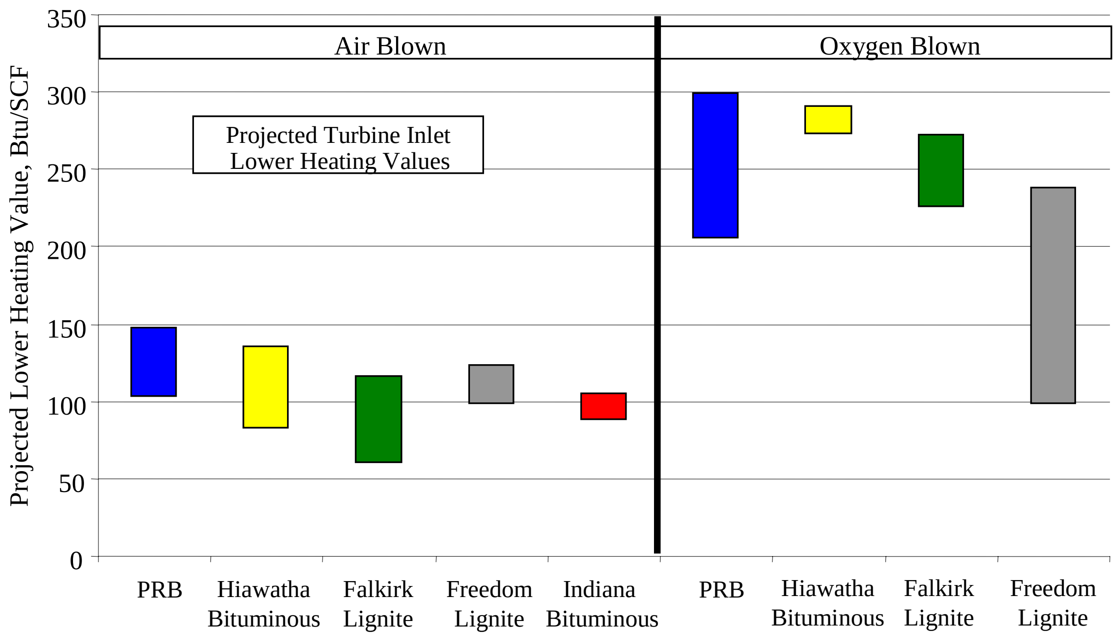

Figure 3: Projected Turbine Inlet Lower Heating Values

Carbon conversion is an important design variable in Integrated Gasification Combined Cycle (IGCC) process design. Carbon conversion is the percentage of carbon leaving in the syngas divided by the total carbon exiting the gasifier. Higher carbon conversion results in a lower amount of carbon in the coarse and fine ash streams and increases the efficiency of the gasification process. A higher carbon conversion reduces the amount of ash having to be disposed and associated handling costs decrease.

Figure 4 shows the carbon conversion in the Transport Gasifier for various coals tested. As shown below, the higher carbon conversions achieved at the PSDF have been during Powder River Basin and high temperature lignite testing, while the lower carbon conversions were attained using bituminous coals and low temperature lignite testing. The carbon conversion in oxygen-blown mode was typically less than the carbon conversion in air-blown mode due to a lack of oxygen distribution, lower riser temperatures, and an uneven temperature profile. Carbon conversion using PRB in air-blown mode is typically about 95 percent. Based on preliminary analyses, the highest carbon conversions are around 97 percent and 95 percent in air-blown mode for Falkirk and Freedom Lignite, respectively. The low temperature Freedom Lignite testing was performed using high sodium lignite. During this time, temperatures were greatly reduced to prevent operational problems due to a low melting point sodium-silicon eutectic. As a result, carbon conversion was significantly lower. The air-blown carbon conversions of the two bituminous coals test, Hiawatha bituminous and Indiana bituminous, were lower than PRB and both lignites at 90 and 85 percent, respectively.

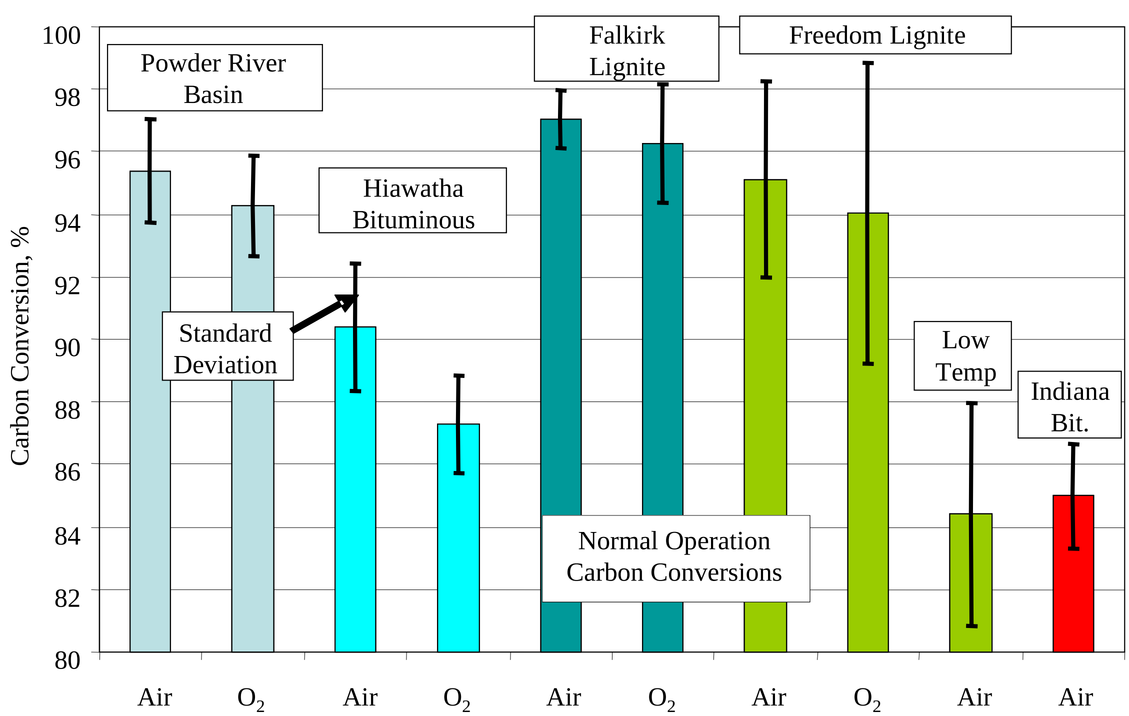

Figure 4: Carbon Conversion in the Transport Gasifier

OTHER SYSTEMS TESTING AND PERFORMANCE

Testing and demonstration of the PCD system and its components at the PSDF have significantly advanced hot gas filtration technology. More than twenty types of filter elements in four major categories have been tested and evaluated, with iron aluminide and HR-160 experiencing extended exposure. The longest exposure for individual filter elements is 7,676 hours for iron aluminide and 1,531 hours for HR-160. The outlet particulate loading of the PCD system has been consistently below 0.1 ppmw during normal operation, which is the lower detection limit of the particulate sampling system. As a critical safeguard component, failsafe devices have also been tested. Several commercially available designs and one PSDF-designed failsafe device have been tested with simulated filter element failures under real PCD operating conditions. Promising results have been obtained, and needs for further improvements have been identified and are being addressed.

The characterization and particulate analysis of gasification ash have provided a better understanding of PCD performance and have improved knowledge for transferring the technology to commercial PCD designs. To continuously monitor particulate loading in the PCD outlet gas stream, two types of online particulate monitors have been tested at the PSDF, the PCME Dust-Alert-90 Electrodynamic monitor and the Process Metrix Process Particulate Counter (PPC). The PCME Dust-Alert-90 Electrodynamic monitor demonstrated reliable detection of particle concentrations of a few ppmw when particles larger than 25 micron were present in the gas stream. The preliminary testing of the laser-based PPC monitor showed the potential for much greater sensitivity to lower particle concentrations and smaller particles.

Advancements in cold and warm syngas cleanup are also a primary focus at the PSDF. Syngas cleanup systems such as the one at the PSDF provide a competitive edge for gasification over pulverized coal units. At the PSDF, cold and warm syngas cleanup tests have been conducted through a slip stream to screen a number of different sorbents, catalysts, and solvents. In addition to testing with syngas when the PSDF gasifier operates, tests are continued during plant outages using bottled gases. Warm syngas desulfurization tests were typically conducted at 550 to 700°F and about 200 psig with syngas from both air-blown and oxygen-blown gasifier operations. Ammonia cracking and organics reforming tests were conducted between 1200 and 1700°F. Long-term tests have shown that, at these temperatures, the typical nickel catalysts are not susceptible to poisoning effects by sulfur compounds. Other catalysts tested for cracking and reforming include an alumina based catalyst, a titanium dioxide based catalyst, and a fluid cracking catalyst.

The syngas cleanup slipstream also made fuel cell testing possible. In support of this testing, clean syngas was provided for over 150 hours of fuel cell testing at the PSDF during both of the summer test campaigns during 2003 and 2004. During these test runs, the Transport Gasifier operated using PRB in oxygen-blown mode. Throughout these tests, the total sulfur in the syngas to fuel cell test unit was less than 60 ppb and the total organics was less than 200 ppm. Trona sorbent was used to scrub the HCl to less than 1 ppm.

CONCLUSIONS

The PSDF continuously researches ways to improve the entire gasification process, including the particulate and syngas cleanup process. The PSDF Transport Gasifier has been successful, operating in air-blown and oxygen-blown gasification modes for a total of 8,200 hours. Projected lower heating values and carbon conversions using low ranked fuels such as PRB and lignite have exceeded the suggested values to operate a commercial facility. Advances in syngas cleanup and particulate removal learned at the PSDF will greatly improve commercial designs.

FUTURE PLANS

The PSDF is currently undergoing a number of gasifier modifications in attempt to further enhance process performance. As a result of the modifications, the carbon conversion and lower heating value are expected to increase due to an increase in solids residence time. The PSDF will also continue enhancing different aspects of the gasification process such as fuel diversity, automation, sensor development, gas cleanup, and coal feed and ash removal systems.

The Transport Gasifier is also the foundation of an IGCC unit in Orlando, Florida. This facility is part of the DOE's CCPI program and is designed to be a 285-megawatt unit. The gas turbine will be capable of operating on natural gas or syngas produced by a Transport Gasifier. Southern Company and KBR are currently in the design phase, and the projected start date is mid-2010.

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