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Update on Gasification Testing at the Power Systems Development Facility

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Introduction

The Power Systems Development Facility (PSDF) located in Wilsonville, Alabama, was established in 1995 to lead the United States' effort to develop cost-competitive, environmentally acceptable, coal-based power plant technologies. The PSDF includes an engineering scale demonstration of key components of an Integrated Gasification Combined Cycle (IGCC) power plant, including a KBR (formerly Kellogg, Brown, & Root) Transport Gasifier, a Siemens Particulate Control Device (PCD), syngas cooling, and high pressure solids handling systems. These components are designed at sufficient size to provide data for commercial scale-up. As of May 2007, the PSDF gasification process had been operated for more than 10,000 hours.

The Transport Gasifier is a circulating fluidized bed reactor designed to operate at higher circulation rates and riser densities than conventional circulating bed units. The higher circulation rates result in higher throughput, better mixing, and higher mass and heat transfer rates. Since the gasifier uses a dry feed system and does not slag the ash, it is particularly well-suited for high moisture and high ash fuels such as subbituminous coal and lignite. The gasifier has operated in both air-blown and oxygen-blown modes. This paper will discuss the most recent testing of the gasification process at the PSDF.

Project Description

Figure 1 below illustrates the general flow diagram of the gasification process at the PSDF. A lock hopper assembly supplies fuel to the pressurized gasifier, while a separate system supplies sorbent, if necessary, to capture sulfur in the fuel. A burner is available to heat the gasifier from ambient conditions to a temperature suitable for adding coal, but is only necessary during startup. The continuous coarse ash depressurization (CCAD) system, located beneath the gasifier, allows for the removal of bed material to control the gasifier bed inventory.

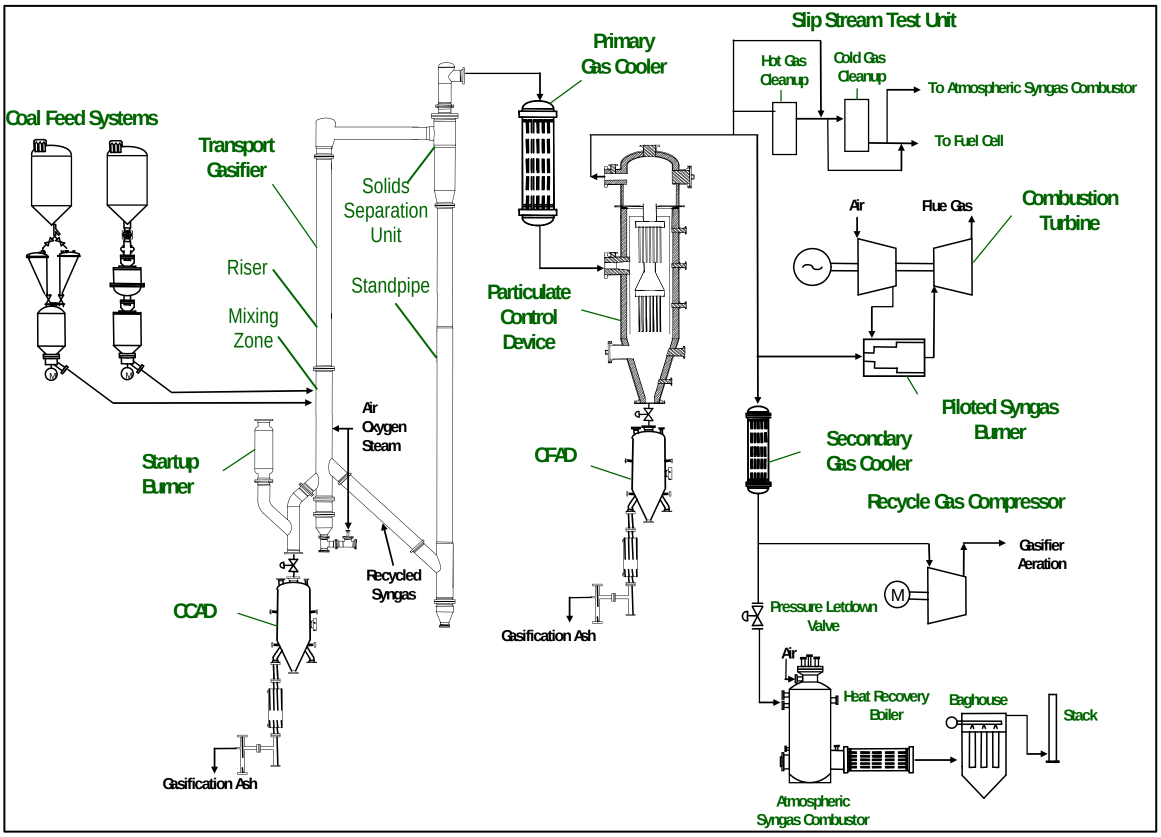

Figure 1. PSDF Gasification Process Flow Diagram.

The gasifier consists of an assembly of refractory-lined pipe that includes a mixing zone, riser, solids separation and collection unit, and a solids recycle section. The solids from the separation and collection unit enter the lower portion of the mixing zone and combust to provide the heat necessary for the gasification reactions. The coal and sorbent are fed to the gasifier in the upper mixing zone, where the hot circulating solids traveling upward from the lower mixing zone provide the heat necessary to devolatilize and gasify the coal in the riser, producing syngas and gasification ash. The Transport Gasifier operating temperature for Powder River Basin (PRB) subbituminous coal and lignite is nominally 1750°F. The PSDF gasifier has a maximum operating pressure of 294 psig and a thermal capacity of about 50 MMBtu/hr.

The syngas and solids mixture from the mixing zone flows through the riser to the solids separation unit. The separation system removes the majority of solid particles and sends them via the recycle section to the lower mixing zone for combustion, while the syngas exits the solids separation unit and proceeds to the primary gas cooler and the PCD. Although the carbon content in the circulating solids is low, the high circulation rate ensures that enough carbon is present to provide the heat necessary to maintain sufficient gasifier temperatures. Nitrogen or recycled syngas is used to fluidize the solids recycle sections to ensure that the circulating solids flow properly. Air or oxygen is necessary for combusting the recycled carbon, while steam provides a means for dispersing the oxidant and regulating the temperatures when using pure oxygen.

After leaving the solids collection unit of the gasifier, the syngas flows into the primary gas cooler at a temperature of approximately 1700°F. The primary gas cooler decreases the syngas temperature to about 800°F before the gas enters the PCD. The gas flows into the vessel through a tangential entrance, around a shroud, and through the filter elements into the plenums. Virtually all the particulate from the syngas is removed by the PCD shown in Figures 2 and 3, which uses candle-type filter elements. The PCD contains a tube sheet holding up to 91 filter elements that are attached to one of two plenums. A failsafe device located on the clean side of each element is designed to stop solids leakage in the event of a filter failure by acting as a back-up filter. High pressure gas is used to pulse clean the elements periodically to remove the accumulated solids, forcing the filter cake to fall to the PCD cone and into the continuous fine ash depressurization (CFAD) system. A common ash silo collects the solids removed via the CCAD and CFAD for disposal.

Figure 2. PCD Internals.

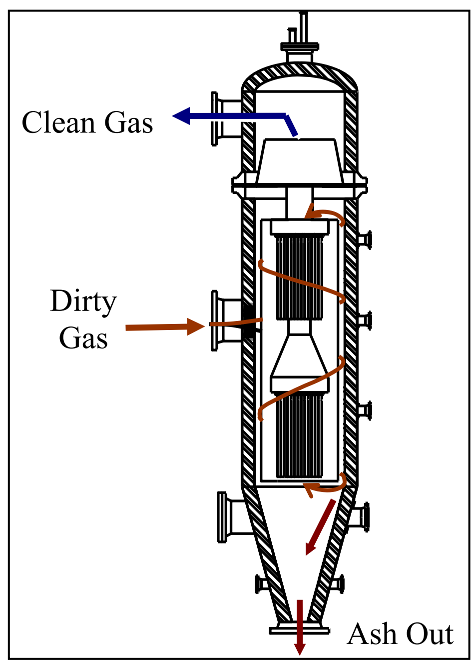

Figure 3. Schematic of PCD.

The filtered syngas exiting the PCD continues to either a combustion turbine for producing electricity or to the secondary gas cooler and the atmospheric syngas combustor, where the gas is burned and all reduced sulfur compounds (H_2S, COS, CS_2) and reduced nitrogen compounds (NH_3, HCN) become oxidized. Upon leaving the syngas combustor, the flue gas flows through a heat recovery boiler to cool the gas and to generate steam. The cooled gas then passes through a baghouse and out an exhaust stack. A slipstream test unit is also available for testing various catalysts and sorbents for removing syngas contaminants before sending the syngas to the atmospheric syngas combustor or to a fuel cell. To improve heating value and reduce nitrogen consumption, a recycle gas system can send a portion of the syngas back to the gasifier as fluidization gas.

Operational History

System commissioning and initial test campaigns were performed in combustion mode from 1996 to 1999. Operation in air-blown gasification mode began in September 1999. Four gasification commissioning tests, each lasting nominally 250 hours, were completed by early 2001. Since then, 17 test campaigns, each nominally 250 to 1,500 hours in duration, have been completed, resulting in over 10,000 hours of gasification testing. PRB subbituminous coal has been tested extensively, totaling about 7,700 hours. Three bituminous coals and four different lignite coals have also been tested. Transport reactor operation during combustion mode operation has been previously described (Liu, 1999), as has operation in early gasification testing (Loganbach, 2005).

Prior to 2006, the Transport Gasifier configuration was based on a combined combustor/gasifier design that limited its performance as a gasifier. In early 2006, changes to the gasifier provided a new, more robust solids separation system as well as a larger diameter riser. These changes consisted of replacing approximately 85% of the refractory-lined gasifier. The primary goals were to improve the solids collection efficiency, and to increase the residence time in the gasifier to increase the carbon conversion and syngas heating value and to test a solids collection system better suited for commercial scale-up.

Results

In addition to the continued development of the Transport Gasifier, significant progress has been made in the development of supporting technologies for the gasification process. Some major areas of technology development at the PSDF include the following:

- Hot Gas Filtration—Testing and research has continued to yield critical information needed for commercial design. A companion paper in these proceedings describes recent filtration research at the PSDF (Yongue, 2007).
- Coal Feeding—Additional work on the pressurized coal feed systems has increased the understanding and optimization of these systems.

- Ash Removal—A new design concept for fine and coarse ash cooling and depressurizing was developed and successfully tested at the PSDF, providing reliable ash removal.
- Sensor Development and Process Automation—A continued focus on development of advanced sensors for gasification technology in general has continued to provide critical progress in this area.
- Syngas Analysis and Sampling—Advances in syngas sampling and analysis has improved the operational reliability of the systems and provided the data needed for technology development and process understanding.
- Advanced Syngas Cleanup—A slipstream unit has provided a very flexible test platform for testing numerous syngas contaminant removal technologies.

Transport Gasifier Performance

The gasifier was modified in 2006 to improve the capture efficiency of the gasifier solids separation system and to increase the residence time in the gasifier. In August of 2006, the system was successfully commissioned and tested with PRB coal, achieving the most stable gasifier operations since testing began, and demonstrating improvements in the solids collection efficiency, syngas heating value, and carbon conversion. The increase in separation efficiency led to a decrease in particle size and bulk density of the solids circulating in the gasifier; however, gasifier operations were not adversely affected.

Syngas heating values after the modifications were the highest the Transport Gasifier at the PSDF had achieved. For air-blown operations with PRB, there was about a 20% increase in the raw syngas lower heating value. The raw lower heating values ranged as high 87 Btu/SCF on a wet basis and occasionally exceeded 100 Btu/SCF on a dry basis. Listed below in Table 1 are the commercially projected lower heating values achieved for the fuels tested during the runs following the gasifier modifications. All values are acceptable for operating a combustion turbine.

Table 1. Projected Lower Heating Values.

Type of Fuel	**Projected Lower Heating Value at Turbine Inlet (Btu/SCF)**
Mississippi Lignite	119
North Dakota Lignite	128
PRB	128

Typically, carbon conversion for the Transport Gasifier has been high for low rank coals such as PRB (averaging 95%) and lignite (averaging 97%). The conversion, however, is notably lower at lower gasifier temperatures and also with higher rank coals. The gasifier has been operated at lower operating temperature with lignite containing large amounts of sodium in the ash to prevent agglomeration caused when the sodium reacts with silica to form low melting point compounds. (Agglomeration with high sodium lignite has prevented long-term operation with these coals; operating strategies for more acceptable gasifier performance with high sodium lignite are currently being developed.) Table 2 lists the average carbon conversion for fuels tested to date, including PRB coal, lignite coals from the Falkirk and Freedom Mines in North Dakota and the Red Hills mine in Mississippi, and bituminous coals from Indiana and the Hiawatha seam in Utah. All of the carbon conversions shown on Table 2 were at similar gasifier temperatures with the exception of the Freedom Lignite (high sodium content). The data indicate that the carbon conversion improved after the gasifier modifications, with the average conversion for PRB coal increasing from 95.4% to 98.1%.

Table 2. Average Carbon Conversions.

Type of Fuel	Gasifier Configuration	Average Carbon Conversion	Standard Deviation
Falkirk Lignite	Original	97.0	0.9
Freedom Lignite	Original	95.1	3.1
Freedom Lignite	Modified	97.8	0.5
Freedom Lignite (Low Temperature)	Original	84.4	3.6
Freedom Lignite (Low Temperature)	Modified	93.9	2.2
Hiawatha Bituminous	Original	90.4	2.0
Indiana Bituminous	Original	83.2	1.8
Mississippi Lignite	Modified	97.8	1.0
PRB	Original	95.4	1.6
PRB	Modified	98.1	0.6

Coal Feed Systems

A coal preparation and feeder development program has been implemented to demonstrate and quantify systems that will optimize process performance, reduce capital cost, and improve reliability. Work to date includes determining the effect of feed particle size on the gasifier operations and performance and developing the operating envelope for different fuel types. Test run results achieved after the gasifier modifications have shown that the range of particle size (250-600 microns, mass median diameter) gives acceptable gasifier performance. Two key parameters for coal feeder system performance are the moisture content in the feed and the particle size distribution of the material. If the moisture content is too high, there are operating issues associated with the flowability of the material. If the feed contains an excessive amount of fines, the material will pack in the pressurizing vessel in the feed system; however, if the feed size is too large there can be issues with the discharge line plugging.

Ash Removal Systems

Two new ash removal systems were designed and tested as part of the Transport Gasifier train. These proprietary systems (CCAD and CFAD) have no moving parts and do not require a pressurizing gas. These ash removal systems have together operated over 8,500 hours with 100% availability over a range of particle size distributions. Figure 4 shows the particle size range of material typically discharged by the CFAD and CCAD systems.

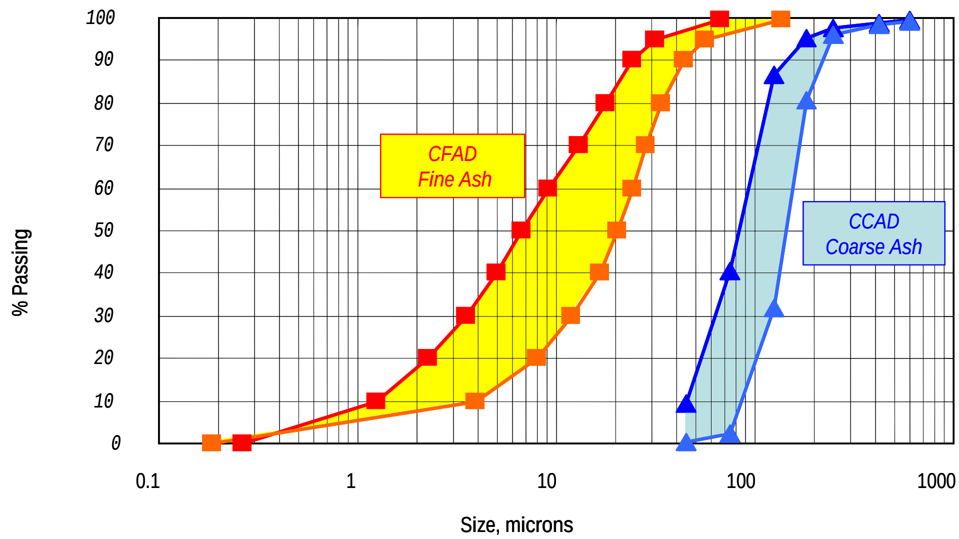

Figure 4. CFAD and CCAD Material Particle Size Distribustions.

Sensor Development/Automation

Significant progress with sensor development and process automation has been achieved. Development of reliable and accurate sensors for the gasification process has concentrated on coal feed, Transport Gasifier, and PCD systems. Extensive testing of a nuclear based coal feed rate measurement revealed limitations in the measurement capability. A combination of capacitance velocity and nuclear density was tested and proved to be an accurate instantaneous coal feed rate measurement.

To improve gasifier temperature measurement reliability, various materials and instrument configurations have been tested. The effect of thermowell insertion length has also been studied. In low velocity regions, HR-160 thermowells have shown to be adequate; however, in higher velocity areas, extensive wear of these thermowells has been problematic. Ceramic thermowells procured from SynTemp have shown promise in high velocity regions, lasting over 1,000 hours with only minimal wear. Because of the lower operating velocities in the riser after the gasifier modifications, erosion problems with the HR-160 thermowells have been minimized. Based on the different insertion lengths tested, it was determined that a 2 inch insertion beyond the refractory wall plane is sufficient for 0.75 inch thermowells. There was no difference between the measurements made at insertion lengths from 2 to 8 inches. Results from the temperature measurement development at PSDF could be used for other gasification technologies as well.

To reduce purge flow requirements and to prevent plugging of nozzles for gasifier pressure differential measurements, ceramic filters have been installed and tested. Although balancing the measurement is more sensitive, the measurement correlated well with standard measurements, as shown in Figure 5, and the instrument has not plugged during the testing.

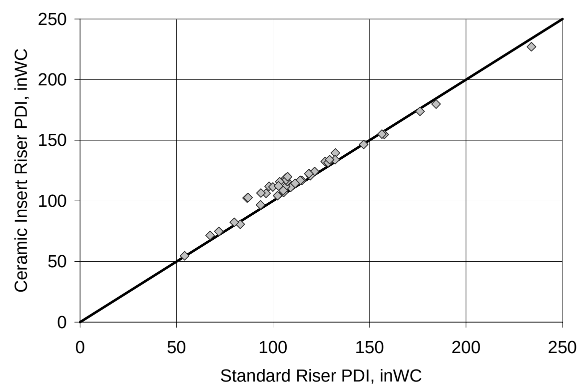

Figure 5. Pressure Differential Indicator (PDI) Instrument Using Ceramic Filter versus Standard PDI without Ceramic Filter.

Another area of sensor testing has been on-line particulate monitoring at the PCD outlet. The Dust Alert 90 monitor from PCME infers a particulate concentration from the electrical charge flowing near the probe and has proven to reliably detect significant particle penetration through the PCD. For detection of very small levels of particulate penetration, which is much more typical, the Process Metrix, Inc. Process Particle Counter (PPC), an extractive, laser-based single-particle counter, has been tested in recent runs. The PPC appears to be able to reliably detect mass concentrations as low as 0.5 ppmw and can potentially predict particle size distributions as well. Although more development is needed, real-time, reliable particulate monitoring has been realized.

Automation efforts have focused on Transport Gasifier operation. As shown in Figure 6, the gasifier temperature control scheme effectively controls the gasifier temperature within 5°F by modulating the air flow rate. Changes in set points are also effectively met, as shown in Figure 7. Gasifier standpipe level control has also been tested and has maintained the level within an acceptable range. Additional automation work has included automatic ramp rates for increasing the gasifier temperature and pressure during startup, as well as automated operation of most of the auxiliary equipment.

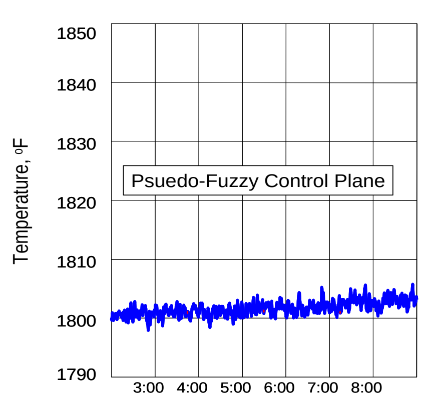

Figure 6. Automatic Gasifier Temperature Control.

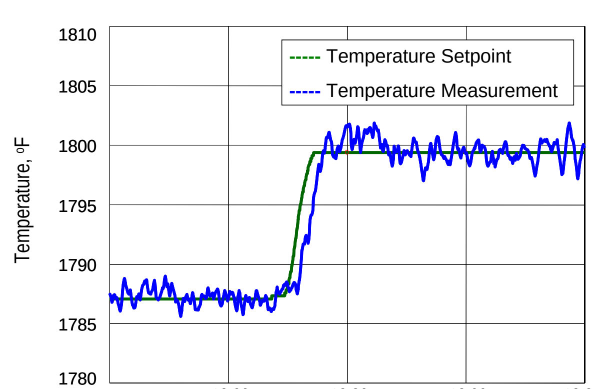

Figure 7. Gasifier Temperature Control Response to Setpoint Change.

Gas Analysis and Sampling

There have been several recent advances in the areas of gas analysis and sampling. Often performed in coordination with vendors, these include design changes to existing instruments, the employment of performance coatings, and novel applications of sampling techniques in conjunction with laboratory instruments. For example, there have been changes made to a Gasmet Fourier Transform Infrared (FTIR) analyzer manufactured by Temet. These changes include the relocation of several electrical components and the installation of a deflector directly into the sample cell. These changes have dramatically increased this analyzer's effectiveness. Advancements in measuring active sulfur compounds have been achieved by the use of Sulfinert performance coatings by Restek Corporation. These coatings allow for a fast and accurate analysis of hydrogen sulfide as well as other reactive compounds such as ammonia. Recently, laboratory gas chromatography (GC) analyzers have been used for the sulfur analyses previously mentioned. These analyses, coupled with performance coatings and specific columns, have provided reliable and accurate data previously unattainable. Lastly, bomb sampling techniques as well as new reflux probe applications have opened up numerous sample locations that were inaccessible in the past. These applications allow for the direct sampling of gasifier locations, particulate-laden streams, and various points on gas cleanup systems.

Advanced Syngas Cleanup

In order to develop commercially viable syngas cleanup systems to achieve ultra low emissions from coal gasification processes, a slip stream test facility was implemented in mid-2003. The cleanup facility is a flexible unit, and testing can be done simultaneously for individual components or removal technologies or for combinations thereof. In addition to testing with syngas when the Transport Gasifier is in operation, tests are conducted during plant outages using bottled gases.

The equipment includes several small reactors, knock out pots, and scrubbers which operate at varying temperatures, pressures, and flow rates. Table 3 below lists the major equipment including approximate sizes and operating conditions. The small reactors and solution scrubbers are shown in Figures 9 and 10, respectively.

Table 3. Advanced Gas Cleanup Major Equipment.

Equipment	Temperature ^{o}F	Pressure psig	Syngas Flow Rate lb/hr
Micro Reactors (2” X 6”)	600	350	1
Mini Reactors (1.5” X 3’)	1800	14	1
Small Reactor RX700A (5.1” X 4’)	800	350	100
Small Reactor RX700B (5.1” X 4’)	1400	45	50
Small Reactor RX700C (5.1” X 4’)	700	350	100
Mini Reactor RX700D (2” X 4’)	1600	200	20
2 Water Scrubbers (12” X 4’)	250	100	30
2 Knock out Pots (4” X 6’)	40	100	30
2 Solution Scrubbers (12” X 4’)	150	100	30
CO_2 Capture Test Unit	400	2000	6

Figure 9. Small Reactors in Syngas Cleanup Facility.

Figure 10. Solution Scrubbers in Syngas Cleanup Facility.

A number of analytical methods have been used for determining removal efficiencies, including FTIR and GC analyzers and wet chemistry sampling. The slip stream facility has also been used to provide outside researchers and developers a platform for testing of various technologies, such as fuel cell testing and trace metals removal, and is accessible for future testing, pending the availability of resources.

Several hundred hours of testing have been achieved thus far using various contaminant removal technologies. The main contaminants of interest and the general technologies employed are shown below in Table 4.

Table 4. Syngas Cleanup Contaminants and Removal Technologies.

Syngas Contaminant	Technology	Examples of Sorbents/Catalysts
Ammonia	High Temperature Cracking; Hot Gas Sorbents	Nickel-based catalysts; Zeolites
Alkali, Trace Metals	Hot Gas Sorbent; Scrubbing	Various materials; condensate scrubbing
Carbon Dioxide (CO_2)	Solution Absorption/Regeneration	Conventional solvents
Carbonyl Sulfide (COS)	COS Hydrolysis Catalysts	Activated aluminum oxide; titanium dioxide
Chloride	Acid Gas Cleanup Solutions and Sorbents	Trona sorbent
Mercury	Hot Gas Sorbents	Activated carbon; Coated sorbents
Organics	High Temperature Cracking; Reforming	Fluid Catalytic Cracking catalysts; Nickel-based catalysts
Sulfur	Hot Gas Sorbents and Solutions; Direct Oxidation	Nano materials; Iron and zinc based sorbents; Conventional solvents

Conclusions

The PSDF continuously endeavors to improve all aspects of the gasification process. The Transport Gasifier has been successfully tested, operating in air-blown and oxygen-blown gasification modes for over 10,000 hours. Operations to date have generated data and experience valuable to the design of the first Transport Gasifier-based commercial plant. Sponsored by the Department of Energy's Clean Coal Power Initiative program, this 285-MW IGCC unit will be built in Orlando, Florida. Southern Company and KBR are currently in the design phase, and the projected start date is mid-2010.

Future Testing

To support the development of CO_2 reduction technology, a major area of future testing at the PSDF will be advanced syngas cleanup with CO_2 separation. In addition to exploring the operating envelopes for conventional separation technologies, developmental technologies will also be evaluated. Other testing to support further enhancement of the entire gasification process will involve expanding gasifier fuel diversity, continuing process automation work and sensor development, and evaluating developmental coal feed system technologies. The next test run is scheduled to begin in late July 2007 using a lignite coal from North Dakota.

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