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Authors:
Harvey M. Ness (METC)
R. Daniel Brdar (METC)

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INTEGRATED GASIFICATION COMBINED-CYCLE RESEARCH DEVELOPMENT AND DEMONSTRATION ACTIVITIES IN THE U.S.

Harvey M. Ness, R. Daniel Brdar
Morgantown Energy Technology Center
U. S. Department of Energy
Morgantown, WV 26507-0880

Abstract

The United States Department of Energy (DOE)'s Office of Fossil Energy, Morgantown Energy Technology Center, is managing a research development and demonstration (RD&D) program that supports the commercialization of integrated gasification combined-cycle (IGCC) advanced power systems. This overview briefly describes the supporting RD&D activities and the IGCC projects selected for demonstration in the Clean Coal Technology (CCT) Program.

Introduction

In the early part of this century, more than 11,000 coal gasifiers were operating in the United States to produce industrial and residential fuel gas. Many of today's utilities began as coal gasification-based town gas manufacturers, transporters and distributors. U.S. interest in coal gasification dropped to a low level by the late 1960's due to the increasing availability of inexpensive domestic natural gas and oil, together with the discovery of large new reserves in the Middle East. Interest in coal gasification was renewed in the 1970's in response to the Arab oil embargo and the drastic rise in the price of oil. These events precipitated extensive research on improved coal gasification technologies.

In gasification only a fraction of the carbon in the coal oxidizes completely to CO_2. The heat released by partial combustion provides the energy required to raise coal to gasification reaction temperatures, to break the chemical bonds in coal, and to initiate and drive the endothermic gasification reactions that produce a fuel gas. Important gasification reactions are as follows:

1.	C	+	O_2	=	CO_2	exothermic
2.	C	+	$1/2O_2$	=	CO	exothermic
3.	C	+	H_2O	=	$CO + H_2$	endothermic
4.	C	+	CO_2	=	2CO	endothermic
5.	CO	+	H_2O	=	$CO_2 + H_2$	endothermic
6.	CO	+	$3H_2$	=	$CH_4 + H_2O$	exothermic

Reactions 1 and 2 are the sub-stoichiometric coal combustion reactions that provides the energy necessary to initiate the endothermic gasification reactions (equations 3, 4 and 5). Methane formation is favored by high temperatures and low pressures and increases the efficiency of gasification and the heating value of the fuel gas. It is desirable only because methane formation is the only exothermic reaction that does not consume oxygen. Under the sub-stoichiometric (reducing) conditions of gasification, the fuel gas will also contain contaminants such as hydrogen sulfide and ammonia (commonly called acid gas components).

The gasification reactions can be initiated using air-blown reactions (low-Btu fuel gas 90 to 150 Btu/scf) or oxygen-blown reactors (medium-Btu fuel gas 250 to 400 Btu/scf). Gasification processes in the U.S. presently in use or planned for use utilize moving bed, fluidized bed or entrained flow reactors (see Figure 1), the latter two reactors currently being demonstrated in the DOE Clean Coal Technology program. The fuel gas mixtures from the above reactors can be readily utilized in combustion turbines providing opportunities for even higher system efficiencies as advanced gas turbines are developed.

These improved gasification technologies have been integrated into a power generation concept called Integrated Gasification Combined Cycle (IGCC), an attractive technology for power generation, competing favorable with conventional pulverized coal steam plants. An IGCC system would replace the traditional coal combustor and steam turbine with a gasifier integrated with the combined cycles of a combustion gas turbine and a steam turbine. The IGCC application could be either a greenfield or repowering applications (Figure 2).

The modern IGCC power generation station will provide greater system efficiencies, lower emissions of air pollutants, reduced solid waste generation, and possible recovery of high-value added byproducts when compared to conventional pulverized coal-fired boilers. This advanced technology may have unique advantages over direct coal combustion for the following power generation applications: Phased capacity addition; natural gas and oil replacement; cycling load power generation; value added byproduct or coproducts; cogeneration; and repowering old coal-fired power plants.

In the United States, coal will continue to be an energy mainstay, currently supplying more than 56 percent of the nation's electricity. Through the DOE's Fossil Energy research and development (RD&D) programs, clean coal-based power generation will enable the nation to continue using its plentiful domestic coal resources in both greenfield and repowering applications at competitive capital and operating costs, while meeting and exceeding existing and more stringent emerging environmental quality requirements.

IGCC Enabling Technology

Advanced gas turbines are a key enabling technology for the IGCC power generation systems, and the foundation for increasing system efficiencies up to 50 percent. DOE is funding the development of advanced gas turbines in the Advanced Turbine Systems (ATS) Program. The turbines, which will have natural gas efficiencies of up

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to 60 percent, are being evaluated for coal-derived fuel gas compatibility as a part of the development program.

The ATS is one of DOE's highest priority natural gas initiatives. Ultimately, the program projects commercial demonstration for the year 2000 and will be adaptable for coal and biomass firing; the systems will be highly efficient, environmentally superior, and cost competitive. (See Table 1.)

Table 1
Advanced Turbine System Goals
(Based on Natural Gas-Fired System)

Parameter	Goal for Utility Scale Systems
Highly Efficient	60% combined-cycle -- lower heat value.
Environmentally Superior	10% reduction in NO_x emissions over today's best system.
Cost Competitive	10% reduction in cost of electricity.

The ATS program is a cooperative effort by DOE's Office of Fossil Energy and Office of Energy Efficiency and Renewable Energy. A steering committee including Electric Research Power Institute (EPRI), Gas Research Institute (GRI), and the Environmental Protection Agency, along with the DOE offices, is designed to ensure that ATS-developed products are consistent with user industry needs and will be adaptable throughout the country.

IGCC RD&D PROGRAM

DOE's IGCC RD&D program focuses on system improvements that will lead to lower cost systems and efficiency improvements without compromising the superior environmental performance of this technology.

The RD&D program is organized to support near- and long-term objectives. The near term objectives are to ensure the successful demonstration of the current CCT IGCC projects (discussed later). The long term RD&D objectives represents an investment that will result in the achievement of technical performance goals of over 50 percent system efficiency at costs of $1000 per kilowatt or less, by advances in high-temperature gas cleanup and gas turbine systems used by IGCC power systems. Considering forthcoming product improvements, capital cost will be reduced and increased efficiencies will lower the cost of electricity without relaxing the very high environmental performance.

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Hot Gas Desulfurization

The cleanup systems targeted for IGCC must control contaminants such as sulfur and nitrogen compounds, particulate, alkali metals, and chloride compounds. Contaminant control requirements have been based on New Source Performance Standards and tolerance criteria for process sub-systems such as gas turbines.

The hot gas desulfurization (HGD) R&D program objectives for removal of hydrogen sulfide (H_2S) from IGCC gas streams has two distinct thrusts. The first is to develop suitable reactors for the process, and the second is to develop suitable regenerable sorbents for use in the reactor. RD&D activities are being focused on several reactor types and a wide array of sorbent formulations applicable to each reactor design. The sorbents are effective at temperatures of about 1000 F, thus avoiding temperature quenching of the hot flue gas produced during gasification. The most promising techniques for removing hydrogen sulfide from the gasifier fuel gas employ a dry, mixed-metal oxide regenerable sorbent for use in moving-bed, fluidized-bed, and transport or entrained reactors.

In general, the desulfurization and regeneration reactions can be expressed as follows:

Desulfurization	ZnTiOx	+	H2S	=	ZnSTiOx	+	H2O
Regeneration	ZnSTiOx	+	O2	=	ZnTiOx	+	SO2

A brief description of HGD RD&D activities are as follows:

<u>General Electric Environmental Services, Inc. (GEESI) - Sorbents.</u> GEESI is developing a moving-bed, high-temperature desulfurization system at their corporate RD&D center in Schenectady, New York. A fixed-bed, air-blown gasifier capable of processing about 1800 pounds per hour (nominal 3 MW_e) of bituminous coal supplies fuel gas to the desulfurization system at a pressure of 20 atm and a nominal temperature of 1000 F. The desulfurization system will be utilized by the TECO CCT project in Lakeland, Florida.

The GEESI hot gas cleanup subsystem consists of a circulating fluidized bed chloride removal system installed upstream of moving bed desulfurization subsystem. The subsystems has been developed via intensive testing over several years. The chloride control subsystem will prevent chloride damage to the mixed metal oxides used for desulfurization, and other downstream corrosion. Up to 95 percent chloride removal has been demonstrated with using #2 food-grade sodium bicarbonate as their baseline chloride sorbent with up to 50 percent sorbent utilization. A more promising sorbent developed (discussed later) under the contract has been NS-02, a nahcolite-based, spray-dried formulation for fluidized and transport reactors. Up to 97-pct chloride removal efficiencies of have been achieved at high sorbent utilization values. At 1,000

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degrees F, vapor phase alkali metals have been well below specifications for gas turbines.

Hydrogen sulfide is removed from the fuel gas in a counterflow moving-bed absorber used to characterize the performance and durability of mixed-metal oxide sorbents. An external sorbent regeneration loop produces an off-stream of sulfur dioxide. The off-stream will be routed to a sulfuric acid plant in commercial practice for production of a value added byproduct. The GE system controls hydrogen sulfide levels to less than 50 parts per million. The GEESI hot gas cleanup system development has directly supported the systems being designed for Tampa Electric CCT project. GEESI, in partnership with Pall Corporation, evaluated ceramic and metal barrier filters in a slipstream test at the Dakota Gasification Plant (Beulah, N.D.). The metal filters will also be incorporated into the Tampa Electric CCT project.

Sorbents to be tested in upcoming tests include a class of proprietary sorbents (denoted as Z-Sorb™) developed by Phillips Petroleum Catalyst Development Center (Bartlesville, OK). Of particular note, the first sorbent fill for the Tampa Electric CCT desulfurization unit will be provided by Phillips.

Gas turbine components are also being tested to measure combustor performance on low-Btu gas, assess the effect of impurities in the fuel gas on deposition/corrosion in the gas turbine hot flue gas path, measure the level of trace impurities in the exhaust, and testing of staged combustion configurations to reduce nitrogen oxide emissions. Using dimensions suitable for axial combustors, novel staged combustion technology has produced significant reductions in the formation of nitrogen oxides from fuel-bound nitrogen. As little as 15 percent of fuel bound nitrogen is converted to nitrogen oxides in the configurations tested to date.

<u>METC In-house Research - Sorbents</u> -- The Office of Technology Base Development (OTBD), the METC inhouse research arm, has developed a desulfurization sorbent for use in GEESI moving bed desulfurization system. The sorbent, denoted METC-10, has demonstrated excellent sulfur capture reactivity and attrition resistance in bench-scale qualification tests. In cooperation with United Catalyst, Inc., (St Louis, KY), a batch quantity has been manufactured and provided to GEESI for evaluation in its moving bed desulfurization system. The tests are scheduled for March, 1996. If the tests are successful, the sorbent would be a candidate for use in the Tampa Electric CCT project hot gas cleanup system.

<u>General Electric Corporate Research and Development Center (CE-CRD) - Sorbents.</u> The sorbents that are currently nearing commercial availability are utilized at fuel gas temperatures of 950 F up to 1100 F. A long-term objective is to develop a desulfuriztion sorbent that will effectively capture hydrogen sulfide in a temperature regime ranging from about 650 F to about 900 F. IGCC system efficiency studies have shown that system efficiencies decrease by about one percent at about 700 F when compared to about 1000 F. Operation at lower temperatures may reduce cost of equipment, materials of construction, refractory and insulation requirements, and also,

reduce ceramic filter operating temperatures, thus increasing filtration overall reliability and possibly capital and operating costs. For these reasons, GE-CRD is conducting a study to develop a regenerable sorbent for use in this moderate temperature range. Results to date are encouraging.

Research Triangle Park (RTI). In support of a fluid-bed reactor configuration, activities by RTI have resulted in the development of highly reactive regenerable sorbents and fabrication methods that enhance long-term chemical reactivity and attrition resistent. The sorbents developed to date have focused on fluid-bed and entrained desulfurization reactors. Achievements include the development of zinc titanate (ZT-4) sorbent, manufactured using a granulation technique that promotes long-term chemical reactivity and mechanical strength for fluidized-bed applications. The average sulfur capacity was enhanced and an order of magnitude improvement in attrition resistance was achieved. The sorbent was tested in a fluid-bed desulfurization unit at the Messukyla Research and Development Center in Tampere, Finland. The reactivity was excellent, maintaining less than 20 ppm hydrogen sulfide in the coal gas.

In addition to the above activity, RTI teamed with Contract Materials Processing (Baltimore, MA) to manufacture a spray dried formulation denoted as ZMP-5 and ZMP-7. The sorbent has been tested by M.W. Kellogg, Houston, Texas, in a bench-scale Transport Reactor Test Unit (TRTU-II) in support of the full-scale transport desulfurizer incorporated into the Sierra Pacific Power Company's Pinion Pines CCT project. The sorbents are candidates for future use in the full scale desulfurizer; however, current plans are to use a proprietary sorbent, Z-Sorb, developed by Phillips Petroleum Catalyst Development Center (Bartlesville, OK). Licensed manufactures include Calsicat (Erie, PA) and United Catalyst, Inc (St Louis, KY). The Phillips proprietary sorbent was also tested in M.W.Kellogg's bench-scale transport desulfurizer.

A near-term concept under development by RTI is a direct sulfur recovery process (DSRP) to treat the regenerator gas containing SO2 from sulfided sorbents to produce elemental sulfur. Beginning in late 1994, RTI began operation of a field test unit. Initially the unit consisted of RTI's existing, 2-stage DSRP reactor system integrated with a single stage, 3-inch fluidized-bed reactor for the sorbent. The tests at METC's 10-inch fluid-bed gasifier proved that a single stage DSRP was more effective. The single stage reactor was tested at METC in July, 1995, providing 96% to 99% recovery of elemental sulfur. Present plans are to insert a canister containing the sorbent into a gasifier stream to provide long-term exposure, thus providing an evaluation of sorbent toxicity to fuel gas contaminants.

A long-term advanced sorbent development project to reduce capital, operating costs and subsystem complexity while producing an elemental sulfur byproduct is also ongoing. The advanced sulfur control process will provide for direct production of elemental sulfur during sorbent regeneration (in lieu of SO2), thereby eliminating the need for a separate sulfur conversion process (i.e., sorbent regeneration followed by conversion to elemental sulfur). The work is ongoing at the Louisiana State University

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and RTI. The goal is to develop simpler and economically superior processing for regenerable desulfurization sorbents. Results to date are promising.

SRI International - Chloride SRI International, teaming with Research Triangle Institute (RTI) and General Electric's Corporate Research and Development (GE-CRD), are developing disposable, sodium-based sorbents for removing hydrogen chloride vapor from coal gasification streams. The initial need for the research was to be able to meet a one ppmv inlet specification for the molten carbonate fuel-cell (MCFC), but recently GE has opened up another application with the inclusion of a chloride removal reactor in their pilot-plant hot gas cleanup facility. (GEESI is currently using #2 food-grade sodium bicarbonate as their baseline chloride sorbent).

The most promising sorbent developed is denoted NS-02, a nahcolite-based, spray-dried formulation for fluidized and transport reactors. In bench-scale testing at RTI, NS-02 has achieved capacities on the order of 38 weight-percent chloride for a one ppmv breakthrough at about 1000 F (approximately three times that of the #2 sodium bicarbonate). Results from pilot-scale testing of a small batch of NS-02 last fall indicate the HCl removal efficiency was greater than 97% and the extent of the sodium utilization exceeded 55% (corresponding to a capacity of 35 wt% chloride).

About a ton of NS-02 will undergo further testing in GEESI's next pilot plant run. Both NS-02 and the baseline bicarbonate will be tested for 100 hours, and the results from each will be compared. This involves performance data, as well as post-test characterization and economic analyses.

RTI - Ammonia Control An RTI project attempting to develop and test gas desulfurization mixed-metal oxide sorbent/catalyst combinations which can effectively remove hydrogen sulfide, as well as decompose fuel-bound nitrogen compounds (chiefly ammonia) at HGD operating temperatures was recently refocused. The simultaneous approach was abandoned and high-temperature catalyst screening addressing only ammonia reduction was initiated. For this, RTI is gathering parametric data on several catalyst formulations which are known to work in a "clean" laboratory environment, but may deactivate in the presence of certain coal-gas impurities under certain process conditions. The goal is to determine the process conditions conducive to prolonged catalyst life. Results from a recent test of one catalyst in RTI's mobile field-test unit under genuine coal gas conditions were encouraging. Decomposition ranged from 80 to 95 percent during the 120 hour test conducted at METC's MGCR facility.

Energy and Environmental Technology Corporation (EETC) - Ammonia Control A project entitled "A New and Low-Cost Process to Decompose Ammonia in IGCC Gas Streams," is developing a high-temperature, high-pressure process to reduce ammonia present in fuel gas by injection of a chemical reagent. The process conditions of interest are temperatures of 1000 to 2000 F and pressures up to 500 psia. The process has the potential to reduce ammonia down to less than one ppmv.

Preliminary results from bench-scale tests indicate that the process is effective at reducing ammonia (preliminary results indicate 70 to 99 percent removal at 1700 F). Following some planned apparatus modifications, additional testing will provide additional data to validate the concept. The concept is attractive since additional vessels added to an IGCC process stream would not be required, thus enhancing very low NOx emissions without incurring additional capital expense. The project supports the long-term goal of low cost IGCC systems.

High-Temperature, High-Pressure Particulate Control

A number of major RD&D projects are key components in the development path for IGCC commercialization. In some areas, RD&D applicable to one system is also applicable to another system (e.g., pressurized fluidized-bed combustion). An example of this philosophy is the development, evaluation, and commercialization of high-temperature ceramic filters for IGCCs and PFBCs. A great deal of the information that will be developed in the ceramic filter projects will be directly applicable to both types of systems, regardless of whether the actual ceramic filter testing is done on a PFBC or an IGCC. Major RD&D particulate projects are discussed below.

<u>Tidd Station Hot Gas Cleanup (HGCU) Slipstream Program.</u> A HGCU slipstream program was conducted at American Electric Power Service Corporation's Tidd Station using a nominal 10 MWe slipstream from a 70 MWe PFBC. The filtration system was provided by Westinghouse, and utilized a three-cluster filter element system, incorporating 384, 1.5-meter long silicon carbide candle filters. At the conclusion of the program, 5854 hours of on-line filtration time had been accumulated.

A smaller Westinghouse system was used to qualify mullite and other silicon carbide candle filters as potential candidates for testing at the Tidd 70-MWe PFBC. A Westinghouse filter system one-third the size of the Tidd filter system was installed on a PFBC owned by Ahlstrom/Pyropower, and used to qualify advanced candle filters for additional testing at the Tidd Station PFBC facility as well as the ascertain the effects of different coals on filter system performance. Total on-line filtration time on this PFBC is 2046 hours.

Significant conclusions derived from the above program are as follows: 1) The Westinghouse system has demonstrated the ability to clean large groups of filters from a single remote high pressure pulse gas source; 2) The Westinghouse filter system design including the tube sheet, filter sealing approach, filter blow back system, and the plenum and cluster assembly is a successful design with room for additional scale-up; and 3) The Westinghouse system is a viable concept to provide particulate control for IGCC systems. The Westinghouse filter system will be installed in Sierra Pacific's Pinion Pines CCT project.

Filter Element Development: Five projects have recently been initiated to develop and test a second generation of damage tolerant hot-gas filters. Filters developed under this program are expected to be tolerant of both thermal and mechanical stresses. A brief description follows:

Babcock and Wilcox (B&W) The B&W filter is an alumina based continuous fiber ceramic composite (CFCC) material incorporating a chopped fiber matrix into a filament wound continuous fiber structure. B&W has chosen the alumina Nextel 610 as the continuous fiber and the alumina Saffil chopped fiber as the matrix. The initial phase of the project has successfully fabricated sub-scale filter elements that includes both a flange end and a closed end. Corrosion testing was performed on four distinct compositions in a coal fired utility scale boiler, and no significant degradation of material properties was observed. One composition has been chosen for fabrication and testing of full scale filter elements in the next phase of the project.

Dupont Lanxide PRD-66. This barrier filter is an oxide composition with unique microstructural characteristics. Its composition is alumina, mullite, and cordierite, which should provide good resistance to chemical attack. The filter has a microcracked microstructure that allows for strain accommodation during thermal events. Dupont Lanxide worked to develop this filter with Westinghouse prior to involvement in the METC development program. Improvements have been made to the PRD-66 filter under this program including strengthening of the flange and improvements to the filtration membrane. Analysis of filter elements exposed at the AEP PFBC Demonstration Facility is underway to assess the effect of actual operating environments on the PRD-66 material. The inexpensive raw materials combined with simple processing methods give the PRD-66 a significant cost advantage when compared with the advanced fiber reinforced materials.

Pall Aeropower. This project is building on iron aluminide technology developed at Oak Ridge National Laboratory to develop a sulfur tolerant porous metal filter. Previous experience with metal filters in gasification environments has shown that conventional metals are subject to catastrophic corrosion at high sulfur levels. However, lower sulfur levels, such as those found downstream of hot-gas desulfurization systems may allow metal filters to be used in gasification systems. Sintering trials to optimize the pore structure of the iron aluminide filter media, and laboratory scale corrosion tests to determine the effect of process parameters on extent of corrosion are underway; long term corrosion testing is scheduled to be performed later in the project. In a separate effort,the durability of a SS310 metal filter was recently demonstrated by Pall and GEESI on a slipstream of fuel gas at the Dakota Gasification Plant, Beulah, ND, and will be installed at the Tampa Electric CCT project. The iron aluminde filter is anticipated to be even more tolerant to fuel gas streams than 310SS.

Textron Specialty Materials. Textron is incorporating their SCS-6 monofilament in a nitride-bonded silicon carbide matrix to form a non-oxide based CFCC filter material. The SCS-6 monofilament is a non-oxide fiber that retains its high temperature strength. Textron has fabricated dense, immersion burner tubes with one closed end and one flange end using a filament winding process under a separate DOE

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sponsored program. These components are similar to hot gas filters in size and shape. The objective of the current program is introduce porosity into this material to achieve the proper balance of permeability with strength.

Westinghouse. Westinghouse, in conjunction with Techniweave, is developing a mullite based CFCC filter material using a three dimensional weaving process. This weaving process provides fiber reinforcement in all three directions, which should provide additional mechanical stability when compared with two dimensional structures, such as those that are filament wound. A fiber architecture that optimize strength and toughness has been developed using the Nextel 550 fiber. This fiber preform is infiltrated with a mullite forming sol and mullite filler powder, forming the matrix. Laboratory scale corrosion testing is currently underway to study the effect of high temperature steam and alkali on the composite material.

Westinghouse is also assessing the suitability of damage-tolerant filter elements by providing lab-scale and bench-scale testing. Westinghouse is performing corrosion testing in their lab-scale flow-through test rig at high temperature with air containing alkali and steam, in conjunction with thermal pulsing. A bench-scale test facility capable of holding 16 full sized candle filters is used to evaluate basic filtration characteristics including filtration efficiency, pressure drop, and cleanability. Filter elements are also subjected to accelerated thermal pulsing and simulated process thermal transients in this facility to assess the effect to thermal stress on candle filter elements. The current test program includes evaluations of the 3M silicon carbide-Nextel composite filter, the Dupont Lanxide Composites silicon carbide-Nicalon composite filter, the Industrial Filter and Pump vacuum formed, chopped fiber Fibrosics filter, and the Dupont Lanxide Composites PRD-66 oxide filter. The main thrust of this project is to assist filter manufacturers' RD&D efforts to bring hot-gas filters to market.

R&D RESEARCH FACILITIES

Office of Technology Development - METC The METC inhouse research group has several process development activities supporting IGCC development. They consist of three on-site bench-scale processes: the Modular Gas Cleanup Rig (MGCR), the Riser Reactor, and the larger Fluid-Bed Hot-Gas Desulfurization (HGD) Process Development Unit (PDU) project. These projects are designed to provide data on concept feasibility, process performance, engineering problems, and scaleup issues associated with IGCC technology. The MGCR rig cleans the process fuel gas from a pilot-scale fluid-bed gasifier to generate performance data for particulate control, desulfurization sorbents and ammonia reduction catalysts. These processes have been utilized to conduct cooperative studies with industry. Additionally, construction of a large pilot plant desulfurization transport reactor capable of operating in both a bubbling bed and fast transport mode will be initiated in late summer of 1996. The desulfurization pilot plant will provide a test bed for verifying integrated process operation, control, and long-term sorbent and process durability at a scale large enough to be meaningful and applicable to full-scale plant designs. Near term activities will support the Pinion Pines CCT project. The facilities are available for cooperative research efforts with industry.

Power Systems Development Facility (PSDF). The PSDF facility is located at Southern Company Service's Clean Coal Research Center near Wilsonville, Alabama. Participants in this cost-shared RD&D project include METC, Southern Company Services, Foster Wheeler, American Electric Power, M. W. Kellogg, Westinghouse, Southern Research Institute, GM-Allison, Alabama Power Company, Southern Electric International, and EPRI.

In conjunction with METC on-site facilities, the Wilsonville PSDF will be a focal point of DOE's RD&D program in the coming decade. The PSDF will be used to resolve technology barrier issues, systems integration issues, and support product improvements to enhance the environmental performance and cost competitiveness of the IGCC and advanced PFBC technologies. The PSDF will contain five separate modules (see Figure 3): an advanced PFBC; a transport reactor gasifier; several hot-gas particle control devices (PCD); a topping combustor gas turbine; and a fuel cell test skid provided by EPRI. The PSDF modular design maximizes the flexibility of the facility. Testing of various technologies can be conducted in stand-alone and integrated test configurations, providing a flexible test facility that can be used to develop advanced power system components, evaluate advanced power system configurations and product enhancements, and assess the integration and control issues of these advanced power systems.

The advanced gasifier module uses M. W. Kellogg's transport reactor technology (see Figure 4), which was selected for the gas generator due to its flexibility to produce gas and particulate under either pressurized combustion (oxidizing) or gasification (reducing) conditions. The module will provide for parametric testing of the PCDs over a wide range of operating temperatures, gas velocities, and particulate loadings. The transport reactor potentially allows the particle size distribution, solids loading, and characteristics of the particulate in the gas stream to be varied in a number of ways. The transport reactor is sized to process nominally 2 tons/hr of coal to deliver 1,000 actual cubic feet per minute (acfm) of particulate laden gas to the PCD inlet over the temperature range of 1,000 to 1,800°F at 184 to 283 psia. Two PCDs will be tested alternately on the transport reactor. Startup is scheduled for mid-1996.

The transport gasifier is considered an advanced technology that will incorporated into an IGCC system, providing system efficiencies over 50 percent and capital investment cost of less than $1000 kWhr.

The advanced PFBC represents Foster Wheeler's technology for second-generation PFBC. The advanced PFBC system consists of a high-pressure (170 psia), medium temperature (1600-1800°F) carbonizer to generate 1,500 to 1,700 acfm of low-Btu fuel gas. This is followed by a circulating pressurized fluidized-bed combustor (CPFBC), operating at 150 psia, 1600°F, and generating 6,200 acfm combustion gas. Startup of the PFBC module is scheduled for early 1997.

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Particulate laden gas from the carbonizer and the CPFBC will be routed to a separate PCDs to remove particulate prior to entering a topping combustor. Tests of this process will lead to the first commercial demonstrations of a second-generation PFBC under the CCT program.

The PCDs selected for testing at the PSDF are being developed by Westinghouse Electric Corporation of Pittsburgh, Pennsylvania; Industrial Filter and Pump Manufacturing Company (IF&P) of Cicero, Illinois; and Combustion Power Company (CPC) of Menlo Park, California.

<u>Westinghouse Filtration System</u> -- Westinghouse will install a tiered vessel which can be equipped with ceramic candles, cross flow filters or flexible ceramic bag filters for use on the transport reactor. Qualification testing is in progress at Westinghouse to decide which type of filter element for testing at the PSDF.

<u>Combustion Power Company Granular Bed Filter System</u> -- In the CPC granular bed filter, the transport reactor fuel (or flue) gas is introduced into the center of a downward moving bed of 6 mm granules spheres consisting of aluminum oxide and mullite, and serve as the filter media to remove the particles from the gas stream. The particulate-containing media is removed from the bottom of the filter vessel and pneumatically conveyed and cleaned in a lift pipe and separated in a disengagement vessel. The cleaned recycled media is constantly introduced from the top of the vessel.

<u>Industrial Filter and Pump Filter System</u> -- Initial testing of an IF&P filter will be on the PFBC carbonizer. The filters are ceramic candles made of low density aluminosilicate fiber/silica and alumina binder and have densified monolithic end caps and flanges. The tubesheet is made of the same densified material. The 60-inch diameter, refractory-lined filter vessel will contain 78 candles arranged in 6 groups of 13 each for pulse cleaning.

<u>Westinghouse Ceramic Candle Filter System</u> -- A larger Westinghouse system will be tested on the PFBC combustor. This filter will contain six clusters of ceramic candles in a refractory-lined pressure vessel.

An additional role for the PSDF facility will be as a host site for collaborative and cost-shared RD&D partnerships with developers and users of power systems equipment. This RD&D could be conducted through CRADAs or through participation in the existing Southern Company Services consortium. The PSDF provides an excellent opportunity for utilities to obtain hands-on evaluation and operational experience with IGCC and PFBC components and subsystems.

Clean Coal Technology (CCT) Projects

Through cost sharing cooperative efforts with industry, DOE is supporting the large-scale demonstration of key coal-based technologies as a necessary step toward the

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commercialization of advanced power generation and industrial systems. It is anticipated that following successful demonstration, industry will be able to provide commercial offerings of clean coal technologies at competitive market prices. A prominent technology in the DOE CCT program is IGCC.

Commercial offerings of IGCC systems are anticipated to provide several advantages over conventional coal-based power generation systems. These advantages include superior environmental performance, high energy efficiency, low capital cost and cost of electricity, fuel flexibility including the ability to use high-sulfur coals, and modular designs suitable for repowering or greenfield applications. A brief summary of the six IGCC projects in the CCT program follows:

Piñon Pine IGCC Power Project -- The Piñon Pine Power Project is a 99 megawatt electric (MWe) greenfield IGCC facility that is currently being built at Sierra Pacific Power Company's Tracy Power Station near Reno, Nevada. The facility is expected to begin operations in early 1997 to demonstrate an IGCC system utilizing the air-blown KRW ash agglomerating fluidized-bed gasifier; hot-gas cleanup for particulate removal and a desulfurization system (M.W.Kellogg); and a power island that includes the first commercial use of the General Electric MS6001FA gas turbine. The facility will utilize a M.W.Kellogg transport desulfurization process and a Westinghouse filtration system. A process schematic is shown in Figure 5.

Tampa Electric Integrated Gasification Combined Cycle Project -- The Tampa Electric IGCC Project, hosted by Tampa Electric Company, will demonstrate the greenfield application of a 250 MWe IGCC system using a Texaco oxygen-blown entrained-flow gasification technology, using a full-flow cold gas cleanup system and a 25 MWe General Electric hot gas desulfurization and a Pall Company particulate control system equipped with metal filters. The demonstration is expected to begin in the latter half of 1996. It will be in a commercial utility setting and be located at Tampa Electric Company's Polk Power Station near Lakeland, Florida.

Combustion Engineering Repowering Project -- The Combustion Engineering (CE) IGCC Repowering Project is in the process of being resited and restructured.

Clean Power from Integrated Coal/Ore Reduction (CPICOR - COREX®) -- The CPICOR project objective is to demonstrate an industrial process to produce both power and iron based on the COREX® process. Iron ore is charged into a reduction shaft furnace that receives reducing gas from a melter-gasifier located below it. Only a small percentage of the reducing gas from the melter-gasifier is used for ore reduction. Therefore, a significant amount of gas remains for power production in a gas-fired combined-cycle system. The project team has announced a project development agreement with Geneva Steel of Vineyard, Utah. The project is in the final stages of negotiations and if approved by DOE, the plant would be integrated into the existing Geneva mill in Vineyard, Utah.

Clean Energy Demonstration Project -- The Clean Energy Demonstration Project, proposed by Clean Energy Partners Limited Partnership (CEP), will feature an advanced, commercial-scale, 477-MWe IGCC system and a 1.25-MWe coal gas fueled molten carbonate fuel cell (MCFC). CEP consists of Clean Energy Genco, Inc. (an affiliate of Duke Energy Corp.); Makowski Clean Energy Investors, Inc. (an affiliate of J. Makowski Company); British Gas Americas, Inc. (an affiliate of BG Holdings, Inc.); and an affiliate of General Electric Company. Clean Energy Genco, Inc., is the managing general partner of the CEP. The MCFC portion of the project will be executed under a subcontract with Fuel Cell Engineering, a subsidiary of Energy Research Corporation.

The project will demonstrate four objectives: (1) scaleup of the British Gas/Lurgi gasifier to commercial size; (2) integration of major processes and equipment within the IGCC system; (3) operation of a 1.25-MWe MCFC with coal gas; and (4) construction and operation of an advanced coal-fired power plant by an Independent Power Producer under commercial terms and conditions.

Wabash River Coal Gasification Repowering Project -- The Wabash River Coal Gasification Repowering Project is a joint venture of Destec Energy, Inc., and PSI Energy, Inc. (PSI). The objective is to demonstrate the commercial application of an IGCC system to repower one of six existing units at PSI's Wabash River Generating Station in West Terre Haute, Indiana. The coal-fired boiler will be replaced by a gasifier island to convert coal to clean fuel gas. The station's refurbished steam turbine will be arranged in a combined-cycle power island configuration, with the addition of a gas turbine and heat recovery steam generator to generate a combined total of 262 MWe. Operations have been initiated. A process schematic is shown in Figure 6.

IGCC Repowering

For many utilities affected by the 1990 Clean Air Act, a probable resolution to uncontrolled emissions would be to retire older and uncontrolled plants and construct a new power plant. Considering the risks and opportunities emerging in the U.S. utility industry, the high capital cost, possible siting issues and competition from natural gas combined cycle and independent power producers could impact the above conventional approach.

Repowering old plants with IGCC technology in lieu of retirement, refurbishment or construction of new plants may offer the following advantages to the utility: 1) Use of existing site and appropriate facilities; 2) Old plant compliance deadline extension of the 1990 CAA requirements if clean coal technology is used for repowering; 3) Increase in plant generating capacity up to a factor of two to three; 4) Significant heat rate improvements up to 25-pct using existing technology; 5) Use of low-cost high sulfur coal while maintaining very low environmental emissions; 6) Possible valuable by-products (elemental sulfur) and low volume of solid waste requiring disposal; and 7) Reasonable economics.

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At present, METC is managing and participating (with Parsons) in an eight case study of repowering using various gasification concepts. The results of this effort will be presented at the American Power Conference in Chicago, IL, in April, 1996.

One of the in-progress studies of particular interest is the use of an air-blown transport gasifier (see PSDF facility, previously discussed), a transport desulfurizer, ceramic filters and a combustion turbine, HRSG and the utility steam turbine. The projected net heat rate (HHV) is 6854 Btu/kWhr for an overall net efficiency of nearly 50-pct. The impact on emission are presented in the following Table.

Table 2.

	Original Plant	Repowered Plant
Power output	140 MWe	381 MWe
SO_2	4.64	< 0.07
NOx	1.2	0.3
Particulate	0.075	0.004

Emission are expressed as lbs / 10^6BTU

SUMMARY

Based on engineering studies and verification of on-going bench-scale and pilot plant operations, IGCC technology offers tremendous potential benefits over conventional coal-based power generation technologies in terms of efficiency and environmental performance.

In addition to greatly reduced emissions of sulfur dioxide, NO_x, and particulate, efficiency improvements will result in approximately 35 percent lower carbon dioxide emissions. The superior environmental performance of this IGCC coal-based technology and the timing of the demonstration projects should expand the choices available to utilities to meet their future power generation needs while simultaneously complying with Clean Air Act requirements.

Due to the diverse nature and configuration of the IGCC projects in the CCT Demonstration Program, a wide variety of technical and business approaches to advanced power generation projects will be addressed. In addition to achieving the anticipated specific system efficiency, cost and environmental goals identified above, the projects will demonstrate: 1) the applicability of the technology to power generation or cogeneration in repowering and greenfield applications; 2) the use of modular construction for economic increments of capacity to match load growth; 3) fuel flexibility; and 4) the potential for design standardization due to modular construction to reduce engineering, construction time, and permitting complications for subsequent plants.

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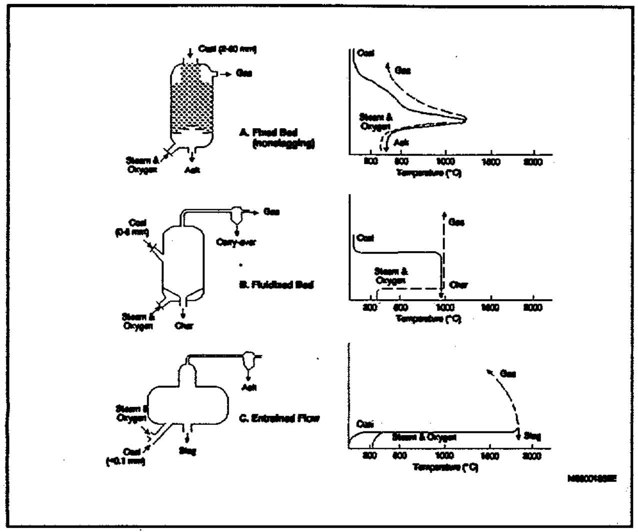

Figure 1. Gasification Concepts

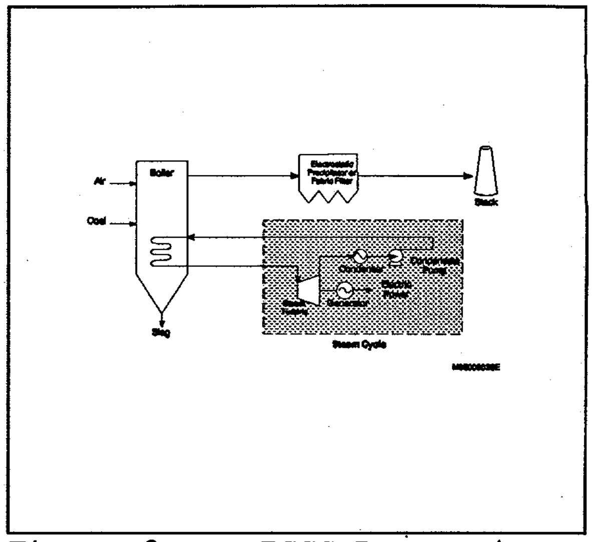

Figure 2. IGCC Repowering Concept

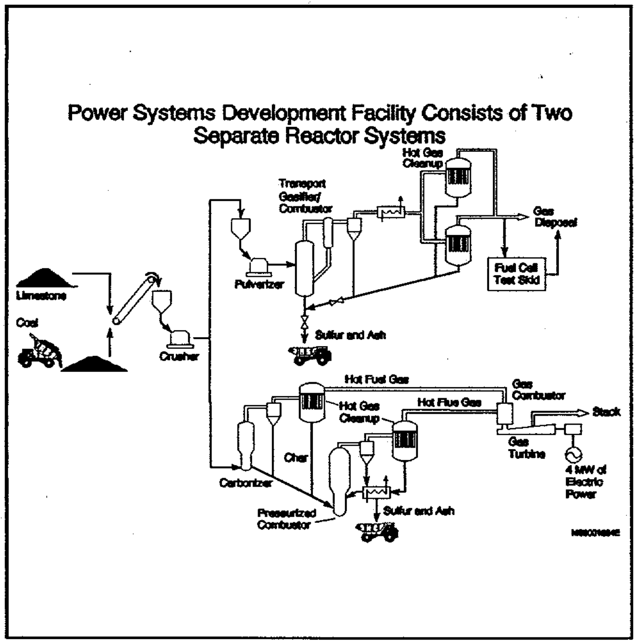

Figure 3. Power System Development Facility

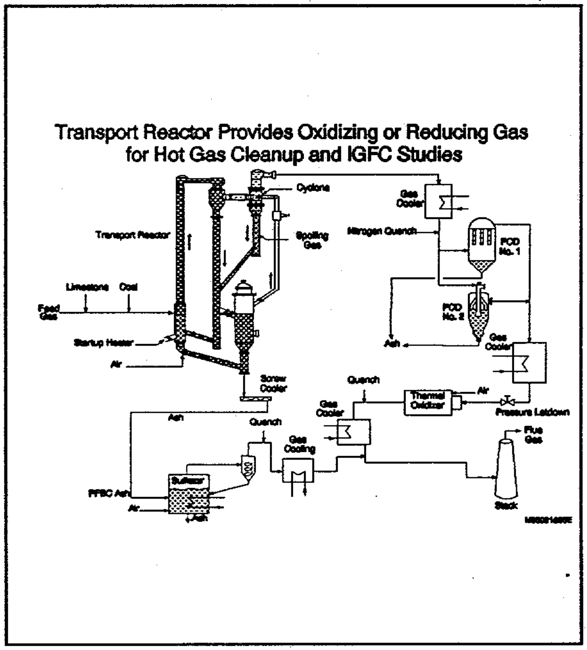

Figure 4. Transport Gasifier

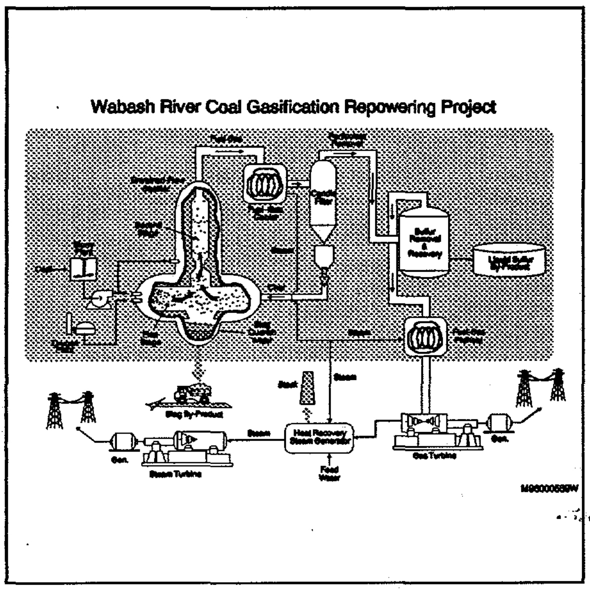

Figure 5. Wabash IGCC System

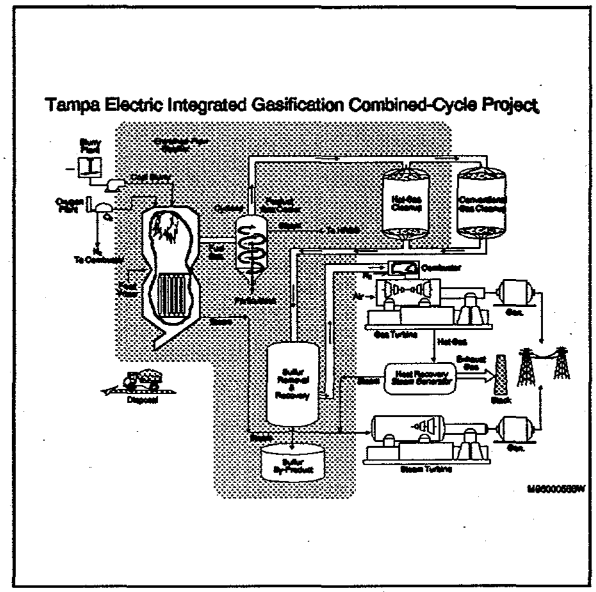

Figure 6. Piñion Pines IGCC Project