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THE U.S. DEPARTMENT OF ENERGY'S INTEGRATED GASIFICATION COMBINED CYCLE RESEARCH, DEVELOPMENT AND DEMONSTRATION PROGRAM

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INTRODUCTION

Historically, coal has played a major role as a fuel source for power generation both domestically and abroad. Despite increasingly stringent environmental constraints and affordable natural gas, coal will remain one of our primary fuels for producing electricity. This is due to its abundance throughout the world, low price, ease of transport and export, decreasing capital cost for coal-based systems, and the need to maintain fuel diversity. Recognizing the role coal will continue to play, the U.S. Department of Energy (DOE) is working in partnership with industry to develop ways to use this abundant fuel resource in a manner that is more economical, more efficient and environmentally superior to conventional means to burn coal. The most promising of these technologies is integrated gasification combined cycle (IGCC) systems.

In an IGCC system, coal is converted to a gas, cleaned of particulate and other contaminants and used to fuel a combined cycle power generation system (Figure 1). The advantages of IGCC systems are well known and won't be recounted in this paper. A brief summary of these advantages are shown in the accompanying table.

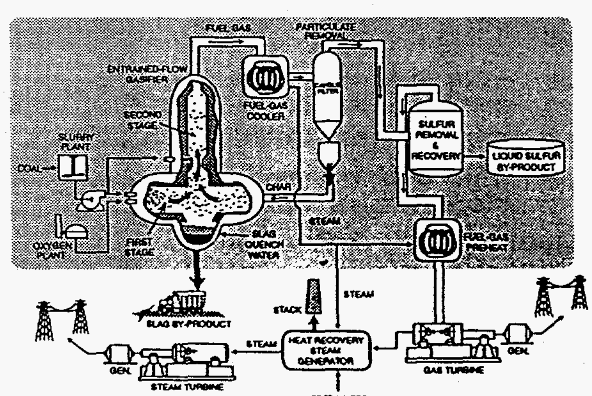

Figure 1 Typical IGCC System

Although IGCC systems offer many advantages, there are still several hurdles that must be overcome before the technology achieves widespread commercial acceptance. The major hurdles to commercialization include reducing capital and operating costs, reducing technical risk, demonstrating environmental and technical performance at commercial scale, and demonstrating system reliability and operability. Overcoming these hurdles, as well as continued progress in improving system efficiency, are the goals of the DOE IGCC research, development and demonstration (RD&D) program. This paper provides an overview of this integrated RD&D program and describes fundamental areas of technology development, key research projects and their related demonstration scale activities.

IGCC Advantages
High Efficiency
Fuel Flexibility
Applicable to Repowering, Greenfield and Cogen
Modular Designs
Low SO_2 and NO_x Emissions
Low CO_2 Emissions
Low Water Consumption
Marketable By-Products
Co-Product Options
Reusable Sorbents
Phased Construction
Multiple System Vendors
Wide Size Range of Plants
Employs Latest Gas Turbine Technology

Eliminating these hurdles will be accomplished through a two pronged approach. The first facet of the program focuses on joint research and development with technology and subsystem suppliers to address key technical and performance barriers on a component and subsystem level. This joint industry/government research will facilitate component and subsystems development and contribute to reduced IGCC system cost and risk. This portion of the program also leads the development of the next generation of IGCC systems.

The second facet of the program is the commercial scale demonstration of complete IGCC systems based on today's level of technology development. In cooperation with utilities, independent power producers and technology vendors, the Clean Coal Technology Program provides the real world cost and performance data necessary to overcome the initial barriers to market entry. The demonstration program, supported by ongoing research and development, plays a pivotal role in establishing the current level of technology performance and identifying the needs of tomorrow's IGCC systems from an end user perspective.

Tying these two facets of the program together is on ongoing technology transfer and outreach program. Through technology transfer and outreach, results of the RD&D program are disseminated and feedback from key stakeholders is obtained. This feedback plays an important role in program planning and is used to guide RD&D activities to address the primary issues of the technology developers, end users, and other stakeholders. IGCC RD&D program planning and outreach is also coordinated with other technology research and development (R&D) areas where there are strong program and technical synergies such as the Advanced Turbine Systems program.

COMPONENT AND SUBSYSTEM RESEARCH AND DEVELOPMENT

Through the use of process simulations and economic analyses, the potential for technology advancements are identified and evaluated. These analyses have identified several areas to be pursued for reducing system complexity and cost, and improving cycle efficiency and environmental performance. As a result of this work, current IGCC research and development is focused in four primary areas. These areas are gas desulfurization and contaminant control, gas particulate removal, advanced gasifier systems and advanced gas turbines.

Current efforts on gas desulfurization and particulate removal are designed to address both near term and long term issues. The near term focus are activities that are closely coupled to the Clean Coal Technology demonstration projects and their successful operation. Longer term efforts in desulfurization and particulate removal are designed to enhance system performance and operability while reducing overall system costs. The results of this research will be embodied in the commercial IGCC system offerings that are approximately 45 percent efficient at a cost competitive with other coal based power generation options.

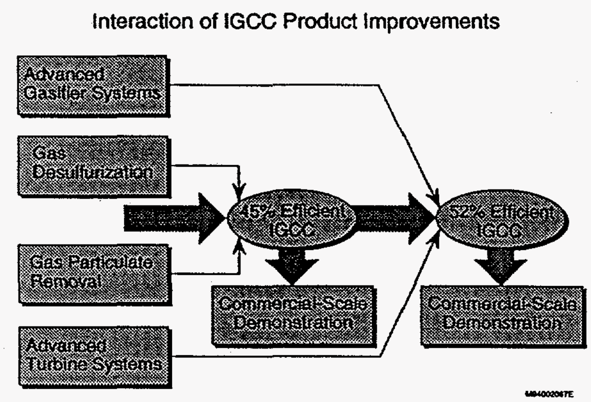

Figure 2 IGCC RD&D Focus

Accompanying this research are DOE-sponsored advances in gasification technology and advanced gas turbines. In conjunction with hot gas desulfurization and particulate removal, these efforts will allow IGCC systems to reach their commercial potential of 52 percent efficiency at less than $1,000/kilowatt (Figure 3). The major R&D activities in each these four areas are described below.

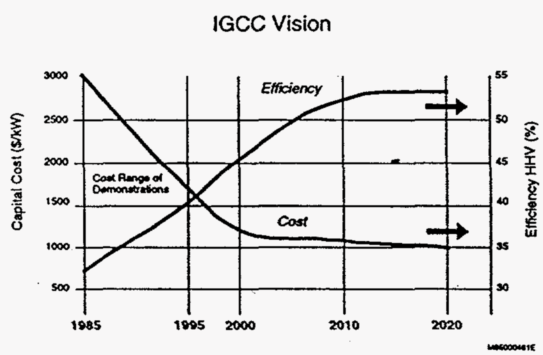

Figure 3 IGCC Goals

Hot Gas Desulfurization and Contaminant Removal

Desulfurization Systems. Numerous studies have indicated that hot gas desulfurization systems offer a two to three percentage point improvement in IGCC system efficiency with potentially lower capital cost. As a result of this significant potential for improvement, DOE has been pursuing several hot gas desulfurization concepts. The three concepts under development include moving and fluidized beds and transport regime desulfurizers.

The development of moving bed desulfurization is being conducted in cooperation with General Electric Environmental Systems Inc. (GEESI) at their corporate research center in Schenectady, New York. This R&D activity directly supports the Tampa Electric Integrated Gasification Combined Cycle Project discussed later in this paper.

The system, shown in Figure 4, employs a slowly moving counterflow bed of mixed metal oxide sorbent to remove hydrogen sulfide from the product gas produced from a 3 Megawatt electric (MWe) equivalent fixed bed gasifier. Desulfurization occurs at pressures of up to 20 atmospheres and at a nominal temperature of 1,000 °F.

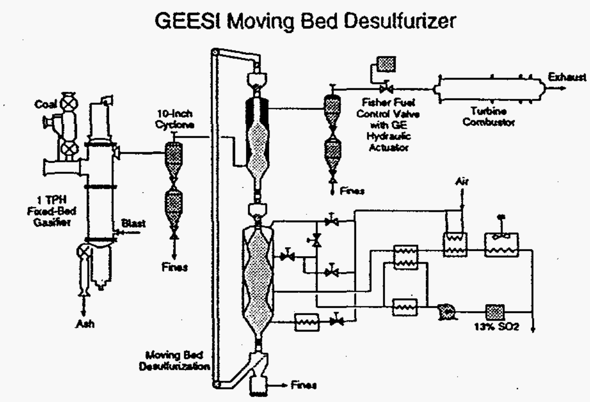

Figure 4 GEESI Facility

Regeneration is accomplished at 10 atmospheres and in temperatures of 1,000-1,400 °F. During regeneration, sulfur dioxide is liberated and offgas is recirculated to build the sulfur concentration to levels suitable for recovery in a commercially available sulfuric acid plant.

A circulating fluidized bed is located upstream of the absorber to protect the metal-based sorbents and downstream equipment from chloride attack. Tests employing the chloride removal system have achieved 95 percent removal using number 2 food-grade sodium bicarbonate as a sorbent. A nacholite-based spray dried formulation is currently being tested as a more economical alternative to food-grade sodium bicarbonate. The new formulation will hopefully achieve higher rates of utilization (greater than 50 percent).

To date, the system has demonstrated high levels of sulfur removal with hydrogen sulfide emissions consistently below 50 parts per million. System operability and performance are well characterized and understood. Current efforts are focused on characterizing the sulfur capture performance and attrition resistance of newly developed sorbents. The results of these tests are critical to the sorbent selection and successful operation of the Tampa Electric IGCC Project due to begin operation later this year.

In addition to moving bed systems, fluidized bed and transport desulfurization concepts are being investigated since they offer several potential advantages. The most significant of these advantages are high throughput and small sorbent inventory requirements. High throughput systems translate to low capital cost while small sorbent inventory requirements mean low operating costs. A Process Development Unit (PDU) capable of operating in both fluidized bed and transport mode is currently being built at DOE's Morgantown Energy Technology Center (METC) in Morgantown, West Virginia.

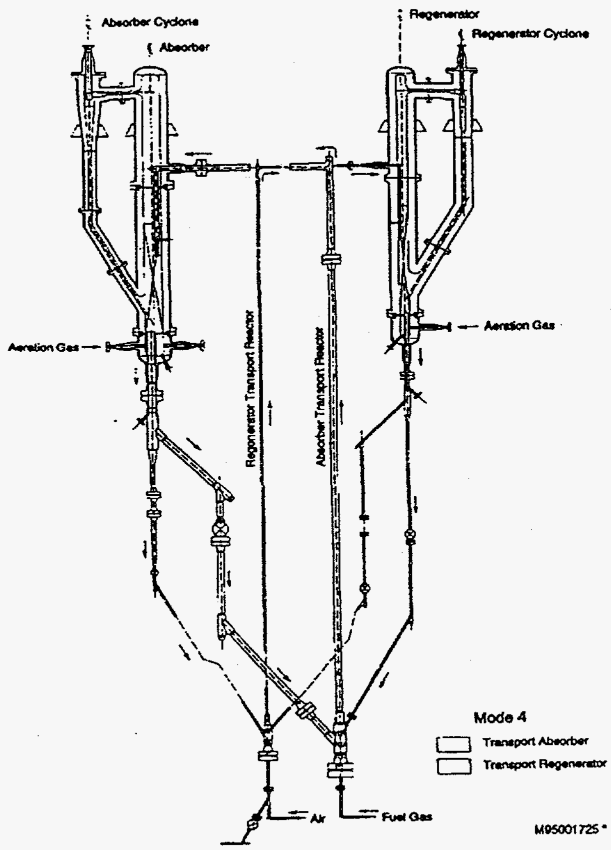

Figure 5 METC PDU

The PDU, shown in Figure 5, is designed to be highly flexible and can be operated in four different modes. Each mode is a pairing of fluidized bed or transport absorption with fluidized bed or transport regeneration. The unit can handle up to 150,000 standard cubic feet per hour of synthesis gas (24 tons per day coal equivalent) at an operating pressure of 400 pounds per square inch. The unit will operate at 800-1,200 °F during sulfidation and 1,400 °F during regeneration.

The PDU is scheduled to begin operation in October 1997 when it will evaluate several hot gas desulfurization sorbents currently under development. The PDU will also serve as sorbent screening tool and provide operational support for the Piñon Pine IGCC Power Project discussed later in this paper.

Desulfurization Sorbents. In addition to developing desulfurization reactor concepts, the IGCC RD&D program is also actively pursuing the development and testing of mixed metal oxide sorbents for these systems. The goal is to have commercially available regenerable sorbents that are cost effective, have and maintain a high level of sulfur capture reactivity and are highly attrition resistant.

Several sorbent developers are actively involved in the program in addition to METC's own in-house research staff. One of the early potential successes from the program is a METC developed sorbent identified as METC-10. This sorbent was formulated specifically for the GEESI moving bed desulfurization system described above. Bench-scale testing of METC-10 has shown high sulfur capacity and excellent attrition resistance. Because of the excellent performance demonstrated to date, the sorbent is currently undergoing pilot-scale testing at the GEESI facility. If the pilot facility run is successful, METC-10 will be a strong candidate for use in the hot gas desulfurization system in the Tampa Electric IGCC Project.

Another source of sorbents for moving bed desulfurizers are those under development by Phillips Petroleum Catalyst Development Center. Phillips has a rich history of sorbent development for process applications similar to IGCC desulfurization. One class of sorbents, denoted Z-Sorb, is currently being evaluated in the program. An existing formulation of Z-Sorb will be used as the initial sorbent in the Tampa Electric IGCC Project. Other formulations of Z-Sorb are also under development. These new formulations are designed to maximize sorbent performance specific to IGCC process conditions. A promising candidate is currently undergoing bench-scale evaluation. If successful, plans call for a pilot-scale test at the GEESI facility later this year.

In addition to sorbents for moving bed systems, several sorbents are under development for fluidized bed and transport desulfurizer applications. Building on their moving bed sorbent successes, METC in-house researchers are working to develop formulations to address the requirements of fluidized bed and transport desulfurizers. These formulations are currently in the early stages of development and there are no testing results to report at this time.

Research Triangle Institute (RTI) has also been working to develop highly reactive regenerable sorbents and fabrication methods applicable to fluidized bed and transport desulfurizers. Achievements include the development of a 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 fluidized bed desulfurization unit at the Messukyla Research and Development Center in Tampere, Finland. The sorbent reactivity was excellent, resulting in less than 20 parts per million hydrogen sulfide in the fuel gas.

In addition to the above activity, RTI teamed with Contract Materials Processing to manufacture a spray dried formulation denoted as CMP-5 and CMP-7. The sorbent was tested by M. W. Kellogg of Houston, Texas in a bench-scale Transport Reactor Test Unit in support of the full-scale transport desulfurizer incorporated into the Piñon Pine IGCC Power Project described later in this paper. The sorbents are candidates for future use in the full scale desulfurizer. The first commercially available sorbent for the Piñon Pine IGCC Project is Z-Sorb by Phillips Petroleum Catalyst Development Center. This sorbent was selected for the Piñon Pine IGCC Project based on successful testing in M. W. Kellogg's bench-scale transport desulfurizer.

The sorbents currently nearing commercial availability are designed for use in reducing environments at gas temperatures of 950-1,100 °F. IGCC system studies have shown that system efficiencies decrease by only one percentage point when hot gas clean-up systems operate in the temperature range of 650-950 °F. Operation at lower temperatures may reduce the system capital cost due to more economical materials of construction, refractory and insulation requirements. In addition, lower ceramic filter operating temperatures may result in increased filter reliability and lower filter capital and operating costs. As a result of these studies, a long-term program objective is to develop a desulfurization sorbent that will effectively capture hydrogen sulfide in a temperature regime of 650-900 °F. Recent efforts to investigate such moderate temperature sorbents have been promising.

Chloride Removal. Due to its deleterious effect on mixed metal oxide sorbents and other downstream equipment, efforts are underway to investigate cost effective means for removing chlorides from coal gas. SRI International, teaming with RTI and General Electric's Corporate Research and Development, are developing disposable, sodium-based sorbents for removing hydrogen chloride vapor from coal gas. Initially, the research was driven by the need to meet the fuel specification for molten carbonate fuel cells of one part per million of chlorides. However, with the need for a chloride removal system identified for the GEESI moving bed desulfurization system, the chloride removal research has developed a wider focus and base of application.

The most promising sorbent developed to date is a nacholite-based, spray-dried formulation termed NS-02 for fluidized bed and transport reactors. In bench-scale testing at RTI, NS-02 has achieved capacities of 38 weight-percent chloride for a one part per million breakthrough at 1,000 °F. This capacity is approximately three times that of the food grade number 2 sodium bicarbonate used in previous testing at the GEESI pilot facility. Results from pilot-scale testing of a small batch of NS-02 last fall indicate the chloride removal efficiency was greater than 97% and the extent of the sodium utilization exceeded 55% (corresponding to a capacity of 35 weight-percent chloride).

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. The results from each will be compared based on their respective performance data as well as post-test characterization and economic analyses.

<u>Ammonia Control</u>. Another undesirable constituent in coal gas is ammonia. Its presence in the turbine fuel gas can significantly contribute to system NO_x emissions. A project awarded to RTI was tasked to develop and test gas desulfurization mixed-metal oxide sorbent/catalyst combinations to concurrently remove hydrogen sulfide and decompose fuel-bound nitrogen compounds (chiefly ammonia) at hot gas desulfurization operating temperatures. This effort was recently refocused. The simultaneous approach was abandoned and high-temperature catalyst screening addressing only ammonia reduction was initiated. RTI is gathering parametric data on several catalyst formulations which are known to perform well under a "clean" laboratory environment, but may deactivate in the presence of certain coal-gas impurities and 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 of nitrogen based compounds ranged from 80 to 95 percent during the 120 hour test.

Energy and Environmental Technology Corporation (EETC) was also awarded a contract to develop an approach to ammonia decomposition. EETC is developing a high-temperature, high-pressure process to reduce the ammonia present in fuel gas injecting a chemical reagent. The process conditions of interest are temperatures of 1,000-2,000 °F and pressures up to 500 pounds per square inch. The process has the potential to reduce ammonia to less than one part per million.

Preliminary results from bench-scale tests have shown 70 to 99 percent removal at 1,700 °F. Following some planned apparatus modifications, additional testing will provide additional data to validate the concept. The concept is attractive since additional vessels would not need to be added to the system. Such an approach could potentially result in very low NOx emissions without the capital expense of additional vessels and their associated piping and valves.

Hazardous Air Pollutants. An area of considerable concern for coal based power generation systems is the potential regulation of hazardous air pollutants (HAPs). Although the substance of any future HAPs regulation would be pure speculation, it appears likely that at least mercury may be subject to some form of control. In an effort to provide a sound scientific basis for assessment, DOE has been pursuing the identification and quantification of HAPs emissions from advanced power generation systems. Trace elements emissions monitoring indicates that emissions can vary by 3-4 orders of magnitude and measurements from day-to-day can vary by an order of magnitude. Such variability is due to process conditions (such as coal) as well as sampling and analytical variability. Trace emissions are divided into 2 subgroups relative to their volatility.

1. Particulate phase metals - Metals which partition to the solid phase and effectively controlled by particulate control devices. These include As, Cd, Ni, and Pb.

2. Volatile inorganics - These are volatile at stack gas conditions and are not consistently controlled by conventional (~300°F) particulate control device. These include Hg, Cl, and Se.

DOE has conducted air toxic measurements at Destec Energy's Louisiana Gasification Technology, Inc. (LGTI) 160 MWe IGCC power plant. This plant produced medium-Btu syngas from an oxygen-blown, slagging gasifier for use in two gas turbines. Conventional low-temperature clean-up processes were used for contaminant control from the syngas. The slag captured the major elements (Fe, Al, Ca) as well as the particulate phase metals (As, Cr, Ni) and the Hg and Cl volatile inorganics were captured in low levels. Results from the LGTI plant are not expected to be completely representative of all IGCC's. DOE is planning continued monitoring of the "state-of-the-art" IGCC's that are part of the Clean Coal Technology program. It has been shown that the more effective the particulate removal devices, the better the particulate phase metal removal efficiency. The volatile inorganics are not usually captured. It is apparent from studies by DOE and EPRI that mercury control is not completely understood and will require additional research. Studies of various advanced power systems have shown from field measurements that air toxics emissions are generally low and are in the parts-per-billion levels. Removal efficiencies of the particulate phase metals are consistently greater than 90%. Removals of volatile inorganics (Hg, Se, Cl) are more variable and generally less efficient. In comparison to conventional power systems, HAPs emissions from advanced systems appear to be lower that the trigger level of the 1990 CAAA, which requires maximum achievable control technologies.

High-Temperature, High-Pressure Particulate Control

Filter Systems. One area where IGCC systems have a potential performance advantage over other advanced concepts is in the area of particulate removal. Since particulate removal typically occurs at 1,000 °F or less, the significant problems associated with higher temperature filtration systems are avoided. Although gas conditions and particle morphology are different, IGCC systems have benefitted from the considerable progress made in developing high temperature filtration systems for pressurized fluidized bed combustion (PFBC). Much of the filter system design information and ceramic filter material development work can be applied to IGCC systems.

The filtration system design demonstrated at American Electric Power Service Corporation's Tidd Station was provided by Westinghouse Electric Corporation. The system utilized a three-cluster filter element system, incorporating 384, 1.5-meter long silicon carbide candle filters. At the conclusion of the program, 5,854 hours of on-line filtration time had been accumulated under PFBC conditions.

Additional filter testing was conducted under PFBC conditions at Ahlstrom/Pyropower to evaluate mullite and other silicon carbide candle filters and to ascertain the effects of different coals on filter system performance. Total on-line filtration time on this PFBC is 2,046 hours.

Based on this work, several significant conclusions were derived for the Westinghouse design that are relevant to IGCC filter subsystems: 1) the system has demonstrated the ability to clean large groups of filters from a single remote high pressure pulse gas source; 2) the 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 system is a viable concept to provide particulate control for IGCC systems. Based on this operational data and the existing body of knowledge concerning filter element exposure under gasification conditions, the Westinghouse filter system was selected for installation at the Piñon Pine IGCC Power Project.

Filter Element Development. In addition to developing and demonstrating effective filter system designs, IGCC R&D efforts are also focused on developing filter elements that can perform satisfactorily in gasification environments. To address this need, five projects were 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 and provide sufficient resistance to chemical attack. The first of these is an alumina based continuous fiber ceramic composite (CFCC) material incorporating a chopped fiber matrix into a filament wound continuous fiber structure. This element is being developed by Babcock and Wilcox and employs 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. Corrosion testing was performed on four distinct compositions in a coal fired utility scale boiler. 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.

The second approach is known as 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. Improvements have been made to the PRD-66 filter under this program including strengthening of the flange and improvements to the filtration membrane. 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.

The third approach 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. Pall Aeropower is conducting sintering trials to optimize the pore structure of the iron aluminide filter media. Laboratory scale corrosion tests to determine the effect of process parameters on corrosion are underway and long term corrosion testing is scheduled to be performed later in the project.

In a separate effort, the durability of a stainless steel (SS310) metal filter was recently demonstrated by Pall and GEESI on a slipstream of fuel gas at the Dakota Gasification Plant in Beulah, North Dakota. Based on the results of this successful operation, these stainless steel filter elements were selected for installation at the Tampa Electric IGCC Project. The iron aluminide filter is anticipated to be even more tolerant to fuel gas streams than SS310 elements.

Textron Specialty Materials 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 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, 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 to 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 to form 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 of 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.

Filter Element/System Testing. In support of these filter element development efforts, METC constructed and operated Modular Gas Cleanup Rig (MGCR). The MGCR is a filtration vessel that receives particulate laden gas from an on-site fluidized bed gasifier. This unit has been used in cooperative studies with industry partners and has proved to be an excellent tool to conduct filter screening and exposure testing. The results from operation of this unit have provided valuable information to filter element and gasification system developers.

A larger facility designed to address particulate filtration system development is currently being built at Southern Company Service's Clean Coal Research Center near Wilsonville, Alabama. The Power Systems Development Facility (PSDF) is a joint industry/government partnership that includes Southern Company Services, Foster Wheeler, American Electric Power, M. W. Kellogg, Westinghouse, Southern Research Institute, GM-Allison, Alabama Power Company, Southern Electric International, the Electric Power Research Institute (EPRI), and METC.

In conjunction with METC on-site facilities, the PSDF will be a focal point of DOE's RD&D program in the coming decade. The facility 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. As shown in Figure 6, the PSDF will contain five separate modules: an advanced PFBC; a transport reactor gasifier; several hot-gas particle control devices; 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

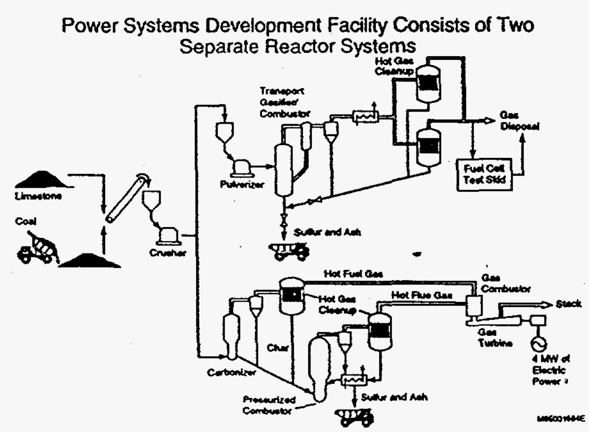

Figure 6 PSDF

and product enhancements, and assess the integration and control issues of these advanced power systems.

The filter element/system development needs of IGCC systems will addressed by the Transport Reactor train of the PSDF as shown in Figure 7. The advanced gasifier module uses M. W. Kellogg's transport reactor technology, 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 be used for parametric testing of the particulate control devices 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 unit is sized to process nominally 2 tons per hour of coal to deliver 1,000 actual cubic feet per minute of particulate laden gas to the filter system inlet over the temperature range of 1,000-1,800 °F at 184 to 283 pounds per square inch. Two particulate control devices will be tested alternately on the transport reactor. Startup is scheduled for mid-1996.

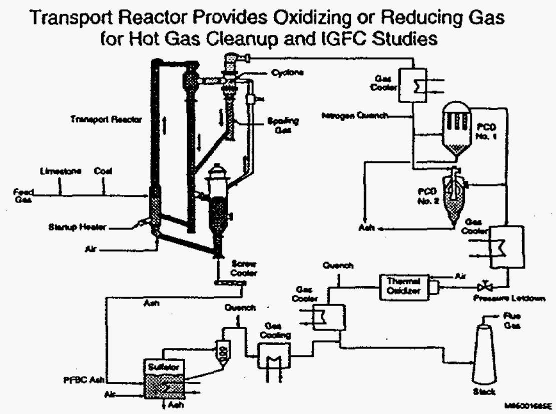

Figure 7 PSDF - Transport

Filter element and system testing are the prime objective of the PSDF. However, because of the need to generate particulate under real gasification conditions, the facility also provides an opportunity to operate an advanced gasification concept such as the transport reactor. The transport reactor represents the current embodiment of the IGCC RD&D program's advanced gasifier development effort. This type of advanced gasifier will play a role in reaching the product goals previously discussed of 52 percent efficiency at less than $1,000/kilowatt.

The particulate control devices selected for testing at the PSDF were 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. Each of these systems is briefly discussed below.

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 identify each type of filter element for testing at the PSDF.

In the CPC granular bed filter, the transport reactor fuel gas is introduced into the center of a downward moving bed of 6 mm granules spheres consisting of aluminum oxide and mullite. These spheres 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 continually introduced into the top of the vessel.

Initial testing of an IF&P filter will be on the PFBC carbonizer which produces conditions very similar to gasification conditions. 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.

Advanced Turbine Systems

One of the major advantages of IGCC systems is the ability to utilize the continuing improvements being made in gas turbine technology. The abundance and current affordability of natural gas have created a large demand for gas turbine based power generation systems. DOE has been working with industry to continually improve the current state of gas turbine technology and develop the next generation of gas turbines.

Combustor testing on low-Btu gas and the effect of impurities in the fuel gas on hot gas path deposition and corrosion are being evaluated. Development efforts to further reduce NO_x emissions from fuel bound nitrogen have demonstrated the ability to reach very low emission levels.

One of the most significant impacts on the potential for IGCC systems will come as a result of developments under the Advanced Turbine System (ATS) Program. The objective of the program is to demonstrate a natural gas fueled gas turbine capable of 60 percent efficiency (lower heating value) in a combined cycle configuration while simultaneously achieving: 1) a 10 percent reduction in NO_x emissions compared to today's commercially available system; and 2) a 10 percent reduction in the cost of electricity. These advanced turbines will be readily adaptable to IGCC configurations and will play a major role in achieving the ultimate cost and performance goals of IGCC systems.

CLEAN COAL TECHNOLOGY DEMONSTRATION PROJECTS

The key to overcoming the obstacles to market entry for any power generation technology is a successful technology demonstration at a scale that is sufficiently representative of commercial offerings. That is one of the primary benefits of the Clean Coal Technology Program. By building and operating these IGCC projects in a commercial setting, the potential end users of the technology can evaluate its potential for their own use based on real operating data and as-built cost information. The potential for IGCC system is tremendous and is reflected in the level of industry investment in the demonstration projects. The projects described below are valued at over $3 billion. Of this amount, DOE's industrial partners are supplying $2.2 billion or 70 percent of the project costs. The DOE investment in these projects has played a critical role in mitigating the financial risk associated with commercial scale demonstrations. As a result of these demonstrations, the industrial participants in the program will be well positioned to provide competitive commercial offerings of IGCC systems to the world power generation market.

Due to the diverse nature and configuration of the IGCC demonstration projects, a wide variety of technical and business approaches to advanced power generation projects will be addressed. In addition to demonstrating system efficiency, cost and environmental goals, the projects will demonstrate: 1) the applicability of the technology to power generation 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.

Wabash River Coal Gasification Repowering Project. The Wabash River Coal Gasification Repowering Project is repowering of one of six existing units at PSI Energy's Wabash River Generating Station in West Terre Haute, Indiana. The 262 MWe project is a joint venture of Destec Energy, Inc., and PSI Energy, Inc. The objective is to demonstrate utility repowering with Destec's two-stage, oxygen-blown gasification system (shown in Figure 1) and to assess the long term reliability, availability, and maintainability of the system at a fully commercial scale. The project began commercial operation in November 1995 and is the world's largest operating IGCC plant. In this project, 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. Since beginning operation, the gasification system has achieved 100 percent capacity and full load on the gas turbine (192 MWe) has been demonstrated.

<u>Piñon Pine IGCC Power Project</u>. The Piñon Pine Power Project is a 99 MWe greenfield IGCC facility that is currently being built at Sierra Pacific Power Company's Tracy Power Station near Reno, Nevada. The facility, depicted in Figure 7, is expected to begin commercial operation in early 1997 to demonstrate an IGCC system utilizing the air-blown Kellogg-Rust-Westinghouse ash agglomerating fluidized-bed gasifier, hot-gas particulate removal and desulfurization system, 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.

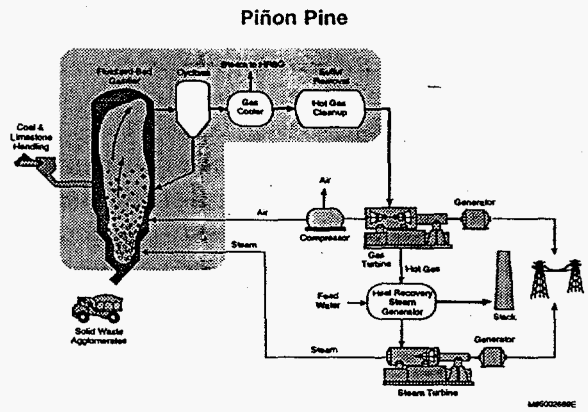

Figure 8 Piñon Pine

<u>Tampa Electric Integrated Gasification Combined Cycle Project</u>. The Tampa Electric IGCC Project, shown in Figure 8, is hosted by Tampa Electric Company and will demonstrate the greenfield application of a 250 MWe IGCC system using a Texaco oxygen-blown entrained-flow gasification technology. The system will employ a full-flow cold gas cleanup system and a 25 MWe equivalent GEESI hot gas desulfurization and a Pall Company particulate control system equipped with metal filters. The demonstration is expected to begin in October 1996. The system will operate in a commercial utility setting at Tampa Electric Company's Polk Power Station near Lakeland, Florida.

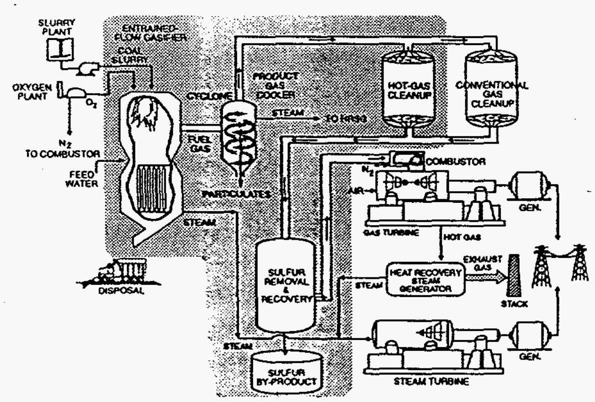

Figure 9 Tampa IGCC Project

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

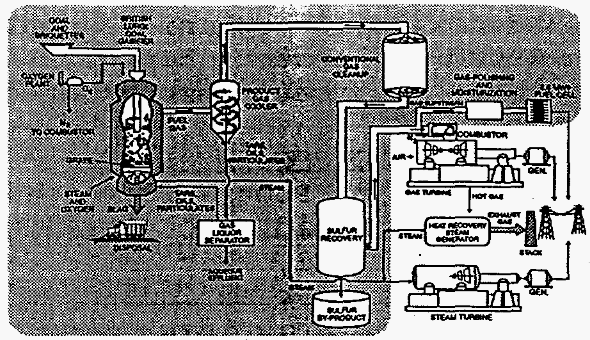

Figure 10 Clean Energy Project

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. The MCFC portion of the project will be executed under a subcontract with Fuel Cell Engineering, a subsidiary of Energy Research Corporation.

The project, shown in Figure 9, will utilize the British Gas/Lurgi gasification system. The project objective is to demonstrate the integration of major processes and equipment within the IGCC system, operation of a 1.25 MWe MCFC using coal gas, and construction and operation of an advanced coal-fired power plant by an Independent Power Producer under commercial terms and conditions. The recently awarded project is currently pursuing project definition activities and working to finalize key project agreements before beginning detailed design.

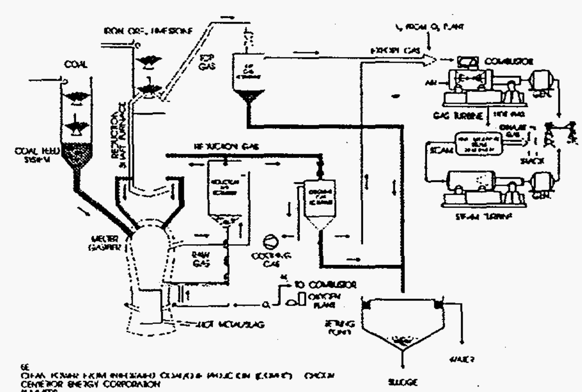

Figure 11 CPICOR Project

Clean Power from Integrated Coal/Ore Reduction (CPICOR). The CPICOR project objective is to demonstrate an industrial process to produce both power and iron based on the COREX® process. As shown in Figure 10, 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. In this configuration, the facility will produce 3,300 tons per day of hot metal (liquid iron) and 195 MWe.

The project team consists of Centerior Energy Corporation, Geneva Steel Company, Air Products and Chemical, Inc. And Deutsche Voest-Alpine Industrieanlagenbau GmbH. This project is in the final stages of negotiations and if approved by DOE, the plant would be integrated into Geneva Steel's existing facilities in Vineyard, Utah.

SUMMARY

Although the potential of IGCC systems has been known for some time, there has now been significant progress toward realizing this potential. Through the successful demonstration of today's technology under the Clean Coal Tecnology program, IGCC systems are beginning to enter the commercial marketplace. Ongoing R&D is also making significant strides in addressing key issues for today's systems as well as identifying and developing improvements for tomorrow's IGCC systems. Through joint industry and government research and development, the U.S. is clearly leading the development of advanced power generation systems particularly those that make the most efficient, cost effective, and environmentally superior use of coal.

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