CONF-9410396--1

DOE/METC/C-95/7193

Integrated Gasification Combined-Cycle Research Development and Demonstration Activities in the U.S.

Authors:
Harvey M. Ness

Conference Title:
10th Korea-U.S. Joint Workshop on Coal Utilization Technology

Conference Location:
Taejeon, Korea

Conference Dates:
October 18-19, 1994

Conference Sponsor:

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

Harvey M. Ness
Morgantown Energy Technology Center
U. S. Department of Energy
P. O. Box 880
Morgantown, WV 26507-0880

Abstract

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

Introduction

In the United States, fossil fuels have been meeting the need for reliable, low-cost energy. At present, coal continues as an energy mainstay, supplying more than 56 percent of the nation's electricity. Through the Department of Energy's (DOE's) Clean Coal Technology (CCT) Program and 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 while meeting existing and more stringent emerging environmental quality requirements.

An Integrated Gasification Combined Cycle (IGCC) system would replace the traditional coal combustor with a gasifier and gas turbine. The primary advantages of IGCC systems are high system efficiencies, obtained with their combined-cycle configuration, and ultra-low pollution levels. In an IGCC, sulfur and particulate from the coal are removed before the gas is burned in the gas turbine; nitrogen oxide (NO_x) is dealt with in conventional fashion in the combustor.

Clean Coal Technology Projects

Through cooperative efforts with industry, DOE is involved in the large-scale demonstration of key coal-based technologies as a necessary step toward the 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, including 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 seven IGCC projects (see Figure 1) in the CCT program follows:

Piñon Pine IGCC Power Project -- The Piñon Pine Power Project is a 95 megawatt electric (MWe) (net) IGCC facility to be built at Sierra Pacific Power Company's Tracy Power Station near Reno, Nevada. The facility will demonstrate an IGCC system utilizing the air-blown KRW agglomerating ash fluidized-bed gasifier; hot-gas cleanup for particulate removal and desulfurization; and a power island that includes the first commercial use of the General Electric MS6001FA gas turbine.

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 based on the Texaco oxygen-blown entrained-flow gasification technology. The demonstration will be in a commercial utility setting, comprising the first unit to be built at Tampa Electric Company's Polk Power Station near Lakeland, Florida.

Combustion Engineering Repowering Project -- The Combustion Engineering (CE) Repowering Project will utilize 600 tons/day of Illinois coal to produce a nominal 65 MWe of electricity from an IGCC system. The IGCC system is based on the CE dry-feed, air-blown entrained-flow pressurized gasifier and a moving-bed hot-gas cleanup system. The project objective is to demonstrate the commercial repowering of an existing unit at City Water, Light and Power's Lakeside Station in Springfield, Illinois.

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. In the COREX® process developed by Deutsche Voest-Alpine Industrieanlagenbau GmbH, iron oxide ore is charged into a reduction shaft furnace. The furnace also receives reducing gas from a melter-gasifier located below it. The melter-gasifier is charged with coal and oxygen, which react to produce the reducing gas and also provide sufficient heat to melt the iron produced in the reduction furnace. In the furnace, the iron oxide ore reacts with the reducing gas to produce direct-reduced iron. The degree of metallization or conversion from iron oxide to iron is above 90 percent. The iron then leaves the reduction furnace and is heated to a molten state in the high-temperature zone of the melter-gasifier. 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. If approved by DOE, the plant would be integrated into the existing Geneva mill in Vineyard, Utah, and use 2,920 tons/day of coal and 4,840 tons/day of iron ore to produce 150 MWe of power and 3,200 tons/day of hot metal.

Toms Creek IGCC Demonstration Project -- The Toms Creek IGCC Demonstration Project is being undertaken by TAMCO Power Partners, a partnership between TP (TAMCO) Company (a subsidiary of Tampella Power Corporation) and CP (TAMCO) Company (a subsidiary of Coastal Power Production Company). As originally conceived, the project will be a greenfield facility located in Coeburn, Virginia, at the Virginia Iron, Coal and Coke Company's Toms Creek Mine. The project will demonstrate a 55-MWe IGCC system based on the Tampella U-Gas® fluidized-bed gasification technology, high-temperature particulate control, and fluid-bed desulfurization using mixed metal oxides.

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) scale-up 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 (net).

IGCC Enabling Technology

Advanced gas turbines are a key enabling technology for the IGCC power generation systems, and the foundation for efficiencies in the range of 52 to 55 percent. DOE is funding the development of advanced gas turbines in the newly instituted Advanced Turbine Systems (ATS) Program. The turbines, which will have natural gas efficiencies of 60 percent, are being evaluated for coal gas compatibility as part of that program.

The ATS is one of DOE's highest priority natural gas initiatives. Ultimately, the program, which could invest more than $700 million in ATS development, projects commercial demonstration for the year 2000. ATS will be adaptable for coal and biomass firing, and 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 valve.
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 locatable throughout the country.

IGCC RD&D Projects

DOE's IGCC RD&D program focuses on system improvements that will lead to lower cost systems and efficiency improvements without compromising the excellent environmental performance of this technology. This RD&D investment will result in the achievement of performance goals of over 50 percent efficiency at costs of $1000 per kilowatt or less, by incorporating high-temperature gas cleanup and advanced gas turbine systems. These increased power plant efficiencies will result in a 35 percent reduction of carbon dioxide emissions, compared with today's coal-fired power plants. Because of system improvements, capital cost will be reduced. Lower capital costs and increased efficiencies will lower the cost of electricity.

A number of major RD&D projects are key components of the development path for IGCC products. 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 projects are discussed below.

Gasification Product Improvement Facility (GPIF) -- The objective of the GPIF project is to provide a test site for the development of a low-cost, fixed-bed gasifier that can process highly swelling bituminous coals, and to support early commercialization of IGCC technology. A team consisting of CRS Sirrine Engineers, Inc., Riley Stoker Corporation, and PSI PowerServ, has been awarded a contract to execute the program. The gasifier concept will be based on PyGas, a patented air-blown, fixed-bed gasification process. The facility will be located at Monongahela Power Company's Fort Martin station near Morgantown, West Virginia. Monongahela Power Company is an operating subsidiary of the Allegheny Power Service Systems.

The overall goal of the GPIF is to improve IGCC technology by developing improved gasification technology. The proposed gasifier (see Figure 2) is an air-blown hybrid concept that combines an entrained-bed pyrolyzer within a fixed-bed of char, which gasifies the carbon. The gasifier will be capable of operating with highly caking eastern coals. The modest off-gas temperature from the gasifier (1500 °F), together with contaminant removal within the gasifier, are projected to lead to significant cost reduction and efficiency improvement for IGCC systems.

The GPIF project will be executed in two phases. Phase I consists of design and construction of a fixed-bed gasifier based on the PyGas process. The plant will operate at pressures ranging from 200 pounds per square inch actual (psia) to 600 psia, and will be designed to process up to 150 tons/day of high-swelling bituminous coal.

Phase I RD&D tests will address process and coal-based issues associated with fixed-bed gasification. These issues include the handling of high-swelling coals, pressure scaleup, combustion of the low-Btu value fuel gas, and system integration.

An optional Phase II activity would consist of the design and construction of a hot-gas cleanup unit integrated with the gasifier. The reaction design would be of an advanced design that would reduce unit complexity and cost, and would test advanced mixed-metal oxide sorbents.

Cooperative Research and Development Agreement (CRADA) work with industry is anticipated and encouraged, and will be used to support the CCT Program. The facility will be operated by Morgantown Energy Technology Center (METC) personnel.

METC In-house -- The Office of Technology Base Development (OTBD) within METC has been developing advanced hot-gas cleanup sorbents for IGCC advanced power systems, providing experimental support to the DOE contractor efforts, and to CCT participants. Current process development activities consist of two bench-scale projects: the Modular Gas Cleanup Rig (MGCR) and 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 scale-up. The MGCR rig cleans the process gas from METC's pilot-scale fluid-bed gasifier to generate both particulate and desulfurization sorbent performance data which will be valuable for supporting the design of the METC HGD PDU. Both, the laboratory and MGCR data will be utilized to design the PDU, which will provide a test bed for verifying the integrated process operation, control, and long-term durability at a scale large enough to be meaningful and applicable to full-scale plant designs. Construction has begun on the 150,000 standard cubic feet per hour Fluid-Bed HGD PDU and the syngas generator that will supply fuel gas to the PDU. Operation of the PDU will support design activities for the optional Phase II GPIF activity. Startup for the PDU is scheduled for October 1996. The PDU desulfurization unit will be considered for scaleup for the GPIF optional Phase II activity.

Power Systems Development Facility (PSDF) -- The PSDF facility will be located at the Southern Company's Clean Coal Research Center near Wilsonville, Alabama. Participants in this cost-shared RD&D project include DOE, 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. Startup is scheduled for the spring of 1995.

The Wilsonville PSDF will be a focal point of DOE's RD&D program in the coming decade. The PSDF will be used to solve systems integration issues and to develop product improvements in several of DOE's power systems. 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 combustion 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. Tests of the PFBC module will lead to the first commercial demonstrations of a second-generation PFBC by Air Products, a CCT participant.

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 feed to the reactor consists of fine coal particles similar to entrained systems, while the reactor has the outlet gas temperature characteristics of a fluidized-bed system. 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.

Plans are currently being made to integrate a 100 kW Molten Carbonate Fuel Cell Test Skid at the facility. The facility will also be an invaluable support for CCT demonstration projects as they enter the operational phase in the latter part of this decade.

The advanced PFBC consists of Foster Wheeler's technology for second-generation PFBC (see Figure 4). 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-British thermal unit (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. The design coal for the facility is Illinois No. 6 bituminous coal, with a Powder River subbituminous coal as an alternate coal. Longview limestone, which is obtained locally near Wilsonville, has been chosen for initial testing. The coal feed rate to the carbonizer will be 2.75 tons/hr. With the Longview limestone, a calcium to sulfur molar ratio of 1.75 is required to capture 90 percent of the sulfur in the carbonizer/CPFBC. Particulate laden gas from the carbonizer and the CPFBC will be routed to a separate PCD to remove particulates prior to entering a topping combustor.

The topping combustor will raise the inlet temperature of the gas turbine, which will raise the net plant efficiency of advanced PFBC systems to 45 percent, while maintaining low levels of NOx. To withstand the expected severe conditions in the topping combustor application, a Multi-Annular Swirl Burner (MASB), under development by Westinghouse and the University of Tennessee Space Institute, has been chosen to combust the carbonizer fuel gas using CPFBC flue gas. The purpose is to increase the temperature of the resulting flue gases to 2350°F, consistent with turbine inlet temperatures offered on advanced commercial high-efficiency turbines. At the PSDF, however, the topping combustor flue gas will be cooled to 1970°F in order to meet the temperature limitation on the small, standard gas turbine (Allison Model 501-KM) which will be used to power both the air compressor and an electric generator to produce a nominal 4 MW of electric power.

The PCDs will be tested at temperatures, pressures, and other gas conditions characteristic of a number of gasifiers and pressurized fluidized-bed combustors. The critical issues include integration of the PCDs into the advanced power systems, on-line cleaning, chemical and thermal degradation of components, fatigue and other modes of physical failure, blinding, collection efficiency as a function of particle size, and scaleup issues.

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.

Westinghouse Filtration System -- Westinghouse will install a tiered vessel which can be fitted with ceramic candles, cross flow filters or flexible ceramic bag filters for use on the transport reactor (see Figure 5). The filter vessel will be a refractory-lined, coded, pressure vessel. The filters will be individual filter elements attached to a common plenum and discharge pipe to form clusters. Clusters of filters will be supported from a common high-alloy, uncooled, tubesheet. Each plenum of the filter will be cleaned from a single pulse nozzle. Qualification testing is in progress at Westinghouse to decide which type of filter element to test and evaluate first.

Combustion Power Company Granular Bed Filter System -- In the CPC granular bed filter, the transport reactor gas is introduced into the center of a downward moving bed of granules, 6 mm spheres mostly made of aluminum oxide and mullite, which serve as the filter media to remove the particles from the gas. The gas reverses direction and moves counter current to the direction of the filter media to leave the pressure vessel. Clean media is constantly introduced from the top of the vessel. The particulate-containing media is removed from the bottom of the filter vessel and pneumatically conveyed and cleaned in a liftpipe. At the top of the liftpipe the particulate and clean media are separated in a disengagement vessel and the clean media is returned to the filter vessel. The transport gas and dust are cooled in a regenerative heat exchanger and the dust is removed in a baghouse.

Industrial Filter and Pump Filter System -- 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. Individual jet pulse nozzles are provided to each candle. An Enhancer™ consisting of an orifice-type device at the outlet of the candle increases the pulse intensity and also serves as a fail-safe plug in case of a candle failure. The IF&P PCD will operate at 1,500 to 1,700 acfm gas flow rates at 1600 to 1800°F, 170 psia, and 11,000 ppmw particle loading.

Westinghouse Ceramic Candle Filter System -- 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. Each array of filters is attached to a common plenum and discharge pipe and is cleaned from a single pulse nozzle source. Several arrays of individual candle filter elements are assembled into a cluster and the clusters are arranged vertically in the filter vessel. The cluster concept allows replacement of individual filters and provides a modular approach to scale-up. The Westinghouse PCD will operate at 6,200 acfm gas flow rate at 1600°F, 150 psia, and 15,000 ppmw particle loading.

A final role for the 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 consortium. The PSDF provides an excellent opportunity for utilities to obtain hands-on evaluation and operational experience with IGCC and PFBC components and subsystems.

Hot-Gas Desulfurization

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

The effort to develop HGD technology to remove 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 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 most promising techniques for removing between 800 and 10,000 parts-per-million-weight (ppmw) H_2S from the gasifier product gas employ a dry, mixed-metal oxide sorbent for use in moving-bed, fluidized-bed, or transport or entrained reactors.

Zinc-titanate based sorbents such as Z-Sorb (a proprietary zinc-based sorbent developed by Phillips Petroleum) and ZT-4 (a proprietary zinc-based sorbent developed by Research Triangle Park manufactured by CMP, Baltimore, MA) are currently the most well-developed desulfurization sorbents being studied and are commercially available with vendor guarantees. They are currently being evaluated for all reactor designs using RD&D and process development facilities.

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

<u>General Electric Environmental Services, Inc. (GEESI), Moving-Bed Desulfurizer Unit</u> -- GEESI is developing a moving-bed, high-temperature desulfurization system (see Figure 6) at their corporate RD&D center in Schenectady, New York. A fixed-bed, air-blown gasifier capable of processing about 1800 pounds per hour of bituminous coal supplies fuel gas to a desulfurization system at a pressure of 20 atm and a nominal temperature of 1000 F and to a turbine simulator. H_2S is removed from the fuel gas in the counterflow absorber, which contains up to 3000 pounds of a mixed-metal oxide sorbent. An external sorbent regeneration loop produces an off-stream of sulfur dioxide suitable as feed stream to a sulfuric acid plant. Over 400 hours of testing have been completed in the 3-MWe scale unit to investigate the performance and durability of mixed-metal oxide sorbents. The most recent pilot plant tests have been conducted with Z-Sorb, a propritatary sorbent commercially available from Phillips Petroleum Company. Favorable results with Z-Sorb have been observed and will be published in the future when data reduction activities are completed.

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, and measure the level of trace impurities in the exhaust. To minimize undesirable sorbent-chloride reactions, the fuel gas hydrogen chloride level must be reduced to less than one parts per million. To achieve this target, a recirculating entrained flow reactor chloride control subsystem has been installed and tested to control levels entering the desulfurizer unit. This work directly supports the systems being designed for Tampa Electric and Combustion Engineering projects in the CCT program.

<u>Other Sorbent Activities:</u> In support of a fluid-bed reactor configuration, activities by Research Triangle Institute (RTI) center on developing new and/or commercially available sorbent formulations and fabrication methods that enhance long-term chemical reactivity and mechanical strength. Work is being conducted in a bench-scale reactor for use in pilot-plant tests. A major achievement has been the successful completion of a 100-cycle test using a commercially made, 200-pound batch of zinc titanate (ZT-4) sorbent. This sorbent formulation was produced by a granulation technique that can promote 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 will be tested in a fluid-bed desulfurization unit at the Messukyla Research and Development Center in Tampere, Finland.

RTI has developed a direct sulfur recovery process (DSRP) to treat the regenerator gas from sulfided metal-oxide desulfurization sorbents to produce elemental sulfur. The next step in the DSRP's development is the operation of a field test unit which consists of RTI's existing, 2-stage fluidized-bed DSRP reactor system integrated with a single stage, 3-inch fluidized-bed reactor for the sorbent. The testing will be performed at METC using a 10-inch fluid-bed gasifier to produce the dirty gas. Startup should occur in late 1994. A larger skid-mounted unit is under construction and is scheduled for testing at 30 ton-per-day gasification pilot plant at the Messukyla Research and Development Center in Tampere, Finland.

A CRADA between METC and Enviropower will demonstrate an Integrated Hot Gas Particulate and Contaminant Control and Sulfur Recovery. Enviropower's objectives are to minimize the technical and financial risk to the Toms Creek IGCC project awarded to Tampella Power Corporation under the CCT program. The scope of this CRADA complements other fluid-bed desulfurization research, development, and demonstration projects. The work will be conducted at Enviropower's operating 30 ton-per-day gasification pilot plant at the Messukyla Research and Development Center in Tampere, Finland, using U-Gas coal gasification technology developed by the Institute of Gas Technology. The CRADA activities include: (1) testing of a full-flow candle filter system for particulate control; (2) provision of two, 2-ton lots of fluidized-bed desulfurization sorbent; (3) bench-scale field testing of desulfurization technology including fluidized-bed sorbents and the DSRP; (4) pilot plant, full flow testing of the sorbents for capture of sulfur contaminants with fluidized-bed regeneration of the loaded metal-oxide sorbents; (5) design, fabrication, installation, and testing of a slip-stream PDU for recovering elemental sulfur from the regeneration gas using the DSRP; and (6) parametric laboratory-scale tests, including mechanistic and durability evaluations of metal-oxide sorbents. The candle filter system has been operational at the Messukyla pilot facility since last year, and the fluid-bed desulfurizer was brought on line for testing this spring. Sorbent materials are being provided by RTI as noted above.

Two contracts were recently awarded to study an advanced sulfur control concept that provides for direct product of elemental sulfur during sorbent regeneration, thereby eliminating the need for a separate sulfur conversion process. The contracts were awarded to Louisiana State University and RTI. The concept will strive to develop simpler and economically superior processing for regenerable desulfurization sorbents. Tasks include: (1) technical assessment of concepts; (2) evaluation of selected concepts as to their feasibility, economic viability, and integration and compatibility with DOE/METC sorbent technology; (3) laboratory-scale development; (4) integrated demonstration at bench-scale; and (5) an economic and engineering evaluation.

IGCC system efficiency studies have shown that hot-gas cleanup systems operating at temperatures above about 1000°F increase efficiency by approximately 1 percent. In addition, hot-gas cleanup systems incur higher equipment and piping costs associated with the higher grade materials of construction, additional refractory, and insulation needed to accommodate the higher temperature operation. For these reasons, a contract was recently awarded to GEESI to conduct a study to develop a regenerable sorbent for use in the moderate temperature range of 650 to 1,000°F.

The OTBD within METC has been developing advanced hot-gas cleanup sorbents for IGCC advanced power systems. Two promising sorbents, denoted as METC-2 and METC-6, have been identified. The current OTBD process development activities consist of two bench-scale projects -- the MGCR and the Riser Reactor -- and the larger Fluid-Bed HGD PDU project. These projects are designed to provide data on concept feasibility, process performance, engineering problems, and scale-up. OTBD is also providing experimental support to contractor fluid-bed development efforts.

High-Temperature, High-Pressure Particulate Control

Tidd Ceramic Filter Slipstream -- In August 1989 a cooperative agreement was signed between Ohio Power Company, through its agent the American Electric Power Service Corporation, and the U. S. DOE to assess the readiness and economic viability of high-temperature and high-pressure (HTHP) particulate filter systems for PFBC applications. In this agreement, known as the PFBC Hot-Gas Cleanup (HGCU) Program, a HTHP particulate filtration system (see Figure 7) has been tested with one seventh of the flow from the Tidd 70-MWe PFBC Clean Coal Demonstration Plant. To support other more advanced filter element tests in the PFBC HGCU program, additional proof-of-concept tests have been conducted through a contract with the

Westinghouse Science and Technology Center in cooperation with Ahlstrom/Pyropower.

The Tidd testing utilizes a three-cluster filter system, incorporating 384, 1.5-meter long silicon carbide candle filters. This system filters approximately 7,360 acfm from the Tidd 70-MWe PFBC. To date over 3,700 hours of filter testing have been accumulated on the filter located at the Tidd facility. The proof-of-concept test has been used to qualify mullite and other silicon carbide candle filters as potential candidates for testing at the Tidd 70-MWe PFBC. In the proof-of-concept tests over 2,000 hours have been accumulated on a filter system one third the size of the filter used at Tidd. Presently filters qualified in the proof-of-concept program are being tested in limited numbers at the Tidd facility. Both filter systems were designed and fabricated by the Westinghouse Science and Technology Center.

Granular Bed Filter (GBF) Systems -- Besides the PCDs to be demonstrated at the PSDF, there are several other technologies being supported by DOE. The first is another GBF designed by Westinghouse. The Westinghouse design is a stand-leg moving granular-bed which can use pelletized-ash bed media in a once-through configuration, as well as the alumina media which can be cleaned of fly ash and recycled back into the filter vessel.

Acoustic Agglomeration -- Manufacturing and Technology Conversion International (MTCI) is developing an acoustic agglomeration particulate control device wherein a coal-fired combustor is permitted to pulse producing a high-intensity acoustic field, which drives together (agglomerates) the particulate component of the products of combustion. These agglomerates can then be more readily removed by conventional cyclone separation. With the injection of limestone into the acoustic field, the adsorption of sulfur is accommodated. MTCI is currently testing and optimizing a PDU scale sonic enhanced agglomeration and sulfur capture system for IGCC and PFBC systems. The project is currently focusing on varying the mass loading, sorbent type, and sorbent/sulfur ratio, in an effort to maximize agglomeration and sulfur capture. In the near future, the system will be modified to study the effects of residence time on agglomeration and sulfur capture.

Other Particle Control Activities: Westinghouse will assess the suitability of damage-tolerant filter elements by providing bench-scale testing of full-scale candles in simulated PFBC and IGCC gas streams using a Filter Component Test Facility. The Facility contains a 16-candle vessel. The main thrust of this project is to assist filter manufacturers' RD&D efforts to bring hot-gas filters to market.

Another METC vehicle for developing advanced damage-tolerant hot-gas filters is the recent Program Research and Development Announcement titled "Advanced Hot Gas Filter Development." The goals of this project are to develop and evaluate a second generation of hot-gas filters with increased durability and resistance to crack propagation. Some of the filter elements to be developed under this effort are likely to be made from continuous fiber-reinforced ceramic composite materials, and capitalizes on work supported by DOE's Office of Energy Efficiency and Renewable Energy.

The Westinghouse Science and Technology Center is developing an Integrated Low Emissions Cleanup (ILEC) concept for HTHP gas cleaning to meet environmental standards, as well as to provide economic gas turbine life. The ILEC concept is based on the Westinghouse Advanced Particulate Filter design, but has the added potential to control sulfur, alkali, and other contaminants (possibly Hazardous Air Pollutants) from HTHP fuel gases in a single vessel. The test program, which was started this past year, has been revised to address key issues relating to hot-gas cleanup. The revised test program's objectives are to: (1) resolve issues related to pulse cleaning of candles in PFBC conditions; (2) observe the relation between candle filter cleaning performance and fly ash source/properties, temperature, pulse intensity, and additives/sulfur and alkali sorbents; (3) determine if pulse cleaning intensity and/or additives can be used to promote effective cleaning with difficult ashes; and (4) determine the sulfur/alkali removal capabilities of the filter.

To resolve the key barrier issues for particle control, METC has a task order contract in place with Southern Research Institute (SRI). Examples of these barrier issues are the long-term stability of ceramic filters to thermal cycling and chemical degradation; ash buildup and cleanability of commercial-size ceramic cross-flow filter modules; and the potential blinding of ceramic filters. Specifically, SRI has built and is operating a ceramic patch test unit to provide information on the long-term performance characteristics of the ceramic materials used in the manufacture of candle filters, cross-flow, and tube filters. A particulate sampling and analysis is being developed to establish an ash database relevant to the evaluation of performance of advanced particle filter systems. In addition, SRI is developing a materials property database to help understand the thermal and mechanical behavior of hot-gas filter materials.

METC also supports the advancement of particulate control technology through in-house efforts managed by OTBD. OTBD performs applied RD&D to support METC contractor efforts. OTBD's HTHP particulate cleanup activities include: evaluation of ceramic filters in support of CCT demonstration projects; development of novel and economical filtration techniques for advanced cycle applications; and, efforts aimed at the understanding filtration fundamentals. In terms of project specifics, the HTHP test facility and the MGCR will be used to qualify full-scale filter configurations. Current lab-scale projects include: cold flow test facilities to study dust cake formation and removal, and a self-cleaning in-bed filter.

Other Contaminants

SRI International is currently developing and testing alkali-based disposable materials to remove hydrogen chloride vapor from high-temperature coal-derived fuel gas stream using natural minerals and/or synthetic sorbents in three different reactor applications (fixed-, moving-, or fluidized-bed). The goal is to reduce the hydrogen chloride concentration to less than one ppm to meet molten carbonate fuel cell inlet specifications and to prevent deterioration of zinc-based sorbents.

RTI is attempting to develop advanced high-temperature coal gas desulfurization mixed-metal oxide sorbent/catalyst combinations which can effectively remove hydrogen sulfide, as well as decompose fuel-bound nitrogen compounds (chiefly ammonia) into elemental nitrogen and hydrogen at HGD operating temperatures. Significant IGCC capital cost savings could be realized if both of these contaminants could be removed in one reactor.

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 particulates, efficiency improvements result in approximately 35 percent lower emissions of carbon dioxide. The superior environmental performance of this 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 specific efficiency, cost and environmental goals identified above, the projects will demonstrate: (1) the applicability of the technology to power generation or cogeneration in repowering or 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.

Bibliography

Bechtel, T. F., "Impact of Advanced Turbine Systems on Coal-Based Power Plants," Twelfth Electric Power Research Institute Conference on Gasification Power Plants, San Francisco, CA, October, 1993.

Brdar, R. D. and G. R. Friggens, "Taking Steps Forward - The IGCC Demos," Eleventh Annual International Pittsburgh Coal Conference, Pittsburgh, PA, September, 1994.

Rath, L. K., G. T. Lee, and P. H. Le, "IGCC System Studies," Proceedings of the Coal-Fired Power Systems 94 - Advances in IGCC and PFBC Review Meeting, DOE/METC-941008, Vol 1,2, June, 1994.

Longanbach, J.R., T.E. Pinkston, P. Vimalchand, and T. Boyd, "Particle Filter Testing at the Power Systems Development Facility, Wilsonville, Alabama," Eleventh Annual International Pittsburgh Coal Conference, Pittsburgh, PA, September, 1994.

McMahon, T. J., M. A. Alvin, H. and Stuart Starrett, "Ceramic Barrier Filters for Advanced Coal-Based Power Generation Systems," Eleventh Annual International Pittsburgh Coal Conference, Pittsburgh, PA, September, 1994.

Staubly, R. K., R. A. Dennis, and D. C. Cicero, "Overview of METC's Gas Stream Cleanup Program," Eleventh Annual International Pittsburgh Coal Conference, Pittsburgh, PA, September, 1994.

Dennis, R. A., T. E. Lippert, G. J. Bruck, M. A. Alvin, M. J. Mudd, and J. D. Hoffman, "Test Results from the Department of Energy's Pressurized Fluidized Bed Combustion Hot Gas Cleanup Program," Eleventh Annual International Pittsburgh Coal Conference, Pittsburgh, PA, September, 1994.

Sadowski, R. S., W. H. Shinner, R. A. Lisauskas, and S. A. Johnson, "Gasification Product Improvement Facility Status," Proceedings of the Coal-Fired Power Systems 94 - Advances in IGCC and PFBC Review Meeting, DOE/METC-941008, Vol 1,2, June, 1994.

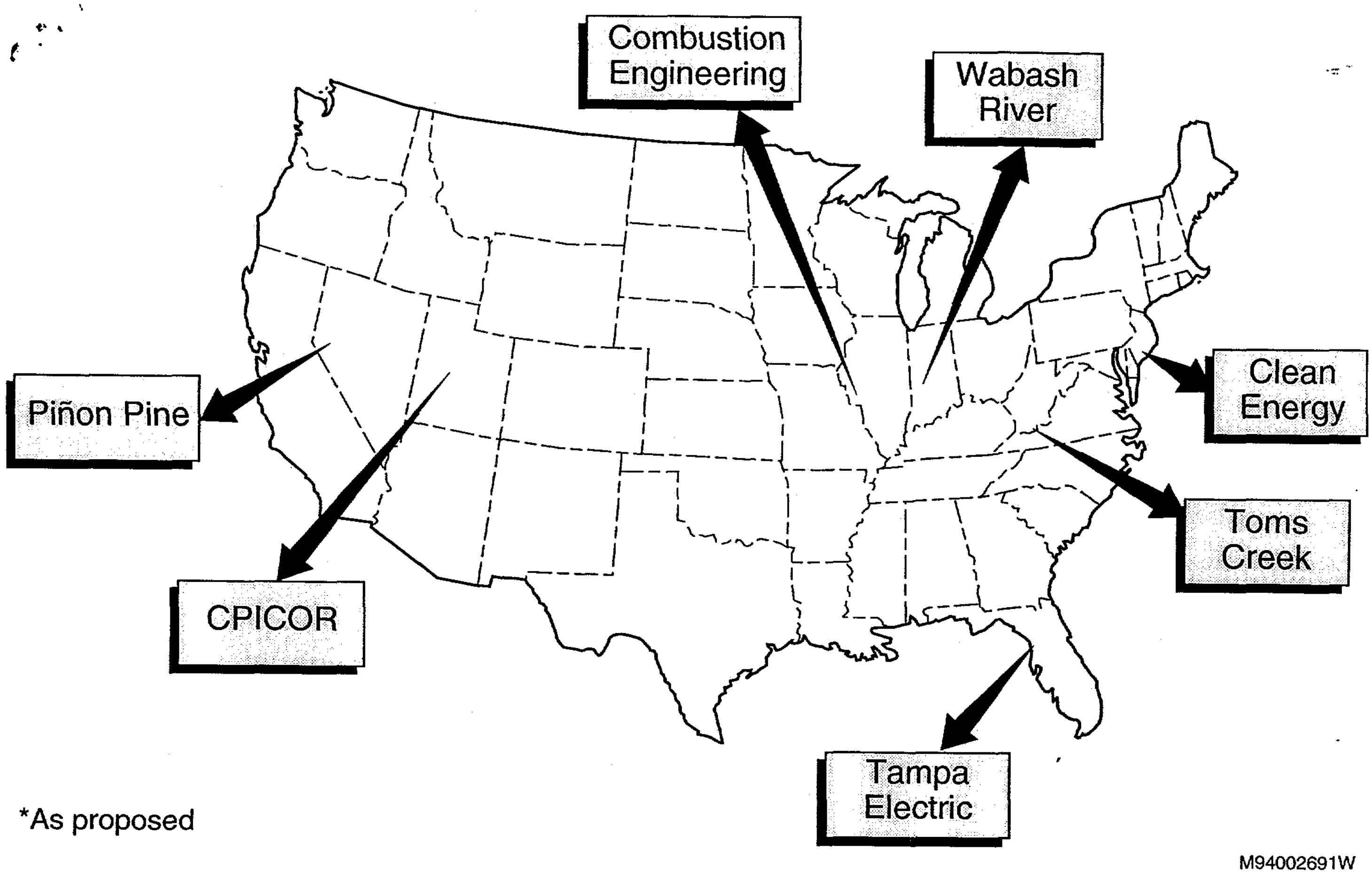

Figure 1. Clean Coal Technology Program IGCC Project Locations

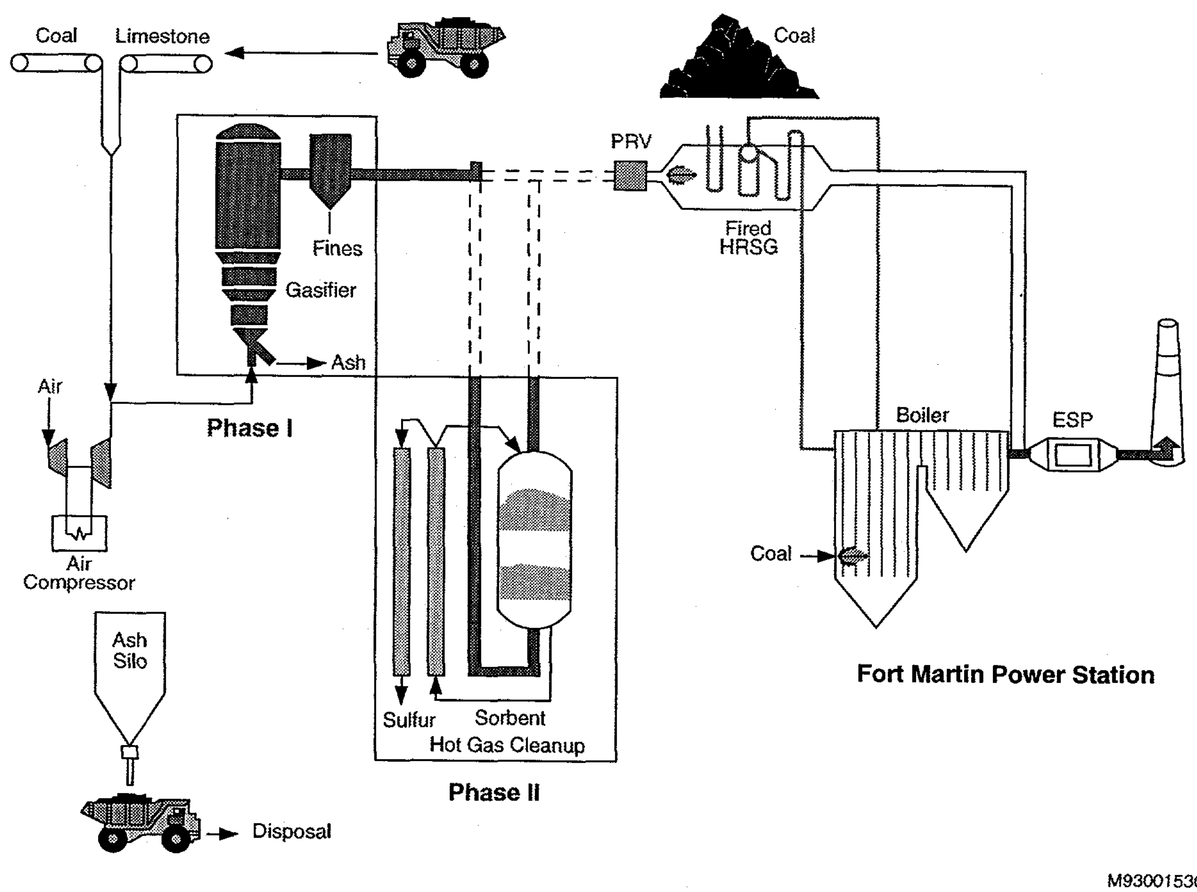

Figure 2. Gasification Product Improvement Facility - Process Schematic

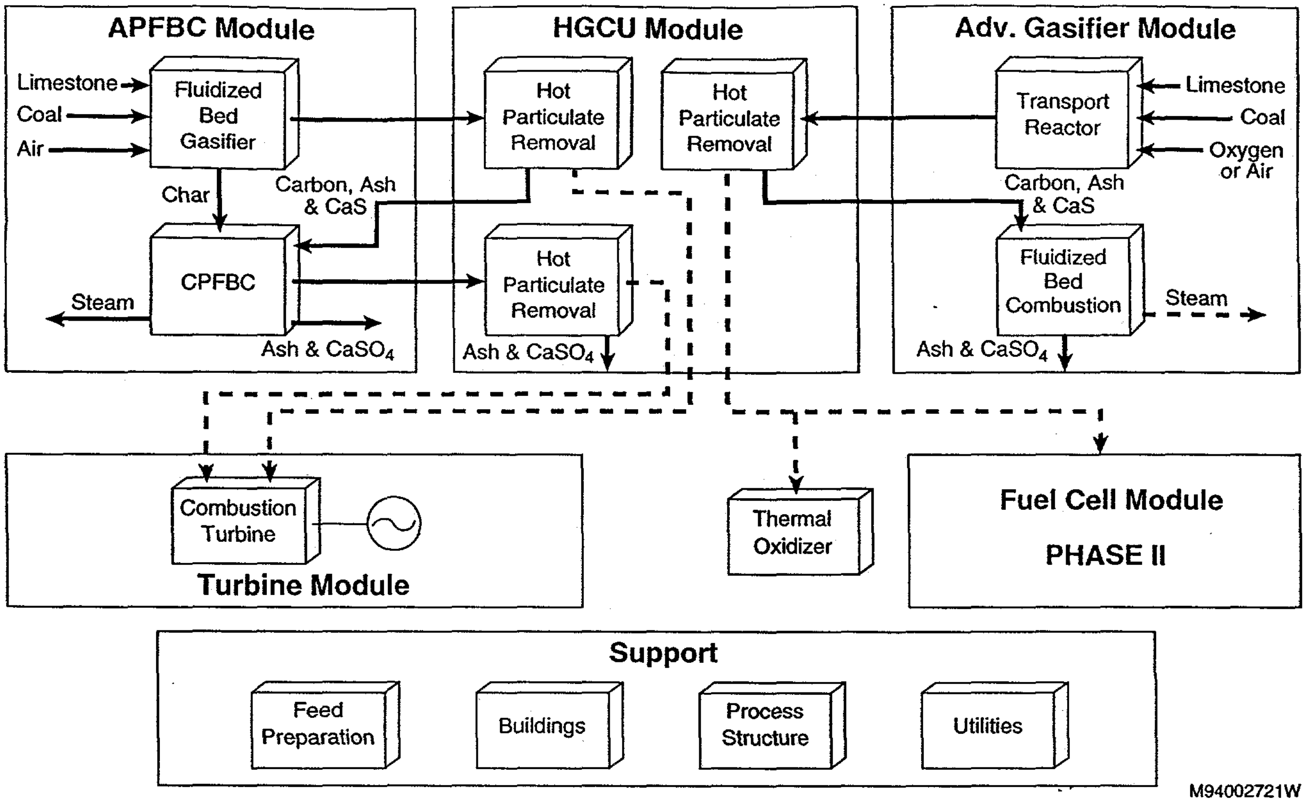

Figure 3. Power Systems Development Facility - Technology Modules

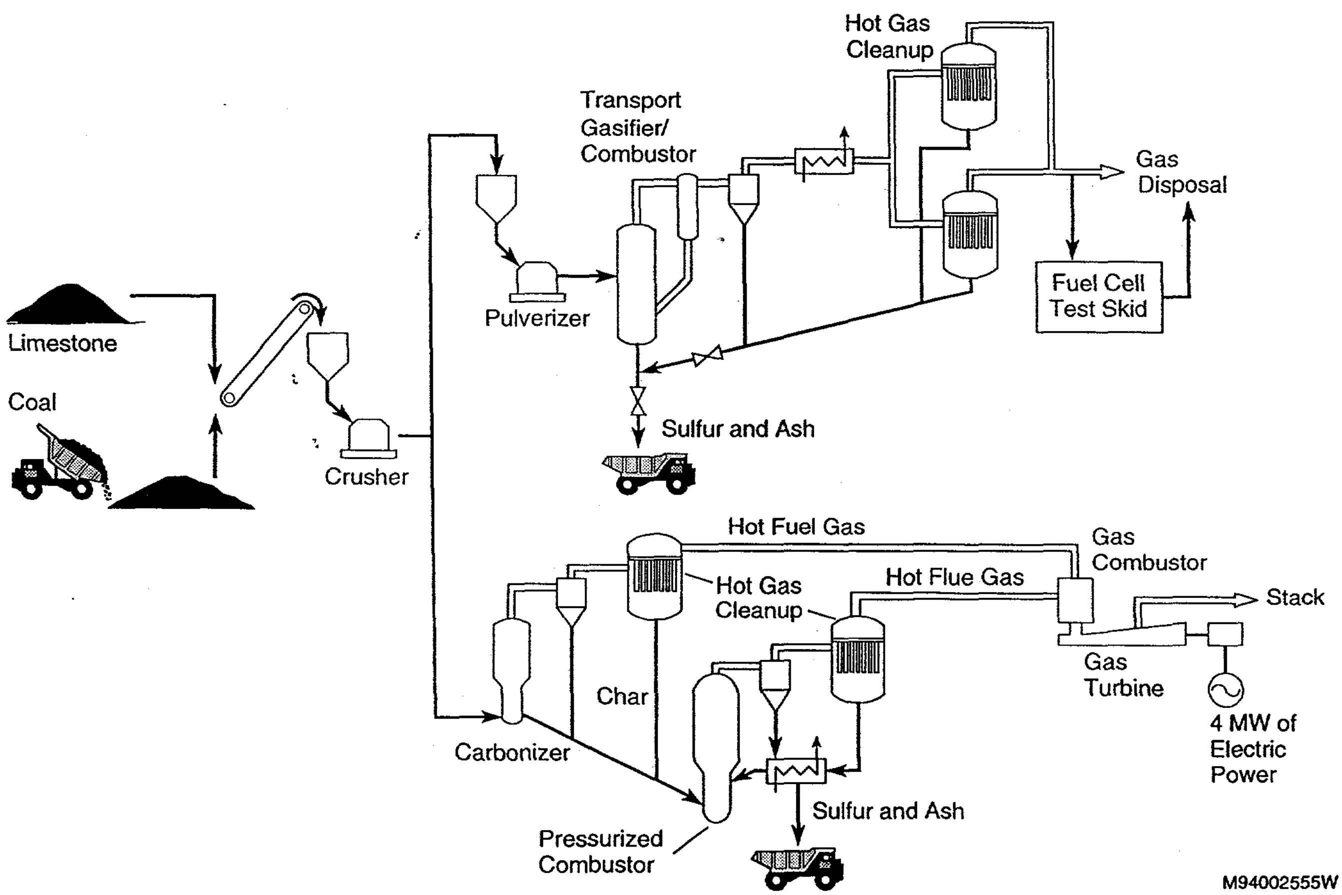

Figure 4. Power Systems Development Facility - Process Diagram

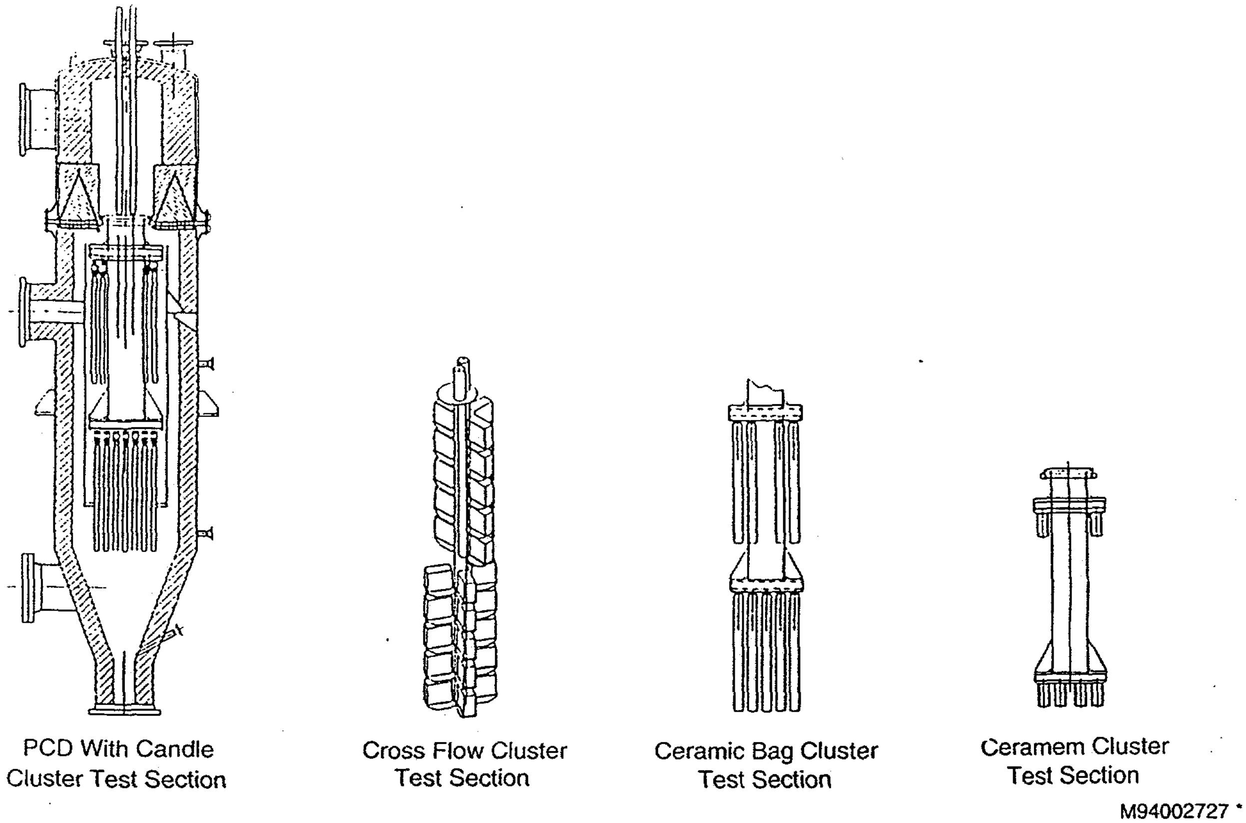

Figure 5. PSDF Westinghouse Filter Vessel and Filter Options

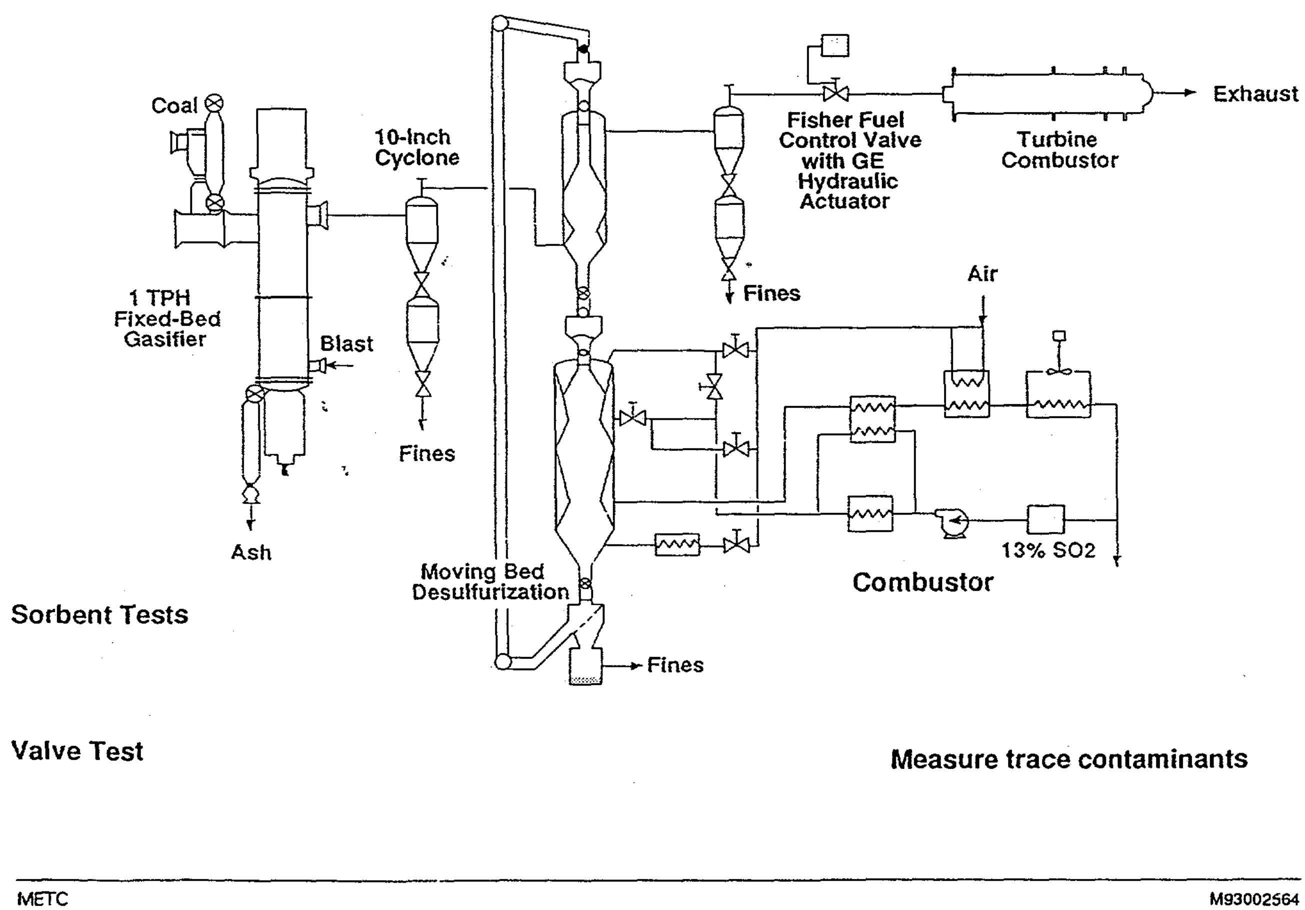

Figure 6. GEESI Moving Bed Desulfurizer

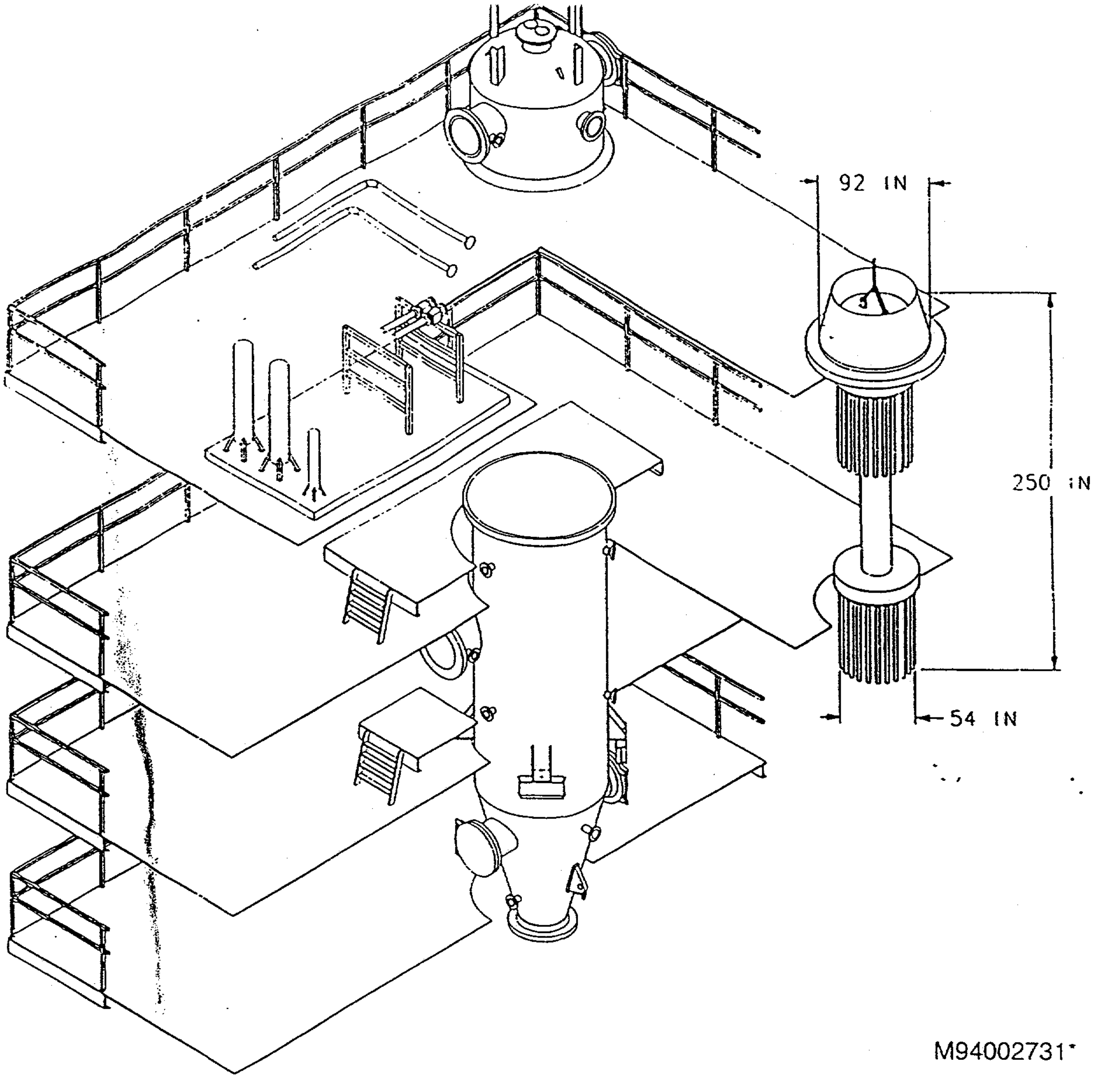

Figure 7. TIDD PFBC Hot Gas Clean Up System