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Turbine and Hot Gas Cleanup at Wilsonville

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DE-FC21-90MC25140

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U.S. Department of Energy Morgantown Energy Technology Center

Turbine and Hot Gas Cleanup at Wilsonville

CONTRACT INFORMATION

Cooperative Agreement Number DE-FC21-90MC25140

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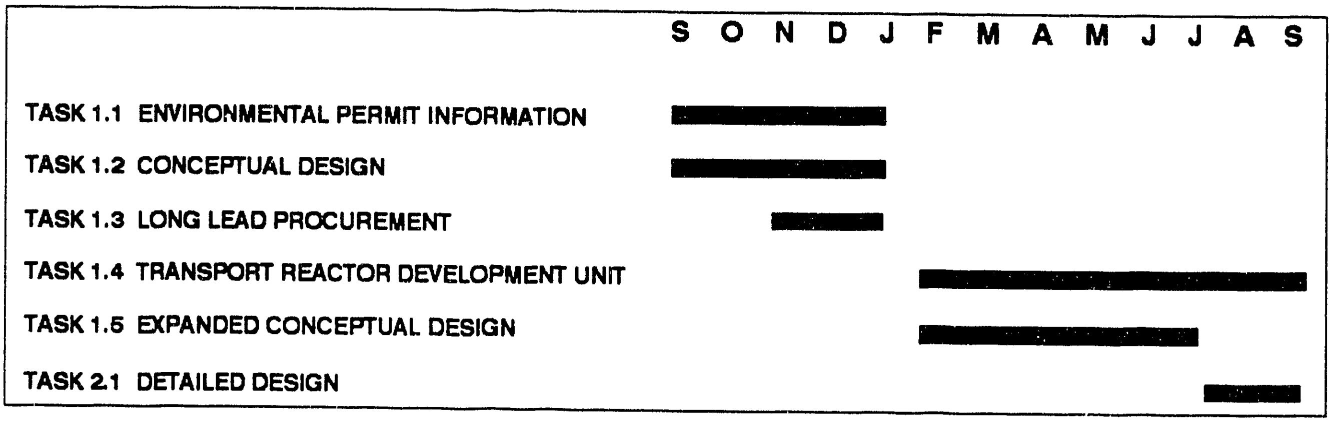
Period of Performance September 15, 1991 to September 15, 1992

Schedule and Milestones

FY 92 Program Schedule



OBJECTIVES

Southern Company Services, Inc. (SCS) has entered into an agreement with the Department of Energy, Morgantown Energy Technology Center (DOE/METC) to design, construct and operate the Hot Gas Cleanup Test Facility for Gasification and Pressurized Combustion. The purpose is to identify and evaluate potential hot particulate cleanup systems on a scale large enough so that these systems can be related to potential commercial system. This entails first developing the criteria for engineering-scale testing of hot particulate control devices which will lead to the design, construction and operation of a flexible test facility capable of operating under gasification and PFBC conditions. This will allow the testing of particulate control devices (PCDs) under realistic conditions in terms of gas composition, temperature, pressure, particulate loading and operating duration.

The conceptual design of the Hot Gas Cleanup Test Facility Project was expanded to include additional modules to better address the scope of the Cooperative Agreement with the DOE/METC. The expanded test facility, referred to as the Power Systems Development Facility (PSDF), will provide a flexible test location in which the development of advanced power system components, the evaluation of advanced turbine and fuel cell configurations, and the integration and control issues of these systems. The facility is intended to provide direct support for upcoming DOE demonstrations of power generation technologies utilizing hot stream cleanup and will provide a resource for rigorous testing and performance assessment of hot stream cleanup devices now being developed with the support of DOE/METC.

BACKGROUND INFORMATION

Efficiencies in advanced power generation systems such as integrated gasification combined cycle (IGCC), pressurized fluidized bed combustion (PFBC) and integrated gasification fuel cells (IGFC) can be maximized by feeding hot fuel gas or flue gas to the power block. However, advanced gas turbines have strict particulate requirements to minimize wear on the blades due to the close tolerances used to maximize the efficiency of the turbomachinery. Molten Carbonate Fuel Cells (MCFC) also have strict particulate requirements to prevent blinding of the electrodes. Therefore, one of the main barriers to developing these advanced power generation systems is the removal of particulates in a hot gas stream. Although the development of several high temperature/pressure PCD systems has been ongoing for the past several years, long term operation under realistic conditions for advanced power generation has been limited. The demonstration of reliable operation is critical to the commercialization of PCD technology for advanced power generation.

Interest in utilizing IGCC to generate power in the utility industry is increasing because these systems have the ability to produce power with coal in a manner that is more efficient with lower air emissions than conventional pulverized-coal (PC) fired units with flue gas desulfurization. The feasibility of IGCC as an environmentally superior advanced power generation technology has been demonstrated with the Cool Water Project. (1,2) Emissions of sulfur and nitrogen oxide compounds from Cool Water were nominally an order of magnitude lower than New Source Performance Standards for coal-fired units. Since Cool Water, design plant efficiencies have increased substantially. Overall plant heat rates are less than 9,000 Btu/kWh. Estimates of proposed highly integrated IGCC demonstration plants have heat rates less than 8,500 Btu/kWh. Commercialization of IGCC technology is rapidly approaching with projects being pursued in Europe as well as the U.S.

Another major trend in advanced power generation is the commercialization effort currently underway for molten carbonate fuel cells. (3,4,5) Integration of gasification with molten carbonate fuel cells (MCFC) offers the potential of a very clean power generation system that, once optimized, could result in efficiencies greater than 55 percent with system heat rates less than 6500 Btu/kWh. This is considered a significant advancement in power generation with coal.

Similarly, PFBC technology is developing to include a topping cycle in the design of advanced PFBC systems. (6) In a first-generation plant, a 1650°F combustor temperature is generally accepted as a safe upper limit. Significantly higher temperatures cause increased alkali releases that are harmful to the gas turbine and, depending upon the temperatures and feedstocks involved, increase the risk of sintering and agglomeration in the coal-burning bed. To achieve a significantly higher gas turbine inlet temperature without increasing bed temperature, second-generation PFBC designs incorporate a topping combustion configuration. In this arrangement a fuel-supply subsystem generates a coal-derived low-Btu fuel gas by partial conversion of the coal, that is burned to increase the turbine inlet temperature. The second-generation APFBC system is capable of achieving 45% net plant efficiency primarily based on attaining higher gas turbine inlet temperatures using a topping combustor.

The success for achieving higher system efficiencies with these advanced coal-based power plants is dependant on the ability to remove hot particulates from the gas stream supplied to the gas turbine. Successful demonstration of systems to remove hot particulates reliably under utility specifications is crucial to the commercialization of these advanced power generation systems.

PROJECT DESCRIPTION

The PSDF will consist of five modules for systems and component testing as shown in Figure 1. These modules include an Advanced Pressurized Fluidized-Bed Combustion Module (APFBC) Module, an Advance Gasifier Module, Hot Gas Cleanup Module, Compressor/Turbine Module, and a Fuel Cell Module. The APFBC module consists of Foster Wheeler's technology for second generation PFBC. This module relies on the partial conversion of the coal to a fuel gas in a carbonizer with the remaining char converted in a PFBC. Both the fuel gas and PFBC exhaust gas streams are filtered to remove particulates, then combined to fire a combustion turbine. The advance gasifier module involves M. W. Kellogg's transport technology for pressurized combustion and gasification to provide either an oxidizing or reducing gas for parametric testing of hot particulate control devices. The compressor/turbine module currently consists of a Westinghouse topping combustor coupled to a GM-Allison 501 gas turbine, nominally producing 4 MW of electric power, which will provide a more cost effective compressed gas source than an electric driven compressor train.

The fuel cell module is integrated with the transport gasifier and can be used to test advanced fuel cells such as molten carbonate and solid oxide designs. Slip-stream testing can be easily accommodated to address contaminants effect on fuel cell performance. Future testing at a multi-MW scale can begin to address integration issues and overall plant performance for integrated gasification/fuel cell (IG/FC) systems.

The Hot Gas Cleanup module is the heart of the facility and contains the Particulate Control Devices (PCD's). The facility will test the PCD's at temperatures, pressures, and gas conditions characteristic of the discharge from a number of gasifiers and pressurized fluidized-bed combustors. The critical issues to be addressed include the integration of particulate control devices into coal utilization systems, on-line cleaning techniques, chemical and thermal degradation of components, fatigue or structural failures, blinding, collection efficiency as a function of particle size, and scale-up to commercial-size systems. To facilitate the assessment of the particulate control devices, it is critical that the test conditions, such as gas temperature and particle loading be variable over a range of values. Long-term testing will be required to establish the durability and reliability of particulate control technologies.

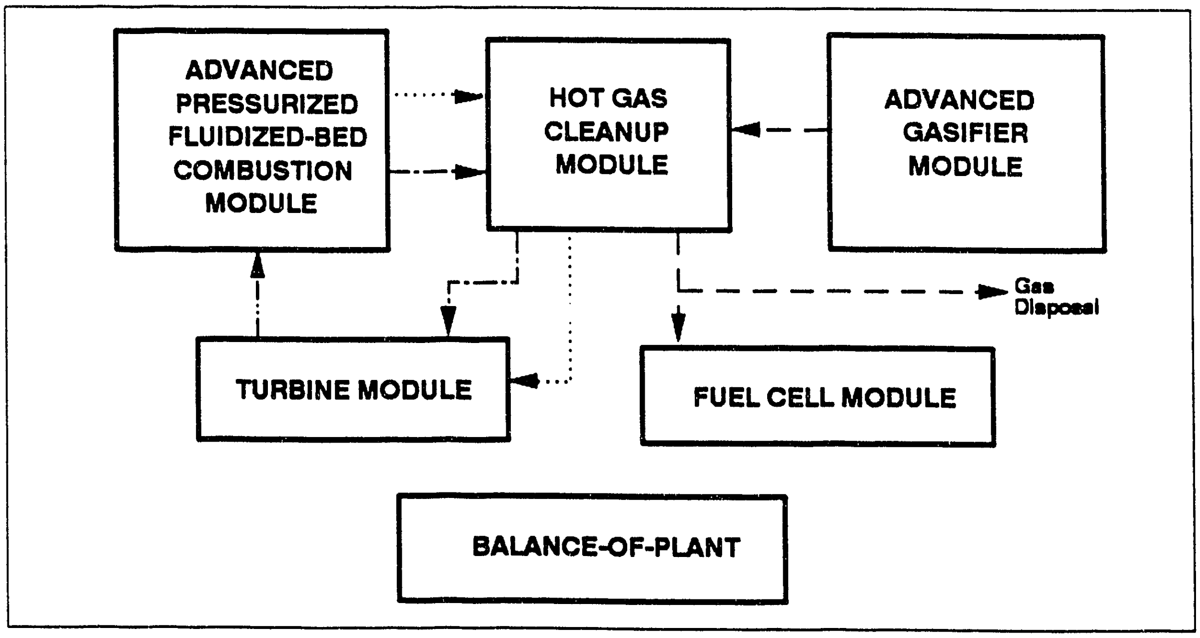


Figure 1. Power Systems Development Facility Block Diagram

Installing and operating the Advanced gasifier, APFBC, Hot Gas Cleanup and compressor/turbine modules at the same time will allow the facility to provide the capability for both parametric and long-term testing of the PCDs which are in support of the DOE Clean Coal Program. Four separate PCD technologies can be tested at the facility by carefully rearranging the PCDs between the transport gasifier and APFBC Modules. The design of the PSDF will allow interchange of PCDs on carbonizer and transport reactor if necessary to increase flexibility and maximum utilization in testing the PCDs. Because of its larger capacity, larger particulate removal devices will be tested with the combustion gases from the PFBC.

The project team consists of SCS, M. W. Kellogg (MWK), Foster Wheeler (FW), Southern Research Institute (SRI), Southern Electric International (SEI), and the Electric Power Research Institute (EPRI). SCS, MWK, FW, and EPRI are sharing in the cost of the project with the DOE.

The SCS Research and Environmental Affairs (R&EA) Department is responsible for overall project management and is taking the lead in directing the research and development activities for the project. In addition to providing cost share funding for the project, EPRI is also providing technical input and guidance. Responsibilities for other entities of The Southern Company include the overall coordination of the design engineering effort and balance-of-plant design by SCS's Engineering function, construction of the facility by SCS, and operation of the facility by SEI. MWK is responsible for the process engineering design for the facility and the design of the transport reactor. Foster Wheeler is responsible for the process engineering design for the design of the advance Pressurized Fluidized Bed Combustor and will take the lead in integrating the APFBC system with the combustion gas turbine, working with Westinghouse for the topping combustor design and with Allison for the design of the gas turbine and air compressor. Southern Research Institute will direct the particulate testing for the PCDs.

RESULTS

The activities during the past year for this project involved the expansion of the conceptual design to include the additional modules for the Power Systems Development Facility. The deliverables to DOE/METC were a conceptual design of the PSDF and a cost estimate to design, install and operate the facility. Other activities included the development of the Transport Reactor Development Unit (TRDU) to expand the data base to verify the design of the transport reactor for the PSDF. The results of each of these activities are described in the following sections.

Conceptual Design and Facility Expansion Estimate

The conceptual design of the Power Systems Development Facility was completed during this time period. This expanded conceptual design and cost estimate included equipment specifications and layout, design of the process structure, and layout of the overall facility.

The conceptual design efforts to date are presented in three detailed design documents which were submitted to DOE in June 1992. The first (Volume II.1) of these three design documents deals with the transport reactor train and fuel cell. Detailed conceptual design of APFBC train including the topping combustor and gas turbine is given in Volume II.2. Volume II.3 deals with the design of balance-of-plant, particular control devices, and specialized sampling probes and techniques. Design information in the three design documents are organized by design areas for ease of reference during detailed engineering design. The conceptual design package will serve as a complete design basis for detail design of the PSDF, for specifications of particulate control devices and fuel cell for testing, test planning and evaluation of various equipment in an integrated operation, and communication of the program concept. The design documents will be updated periodically during Phase 2 of the project.

Facility Description

The facility will be located 40 miles southeast of Birmingham, Alabama, at the Southern Company's Clean Coal Research Center in Wilsonville, Alabama. The proposed PSDF location utilizes the site for the existing Selective Oil Agglomeration Facility (due for decommissioning in December) in addition to a greenfield area west of the agglomeration area.

The design of the test facility is optimized to achieve meaningful and representative testing of both the particulate control devices and other modules in the PSDF. A simplified flow diagram of the PSDF is shown in Figure 2. The facility has two main process trains, one for the transport reactor system and one for the advanced PFBC system. 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 selected.

The transport train involves M. W. Kellogg's transport technology for pressurized combustion and gasification to provide either an oxidizing or reducing gas for parametric testing of hot particulate control devices. The transport reactor was selected for the gas generator due to its flexibility for gas and particulate testing. Conceivably, the transport reactor can run in either a pressurized gasification or a combustion

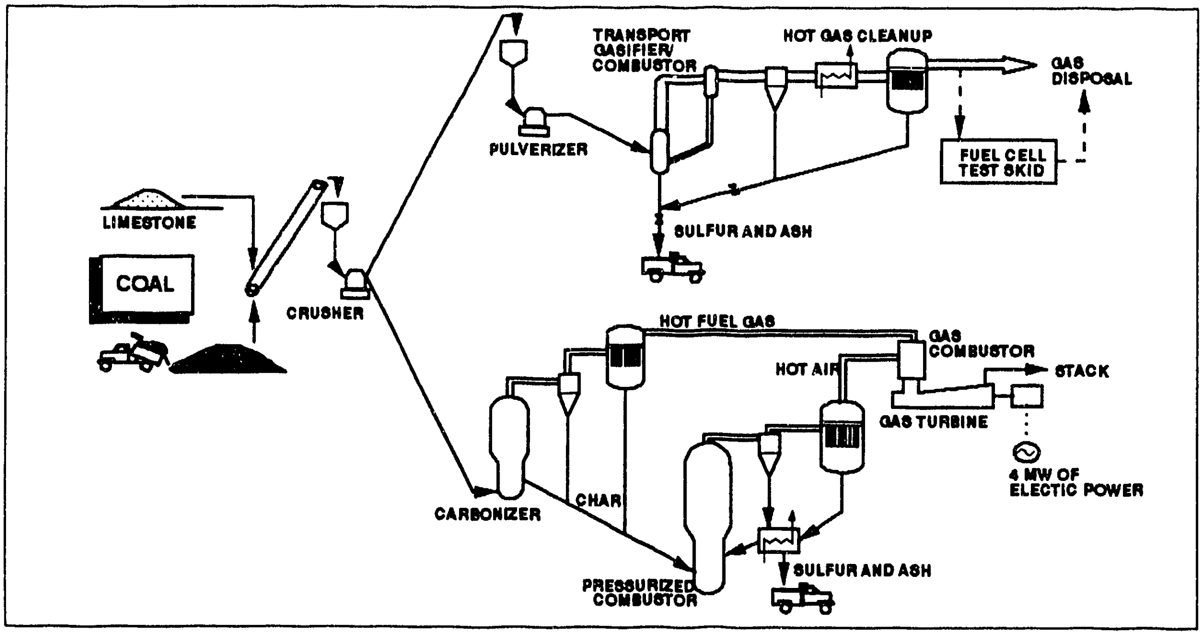


Figure 2. Simplified Process Diagram of the Power Systems Development Facility

mode over a wide range of operating temperatures and velocities. The feed coal to the reactor consists of fine particles similar to entrained systems, while the reactor has the 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 off-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 ACFM of particulate laden gas to the PCD inlet over the temperature range of 1,000 to 1,800°F at 300 psig. This volumetric flow rate is base on PCD vendor estimations as the minimum flow rate required for long term testing which would obtain engineering data for scaleup to commercialization of PCD technology.

The APFBC train designed for the PSDF consists of both a high pressure (170 psia), medium temperature (1600°F) carbonizer to generate 1,500 ACFM of low-Btu fuel gas and a circulating-PFBC (operating at 150 psia, 1600°F) generating 7,500 ACFM combustion gas. The coal feed rate to carbonizer will be 2.75 tons/hr, and with the Longview limestone, a Ca/S molar ratio of 1.75 is required to capture 90-percent of the sulfur in the carbonizer/CPFBC. The gas exiting both the carbonizer and the CPFBC are filtered hot to remove particulates prior to the topping combustor. To withstand the expected severe conditions in the combustor in topping application, a Multi-Annular Swirl Burner (MASB) has been chosen to combust the gases from the carbonizer and increase the temperature of the CPFBC flue gases to 2350°F. The exit gases are, however, cooled to 1970°F in order to meet the temperature limitation on the gas turbine. The wall cooling challenge in the topping combustor is met by effectively utilizing 1600°F air and by maintaining a cooling air layer of substantial thickness through concentric annular passages in MASB. The hot gas is expanded through a gas turbine (Allison Model 501-KM), powering both the electric generator and air compressor.

The hot gases coming off the transport reactor, carbonizer and CPFBC will be cleaned by different PCDs. The design of particulate control devices is made flexible to clean gases from both the Foster Wheeler's Carbonizer and Kellogg's transport reactor. Because of its larger capacity, larger particulate removal devices will be tested with the combustion gases from the PFBC. The PCDs from several different developers are being evaluated for testing at the PSDF. The list includes ceramic cross-flow, candle and tube filters and screenless granular bed filters. Final decision on the PCDs to be tested will be made early in the detailed design phase. However, the varying characteristics in terms of weight, envelope size and lifting requirements, operating conditions and utility requirements have been taken into account in completing the PSDF conceptual design. The design will allow interchange of PCDs on carbonizer and transport reactor if necessary to increase flexibility and maximum utilization for testing the PCDs.

On-line sampling for both particulates and alkali will be conducted at the PSDF. Particulate sampling will done at the inlet and outlet of the PCDs. Alkali sampling will be done at the inlet and outlet of the alkali getter beds for the APFBC system. SRI will also investigate the feasibility of combining the particulate and alkali sampling techniques to reduce the time and cost for sampling at the facility

The conceptual design of the particulate and alkali sampling system was completed. The sampling system is designed to function at pressures up to 300 psig and at temperatures up to 1800°F and to provide representative, size-fractionated samples of the particulate matter entering and leaving the PCDs. These samples will be used to determine the overall collection efficiency of the PCD and the collection efficiency as a function of particle size. Plans call for SRI to provide four inlet sampling systems and four outlet sampling systems. All eight systems will be designed to allow in-situ sampling of both particles and alkali vapor. Each of the eight systems will include a sampling probe, a nozzle, a sample collector, a mechanism for inserting and removing the probe, and means for metering and controlling the sample flow. A cascade cyclone assembly will be used as the sample collector in the inlet sampling system, while a cascade impactor will be used as the sample collector in the outlet sampling system.

The operation of a fuel cell using the gases from the transport reactor in gasification mode is also considered in the conceptual design of PSDF. Input from fuel cell developers was taken into account in completing the conceptual design. The capacity of the fuel cell to be tested initially is set at 100 kW, consuming 10-15% of gases from transport gasifier. This will be accomplished by utilizing EPRI's 100 kW Fuel Cell Test Skid at the facility. Provision has been made in the site layout of PSDF to phase in a multi-MW fuel cell module with commercial stacks utilizing more than 80% of gases from the transport gasifier. However, no conceptual design or cost figures were developed for the multi-MW Fuel Cell module size. Both molten carbonate and solid oxide fuel cells are being considered for testing at this size.

The PSDF is designed to share resources common to different modules. A conceptual layout of the PSDF is shown in Figure 3. The layout illustrates that both the APFBC and Advance Gasifier Modules would share a common support structure with the PCDs located at end bays of the structure for easier access. The shared resources include coal and limestone storage and preparation areas, power distribution, data acquisition, boilers and steam systems, cooling and process water, service and instrument

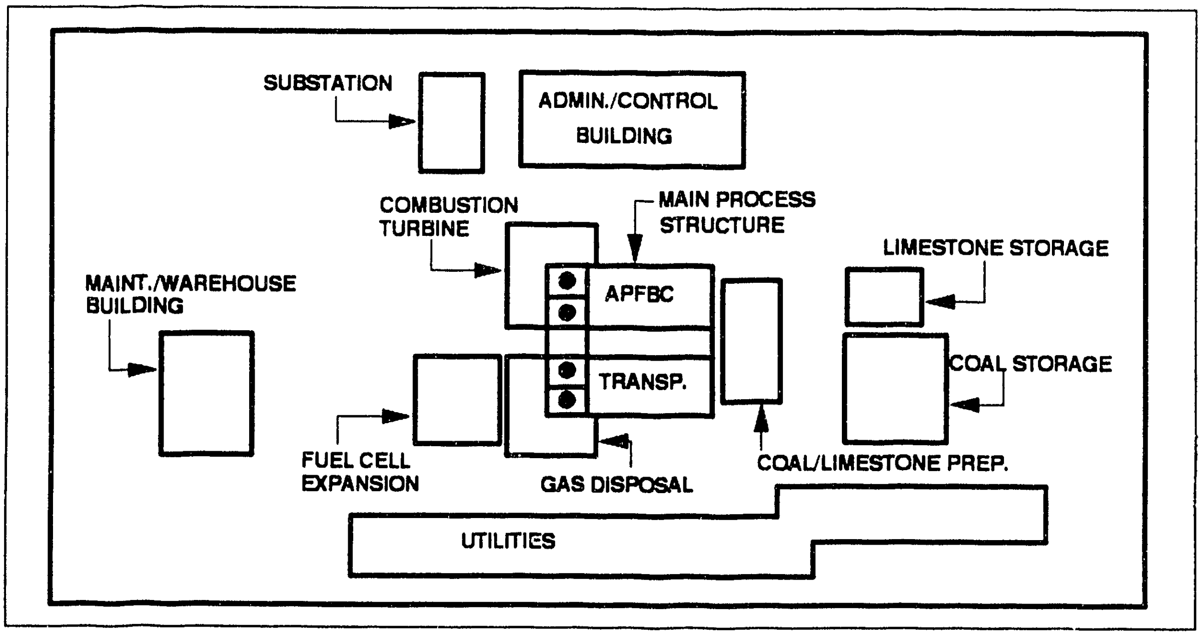


Figure 3. Power Systems Development Facility Plant Layout

air system, auxiliary fuel system, fire protection system, wastewater treatment system, nitrogen system, water treatment and chemical feed systems, and safety and security systems.

The consolidation and integration of the facilities at the PSDF will result in significant cost savings. Also, the integration will provide more flexibility within each module of the overall facility and allow implementation of a broad range of test programs. Provision has been made in the conceptual design of the integrated facility to maximize the use of equipment and technology for testing. For example, the PCDs used with the transport reactor and with the carbonizer can be interchanged for additional testing.

Schedule and Cost

A schedule for the PSDF is shown in Figure 4. The original schedule for the PSDF was based on a 15 month design phase, a 18 month installation period and a 24 month testing period. The schedule was adjusted to a 22 month design period overlapping with a 24 month installation period to better accommodate the design and construction of the facility. An additional three months was included in the operations phase to provide for additional testing. Detailed design for the base facility will commence in July 1992 with construction starting in January 1993. The target date is to have the facility commissioned for testing by January 1995. Additional modules, such as the multi-MW fuel cell, would be phased in further along in the project.

In an effort to maintain the schedule, a revolutionary training technique developed by EPRI for the power industry will be utilized. This new training technique is referred to as Interactive Video Training (IVT). The IVT will

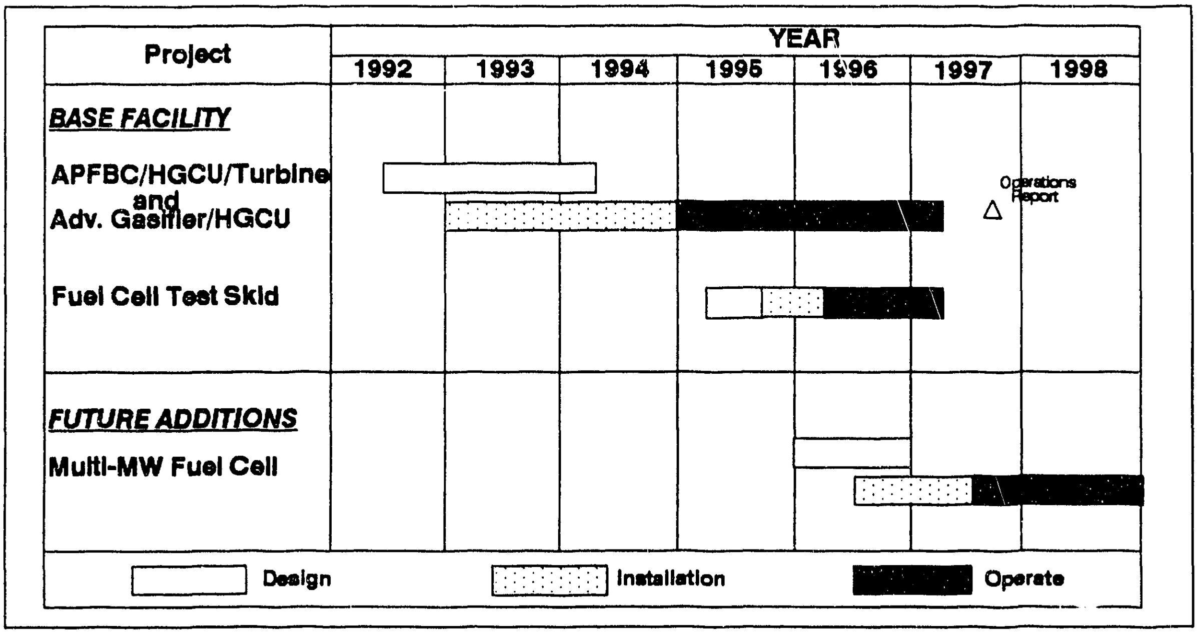


Figure 4. Power Systems Development Facility Schedule

be developed by Nolan Productions in conjunction with the engineering design and operation team. The IVT will serve to train operating personnel quicker, to archive modifications to the facility during the course of operations and to enhance technology transfer to the utility industry.

For the development of the cost estimate for the PSDF, each member of the design team developed a capital cost and engineering cost to design and construct the PSDF pertaining to their envelope of the design. In addition each member of the design team estimated manhours to erect the major pieces of equipment. SCS obtained cost information for the Particulate Control Devices (PCD) and fuel cell information by contacting various vendors. SCS assembled the capital costs and an erection cost for the PSDF. The operations estimate, conducted with the assistance of SEI, was also based on the conceptual design of the facility and experience at SCS' Clean Coal Research Center in Wilsonville, Alabama. SCS complied all the capital cost and construction cost information.

The cost estimate for the PSDF is broken down in Table 1. The total project value for the facility is $145.0 million. The cost to design the PSDF is $17.2 million or 12 percent of the total cost. The cost for installation is $85.3 million and is the major cost for the PSDF. Approximately 8 percent of the installation cost are for startup of the facility. Operations is estimated to be $42.5 million for the base facility schedule in Figure 4.

Transport Reactor Development Unit

Small pilot-scale testing (1-10 lb/hr coal feed) with a transport reactor test unit (TRTU) at MWK's Technology Development Center in Houston, TX was conducted to verify the design of the transport reactor concept. The purpose of the design verification testing by MWK for the

Table 1. Power Systems Development Facility Conceptual Design Cost Estimate

Design		$17.2 Million
Installation		$85.3 Million
Construction	$77.8	
Startup	$7.5	
Operations		$42.5 Million
Total Project Value		$145.8 Million

transport reactor concept was to confirm the engineering database to minimize the scaleup risk for the test facility's gas generator. Although the initial results from the TRTU testing were encouraging, some key design and operating questions remained for the scaleup of the transport reactor. Therefore, a scaleup effort to a transport reactor development unit (TRDU) (nominal 200 lb/hr coal feed) is currently under design to address key design and operating questions.

The TRDU will be installed and operated at the University of North Dakota/Energy & Environmental Research Center (UND/EERC) in Grand Forks, ND. The design of the TRDU was performed by MWK and was completed in July 1992. The design of the transport reactor is similar to the transport reactor design for the PSDF. The height of the TRDU is 40 ft with a 10 ft mixing zone and 30 ft riser section. The TRDU will be integrated with the existing coal feed systems, gas stream cleanup equipment and control system that are currently in place at UND/EERC. Activities at UND/EERC included preparation efforts to install the TRDU.

The installation of the TRDU is expected to be completed by November 1992 with the unit commissioned by January 1993. The results obtained from the TRDU should determine if the transport reactor is ready for scaleup at the PSDF.

FUTURE WORK

Future work for the Hot Gas Cleanup Test Facility (Power Systems Development Facility) include the initiation of the detailed design for the facility and completing the installation and operation of the TRDU. The detailed design effort will utilize the conceptual design of the PSDF as the design basis. The detailed design activities will overlap the construction activities so that the facility can be design and constructed in the most efficient way. In the early stages of the detailed design a request for proposal (RFP) for particulate control devices to be test at the facility will be issued for competitive bid. The particulate control devices for the facility are expected to be selected by January 1992.

The installation of the TRDU is expected to be completed by the November 1992 and the unit commissioned by January 1993. SCS will decide in the spring of 1993 if the transport reactor development is ready for the PSDF scale or if it requires further development.

REFERENCES

1. "Cool Water Coal Gasification Program: Commercial-Scale Demonstration of IGCC Technology Completed" Technical Brief RP 1459-1, Electric Power Research Institute, Palo Alto, CA, 1990.

2. "Cool Water Coal Gasification Project" Final Report GS-6806, Electric Power Research Institute, Palo Alto, CA, July 1990.

3. "Fuel Cell Commercialization Group" AFPS Developments, Summer 1990, Issue 5, Advanced Fossil Power Systems Department, Electric Power Research Institute, Palo Alto, CA.

4. FCCG Update, Vol. 1, No. 1, p. 1-5, Fuel Cell Commercialization Group, Washington D.C., 1990.

5. Fuel Cell News, Vol. VII, No. 4, p. 8, December 1990.

6. "Second-Generation Pressurized Fluidized-Bed Combustion Plant Conceptual Design" Phase I Report, DOE Contract: DE-AC21-86MC212023, June, 1989.

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