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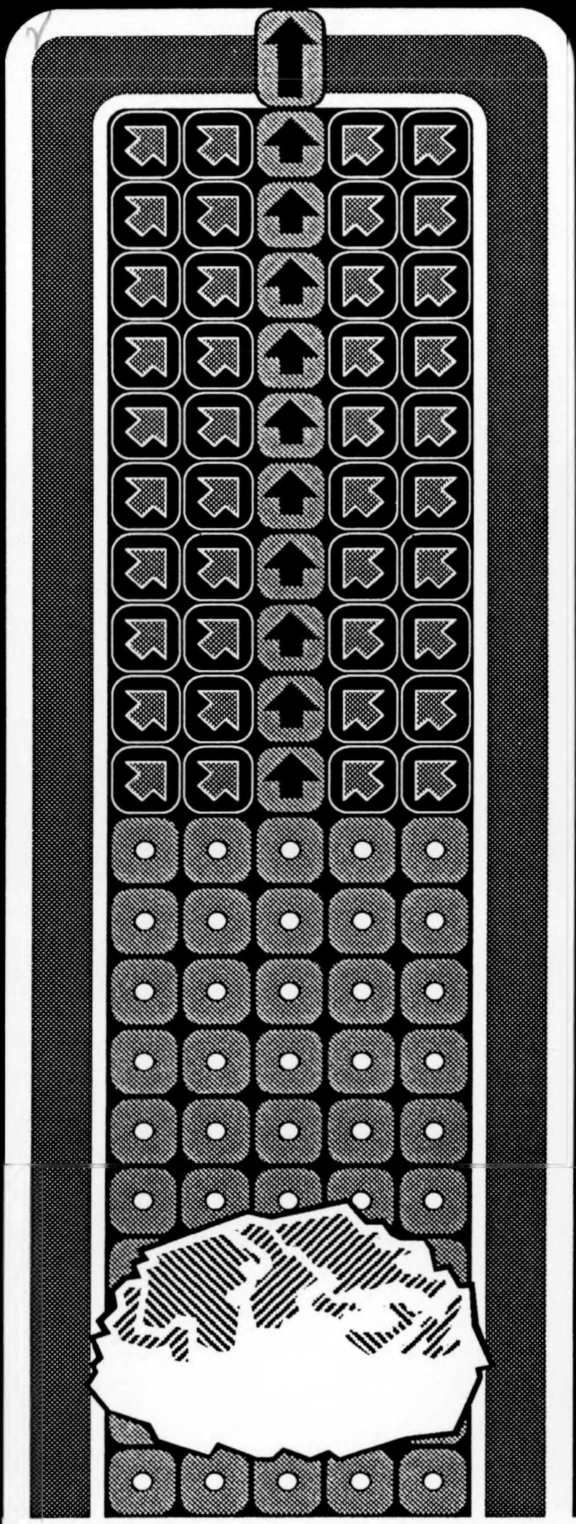

Pressurized Fluidized-Bed Combustion Program

FISCAL YEAR 1990
SUMMARY PROGRAM PLAN

SEPTEMBER 1989

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U.S. Department Of Energy
Assistant Secretary For Fossil Energy
Office Of Coal Technology

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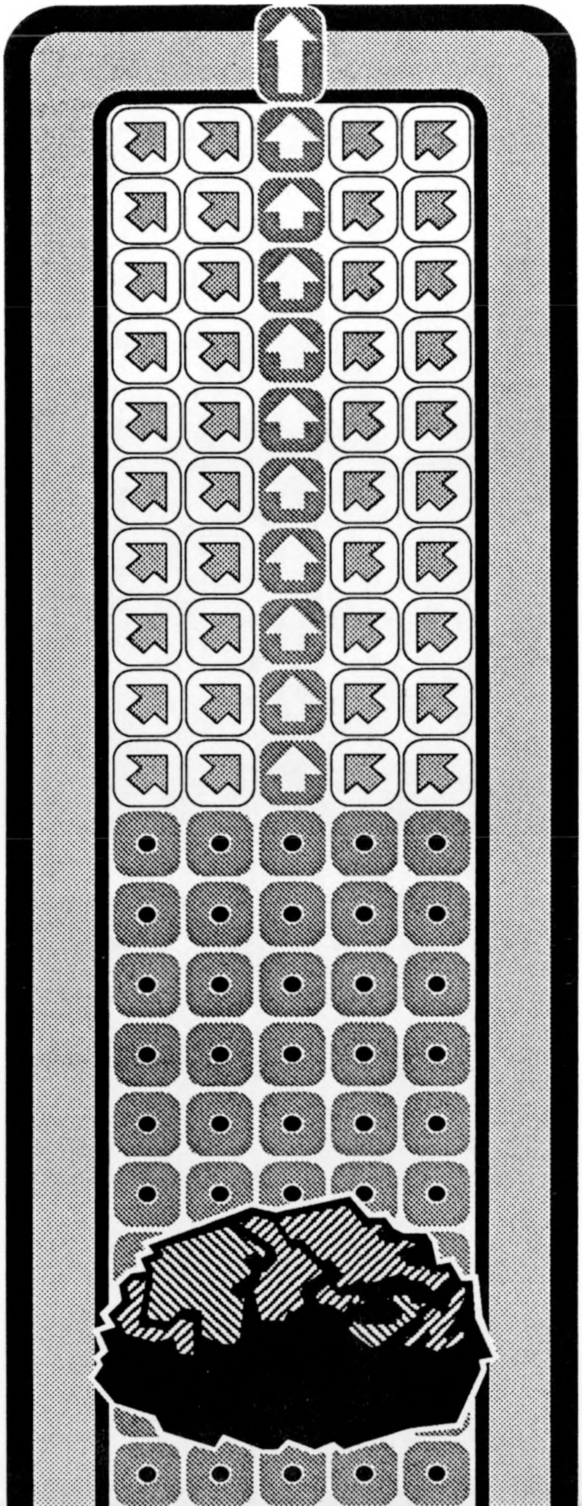

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1.0 BACKGROUND AND PROGRAM GOALS

Coal was the most popular energy resource in nineteenth century America. Its popularity was due to its superior fuel value compared to the other available fuels, e.g., wood and charcoal. Coal was used in all sectors of the economy--residential, industrial, and transportation. In fact, all locomotive transportation was coal-based. Town gas derived from coal was used for lighting, heating, and cooking applications. The first coal-fired utility was started in 1902, and in the 1920's more than 100 utilities provided electric lighting. Also in the 1920's, petroleum and natural gas began to make significant inroads and gradually began to replace coal as fuels of choice by the mid 1900's. One of the major reasons for this replacement was that burning oil or gas was cleaner than burning coal. The pollution of air due to the emission of sulfur and nitrogen oxides during coal combustion was a known phenomenon. In fact, coal burning was severely restricted in the city of London in the early twentieth century due to air pollution. The ease of handling and the use of oil and gas also contributed to the replacement of coal, especially for space heating, water heating, and power supply to light industrial and commercial establishments.

Currently, the fossil fuel resources of the United States are not in balance with the patterns of their utilization. About 94 percent of the nation's proven fossil energy reserves are coal, 3 percent are oil, and 3 percent are natural gas. However, in terms of consumption, coal accounts for only 26 percent of total U.S. fossil fuel consumption, while oil and gas account for 48 percent and 26 percent of the total, respectively. If the vast U.S. oil shale and peat reserves are included, this imbalance becomes even more pronounced. One solution to reducing our dependence on oil as an energy source is to convert oil- and gas-fired facilities to coal-based fuels as quickly as possible, and to develop new technologies for expanding the use of coal in energy generation.

The U.S. Department of Energy (DOE) and its predecessor agencies have continued to foster research and development (R&D) in coal technologies because of coal's vast resource potential. The current DOE program culminating technology demonstration is an outgrowth of this R&D. Several recent developments in the technologies that utilize coal can be attributed to R&D projects sponsored by DOE.

1.1 Background

The nation's energy security is dependent on a continued and effective utilization of all of its domestic energy resources. There is a need to have a diversified energy resource base capable of meeting our domestic energy needs in an environmentally clean and cost-effective manner. Coal is a very important link in our domestic energy security because of its domestic abundance and its substantial potential to limit the nation's dependence on imported oil. Achievement of energy security will require a flexible energy supply that avoids undue dependence on any single source of supply, domestic or foreign. The energy supply system must be able to withstand interruptions in supplies without significant adverse impact on the nation's economy or capabilities. Long-term energy security leads to energy strength and confidence in our energy supply system. The energy supply system must allow a freedom of choice in the mix and measure of energy needed to meet our industrial, commercial, and personal requirements. Furthermore, it must be available at a cost that will permit U.S. industry to remain competitive in domestic and world markets and allow residential consumers to obtain their energy needs without changing their lifestyles.

To accomplish this goal, the Federal Government has adopted two broad and underlying strategies:

- *To maximize the practical reliance on the free decisions of the private sector and to minimize Federal involvement and control in energy markets while maintaining public health and safety and environmental quality.*

- *To promote a balanced and mixed energy resource system.*

The R&D process in energy technologies advances through several phases: basic research, applied research, proof-of-concept and process development, and, eventually, commercialization. Government R&D, directed toward the earlier phases of the process, serves two critical purposes. First, basic research advances the frontiers of scientific and technical knowledge and provides the fundamental building blocks for technological innovation. Second, Government-sponsored applied R&D supports the development of new alternative energy resources by applying scientific and engineering knowledge to novel solutions to energy problems that can benefit the nation as a whole. These applications can then be pursued for further development outside the Federal sector.

The demonstration and commercialization phases are viewed as the responsibility of the private sector. With respect to funding support for R&D projects, it is DOE policy to seek cost sharing with the private sector. The degree of cost sharing varies with the technology and industry involved and the project's position on the development path. The amount is generally lower at the front end than at the more advanced stages. Cost sharing is important as a means of leveraging Federal research funds and as an indication of a long-term institutional commitment to a technology.

One of the specific missions of the Office of Fossil Energy (FE) at DOE is to conduct R&D programs aimed at increasing the contribution of coal as a national energy resource by making improvements in environmental, technical, and economic performance, and by increasing the number of areas of application and the end-use flexibility of coal-based systems. This will allow industry to bring economically competitive and environmentally acceptable coal technology options into the marketplace.

1.2 Program Goals

The goal of the Pressurized Fluidized Bed Combustion (PFBC) Program is to develop a scientific and engineering data base by the 1990's so that the private sector can demonstrate and commercialize PFB systems as a replacement for oil and gas-fired combustion systems within the utility market and as a more economical and environmentally acceptable coal-fired system for the utility market. The PFBC Program focuses on developing engineered systems that will be commercialized by the private sector. The PFBC program stresses economic efficiency, and environmental compliance or betterment.

The objective of the PFBC Program is consistent with, and supportive of, the strategic objectives of the Office of Coal Technology (OCT) and thus accomplishes the FE mission in a timely manner. Relevant strategic objectives of the OCT include the following:

- *Identify and foster development of new processes and/or equipment capable of using coal directly or as modified fuel forms to increase the efficiency in the use of fuel, to extend its applicability, and/or to allow for its substitution of oil or gas.*

- *Make available low-cost, short-construction-time, modular equipment to provide incremental generating capacity needed to meet anticipated shortfalls and provide systems analyses and develop viable low-cost technical options needed to meet the growing demand for electricity.*

- *Support appropriate R&D and associated environmental research to economically manage the environmental impacts of processing and using fossil fuels, including the work needed to establish data bases that help mitigate problems rather than merely expand the range of questions and concerns.*

In additional to the above strategic objectives, the PFBC Program addresses the following guidelines and cross-cutting objectives that are critical for achieving the strategic objectives:

- *Address the front end research requirements of technologies that can potentially contribute to the national objective of providing an adequate supply of balanced energy forms at reasonable costs. This work is to be in support of the private sector in the commercialization of technologies.*

- *Establish and maintain effective technology bases designed to provide guidance that most effectively utilizes scarce R&D funds, and to provide a basis for effective technology transfer to U.S. private sector organizations capable of commercializing the technology.*

- *Provide an adequate technology transfer mechanism to assure that the private sector has the necessary access to the various technology data bases; directly involve the industrial sector in process development activities and cost-shared projects.*

- *Identify and develop a range of processes and systems to enable all grades and ranks of coal, and sources of oil and gas to be processed, recovered, and/or used at a reasonable cost by a spectrum of energy consumers.*

- *Determine and maintain Federal involvement in fossil energy research and development through support of technologies that can potentially reduce the cost of complying with existing regulations or for reducing regulatory concerns for installation.*

- *Develop and plan research programs to enhance the possibility of exporting U.S. technology and coal as a desirable overall national goal. This includes planning and implementing research programs to increase international participation that enhances broader expertise in planning and implementation, in cost sharing, and in fostering eventual free world commercialization.*

2.0 TECHNOLOGY DESCRIPTION

PFBC involves burning coal in a bed of limestone (calcium carbonate) or dolomite (calcium magnesium carbonate) inside a furnace operated at elevated pressure and with bed temperatures normally in the range of 1400°F-1700°F. The bed material (sorbent) is fluidized (suspended) by the injection of air at the bottom of the bed. Sulfur dioxide (SO_2), released during combustion of the coal, reacts with the sorbent (limestone or dolomite) and forms a solid sulfate that can be discharged from the system as a dry solid waste along with the coal ash.

Characteristics of PFBC that offer advantages over other competing technologies for utility applications include high efficiency, lower capital and operating costs (therefore lower-cost electricity), superior environmental performance, ability to burn a wide variety of fuels (including high-sulfur coals within environmental emission limits), and modularity (with no great cost penalty for loss of economies of scale). In addition to new applications, PFBC has potential as a retrofit technology capable of pollution control and capacity boosting for existing coal-fired power plants, as well as a repowering technology for existing oil and gas-fired steam plants.

In the early stages of PFBC technology development, most efforts have been directed toward research related to combustion and environmental performance. Although PFBC has not yet been developed to the fully commercial readiness state, sufficient R&D has been carried out to establish potential advantages and technical uncertainties.

Advantages of PFBC are:

- *Modular units without the usual economy-of-scale penalty*

- *Reduced combustor size permitting shop fabrication and field erection, thereby greatly shortening construction lead time*

- *High-sulfur fuels burned in the presence of sorbent in the FBC eliminate the need for flue-gas desulfurization*

- *Reduced combustion temperature (1400°F-1700°F vs 3000°F for a pulverized coal-fired boiler) which results in:*

  -- *Minimal slagging and bonded deposit ash formation in the boiler, which reduces or eliminates the need for soot blowing*

  -- *Significant reduction of NO_x emissions*

- *Increased heat transfer rate to the working fluid*

- *Increased fuel versatility*

- *Easily handled by-product material consisting of clinker-free, granular, smooth-flowing ash which may be easily disposed of for landfill uses or potentially sold for industrial or agricultural applications.*

Technical uncertainties of the PFBC technology are:

- *Hot gas cleanup for gas turbine protection*

- *Materials survivability for heat exchanger, gas turbine, and solids handling equipment*

- *Solids handling improvement in feeding, distribution, and bed removal*

- *Combustor performance, configuration, including the heat transfer bundles, distributor plate, fuels utilization, and operational parameters.*

- *Development of reliable and accurate flue gas analysis for nitrous oxide and CO_2 emissions from fluidized bed combustion.*

- *Development of advanced third generation, high efficiency, combined cycle systems for suppression of CO_2, N_2O, and SO_2 emissions.*

3.0 CURRENT TECHNOLOGY STATUS AND PROBLEMS

The origin of PFBC is generally traced to the Winkler gas generator developed in Germany during the early 1920's. The technology evolved using atmospheric combustion conditions until pressurization of a fluidized-bed combustor combined with gas turbine expansion of the flue gas was proposed in Great Britain in the 1950's as a means of achieving improved power generation efficiency. The principal groups active in the early development of the PFBC concept were the National Coal Board (NCB) and the National Research and Development Company in Great Britain through their partnership with British Petroleum and Combustion Systems Limited. In 1969 testing began in Leatherhead, England, to pressurize the fluidized bed in hopes of realizing greater advantages over conventional coal-fired boilers and atmospheric fluidized-bed combustion.

Interest in PFBC/Combined Cycle (CC) increased significantly in the early part of the 1970's, with major research sponsored by U.S. Government agencies. The Environmental Protection Agency (EPA) funded tests at the NCB's Coal Utilization Research Laboratory (CURL) as well as fundamental research work at Westinghouse, a "mini-plant" PFBC test facility at Exxon, and a process development unit-scale integrated PFBC/CC facility that featured an adiabatic PFB combustor integrated with a Reston gas turbine. Sweden operates a component test facility in Finspong. Based on information from this facility, the Tidd PFBC demonstration plant is funded under the DOE CCT Program, and is being constructed by the Ohio Power Company in Brilliant, Ohio.

Today, only seven countries in the world have ongoing activities in PFB R&D. The United States, Great Britain, Sweden, Spain, Italy, and the Federal Republic of Germany are the leading countries in the development of PFB technology. Within the U.S., DOE has the responsibility for supporting PFB research and development. The thrust of the current DOE PFBC Program is the development of a PFBC technology data base to support the design, construction, and operation of coal-fired equipment for application as either a combined cycle PFB bed boiler or a turbocharged boiler system.

The Pressurized Fluidized-Bed Combustion Program will provide industry with the scientific and engineering technology base that will enable the private sector to demonstrate and commercialize PFB electric power generation systems. R&D has progressed to the point where sufficient data are available to design and construct a first-of-a-kind PFB demonstration plant capable of achieving overall efficiencies of 40 percent with design conditions that are not totally unreasonable from a materials standpoint. The American Electric Power Service Corporation was selected to construct and operate a 70-MWe PFB combined-cycle demonstration plant at the Tidd Power Station, Brilliant, Ohio, under the Clean Coal Technology Program. Their existing pulverized coal-fired Tidd Plant would be repowered with a pressurized fluidized-bed combustor, and a gas turbine would be added for combined cycle operation. They have also been selected for contract negotiations for construction and operation of a 330 MWe PFBC repowering project at their Philip Sporn Plant, New Haven, West Virginia. Additionally, ASEA-PFB is constructing a PFB demonstration plant in the city of Stockholm, Sweden, and at the Escatron Power Plant in Spain.

During FY 1988, follow-on testing was completed at the Grimethorpe facility to develop pilot scale data on coal slurry feeding and combustion performance using an updated U.S. designed heat exchanger tube bundle. Additionally, DOE will obtain project "core" data from the National Coal Board funded program as well as data from the EPRI furnished advanced hot gas cleanup device. No further testing is planned at Grimethorpe because the AEP Demonstration Plant will be operational by 1990. The New York University (NYU) test rig completed testing of advanced hot gas cleanup devices (HGCU).

The Morgantown Energy Technology Center initiated a metals wastage cooperative R&D program with industry. This effort will continue over a 4-year period. Also in FY 1987, the Foster-Wheeler Development Corporation completed its Phase 1 Advanced PFB Concept systems definition studies, including the conceptual design and cost of a commercial power plant and the identification and preparation of a test program to resolve those key critical technology areas required to confirm proof-of-concept. With the initiation of Phase 2 ("Process Development Unit Investigations"), each key component will be tested to develop its technology and to determine its individual characteristics. Having acquired these data, the Phase 1 plant conceptual design will be updated to reflect this new knowledge, the plant R&D needs will be reevaluated, and the test plan will be revised to define the activities taking place in the next phase of the program.

In Phase 3 ("Integrated Subsystem Pilot Plant Tests"), the plant key components will be built and tested as an integrated subsystem to ascertain system performance characteristics as well as component scale-up effects. Similar to work conducted in Phase 2, the plant conceptual design will be modified to reflect Phase 3 test experience, and previous performance predictions and economic analyses will be updated. The three-phase approach for the second-generation PFB combustion plant is summarized in Table 1.

Table 1

INTEGRATED R&D PROGRAM PLAN
SECOND GENERATION PFB COMBUSTION PLANT

Phase 1 Plant Definition	Phase 2 Process Development Unit Investigations	Phase 3 Integrated Subsystem Pilot Plant Tests
Cycle Optimization	Technology Development Tests (Test Each Component)	Integration Component Tests, 5 Mwe
Establish Configuration	o Carbonizer o CPFBC	Dynamic Tests
Determine R&D Needs	o Topping Combustor o Cross Flow Filter	
Formulate Test Program		

New initiatives in FY 1989 include a request for proposals for advanced components and advanced sorbent research and development. Plans are under way to award contract(s) for the new procurements in FY 1990. Individual Project details and descriptions are contained in the PFB Program Implementation Plan and Annual Topical Report of the Morgantown Energy Technology Center.

Four technology rigs and one major test facility have addressed the major problem areas that have delayed acceptance of the technology in the marketplace. The results of testing performed at the facilities are summarized in the following sections.

Gas Turbine Materials

Static turbine material tests have been performed at the CURL facility (1000 hours in collaboration with the General Electric Company and STAL LAVAL), and a 5600-hour test at General Electric's Long-Term Material Test Rig (LTMT). Dynamic testing, characterized by a "moving" turbine wheel, was completed at the Curtiss-Wright SGT unit. It was concluded from these tests that:

- *Cooling of components to 1340°F-1450°F appears to be a viable method for reducing corrosion in PFB-powered gas turbines to acceptable rates. However, based on LTMT experience, cooling may prove catastrophic if it prevents protective oxides from forming.*

- *PFB flue-gas particulates under 10 micron size do not appear to be erosive at velocities up to 1400 feet per second when corrosion is minimal.*

- *Deposition of trace compounds does not appear to be a serious limitation to the commercial use of PFB gas turbines.*

- *There was no evidence of any measurable loss of material from the surfaces of the FeCrAlY and* $CoCrAl_4$ *coated blades. The STAL LAVAL 1000-hour test indicated a component life of at least 8000 hours and possibly two or three times greater. The results of the 1000-hour SGT test indicate that overlay coatings such as FeCrAlY applied to industrial size blading may provide turbine protection for over 25,000 hours.*

Hot Gas Cleanup

A significant number of PFBC test hours have been accumulated with "conventional" type cyclones at the CURL, SGT, and IEA/Grimethorpe facilities. The cyclone data to date indicate that staged cyclones can obtain outlet loadings of less than 0.1 grains per standard cubic foot (gr/scf). However, loadings are still several times greater than EPA emission standards. The levels of particulate loadings may be low enough to provide adequate turbine life, but some post-turbine cleanup will be needed to meet EPA particulate limits.

DOE has a cleanup program under way that is directed toward the development of devices capable of meeting both EPA and gas turbine requirements. These devices include various types of ceramic filters.

Gaseous Emissions

Two of the most important advantages of PFB are its ability to remove sulfur during combustion and its inherent low NO_x emissions. Estimates of PFBC air emissions accumulated over a significant number of PFBC test hours at CURL, SGT, NYU, and IEA/Grimethorpe as compared to conventional power plants are tabulated in Table 2.

Combustor Performance

Most of the PFBC work accomplished to date has centered on process development, including combustor geometry, operating parameters, and coal and sorbent properties. Generally, these tests indicate that PFBC first generation designs offer acceptable performance and can be built by using state-of-the-art materials and construction techniques. The PFB combustor can readily meet current SO_2 and NO_x emissions standards as well as achieving combustion efficiencies greater than 99 percent.

The Grimethorpe facility has confirmed test programs conducted in the various technology test rigs. The range of tests performed over a period of over 4,000 hours assessed overall combustor performance, sulfur retention, heat transfer, in-bed erosion, coal slurry feeding, gas cleanup, and particulate erosion on turbine materials. Recent testing evaluated the performance of the PFBC with a coal-water mixture fuel. System performance on Pittsburgh No. 8 bituminous coal was very good down to 23 percent water content. Preliminary information from the recently completed follow-on program indicates that acceptable erosion rates could be achieved with the updated tube bundle design; however, this would require careful selection of alloy materials and operating conditions.

Table 2

COMPARISON OF AIR EMISSIONS FROM PFBC-CC TO CONVENTIONAL POWER PLANTS

	Conventional Plant with FGD (1)	PFBC-CC (1)	NSPS (2)
Overall Plant Efficiency, %	34	38-40	--
Sulfur Removal, %	90-95	90-98	90
Emissions			
Sulfur Dioxide, lb/MM Btu	0.9	0.3	1.2
Nitrogen Oxides, lb/MM Btu	1.8	0.5	0.7
Particulates, lb/MM Btu	0.03*	0.01**	0.03

(1) Coal: Illinois No. 6
12,235 Btu/lb HHV
3.7% Sulfur
(2) NSPS: New Source Performance Standards

*Assumes bag house
**Assumes advanced hot-gas cleanup device

4.0 MARKET APPLICATIONS

Most current and past R&D programs have focused on developing PFBC's for utility plant applications because the greatest potential for the technology is in this application. The characteristics of PFBC that offer market advantages include high efficiency and superior environmental performance, ability to burn a wide variety of fuels (including high sulfur coals within environmental emission limits), and modularity (with no great cost penalty for loss of economies of scale). Modularity would enable a utility to install a PFBC in incremental steps. This permits operation with a smaller incremental capacity margin, therefore reducing overall costs. Modularity would also shorten the construction time with smaller modular hardware. Utility market penetration has not occurred because the state of the technology is not sufficiently advanced, especially for acceptance by the electric utilities which take a conservative viewpoint as a regulated industry.

The potential utility market for PFBC consists of:

- *Replacement of retiring coal-fired steam units.*
- *New plants required for demand growth.*
- *Repowering of coal-fired units and oil- and gas-fired steam units.*

PFB may be desirable as a pollution controlling, capacity boosting technology for existing coal-fired power plants. The top 50 Eastern United States utility plants, which were not subject to the NSPS, released approximately 7,600,000 tons of sulfur dioxide to the atmosphere in 1980. These plants had emission rates varying from 3.1 to 11.7 lb sulfur dioxide/MMBtu coal input. Repowering these plants by replacing existing boilers with PFB combustors to reduce the SO_2 emissions would remove approximately 90 percent (6,800,000 tons SO_2) of the sulfur contaminants from the atmosphere annually. Presently, there are no current projections for the number and capacity of existing coal-fired power plants that may be repowered with PFBC. The actual market penetration will be determined by market forces and pending acid rain control legislation or initiatives.

In determining the replacement market potential, the distribution of existing steam capacity by age and energy source was obtained from DOE data for "1981 Inventory of Power Plants in the United States." It was assumed that plants to be retired would have 40 years of service life and would exclude those oil- and gas-fired units that were less than 40 years old by 1990. The latter units were assumed to be potential capacity for repowering.

Projected demand growth capacity of coal-fired plants was obtained from the report, "National Energy Policy Plan Projections to 2010." Table 3 presents the PFB potential utility sector market. A market study is in progress that reflects the current utility market potential for PFBC's.

Successful operation of the IEA/Grimethorpe facility helped to strengthen the PFB market potential for both utility and industrial use. With respect to the industrial market, the PFB concept, whether in true combined cycle mode or operating principally as a supercharged boiler producing process and service steam, has sufficient advantages over the AFBC and the conventional PCF boiler (when high-sulfur fuel must be burned) that it can be expected to become competitive for expansion and replacement installations in industrial service.

Table 3

PFBC UTILITY MARKET POTENTIAL FOR THE YEARS 1990-2020
(in 1000 Megawatts)

Year	Replacement[1] Total	Growth[2] Total
1990-1994	20.9	21.0
1995-1999	47.7	50.0
2000-2004	21.7	50.0
2005-2009	19.5	74.0
2010-2014	32.4	74.0 (a)
2015-2019	45.2	74.0 (a)
Total	187.5	343.0
Total (Quads)	9.6	17.7

1. Survey of Electric Utility Gas and Oil-Fired Boiler Population, EPRI, AP-2342. April 1982.

2. Data derived from National Energy Policy Plan Projections to 2010, DOE/PE-0029, December 1985.

(a) Assumed same as projection for the years 2005-2009.

5.0 PROGRAM STRATEGY

DOE funded research and development of PFB is approaching 10 years duration, and significant progress has been made. Major advantages of the technology have been identified, and industry appears now to be moving to build prototype systems on the way to ultimate commercialization. The technology has advanced to the point where most of the problems requiring R&D attention are known and are being addressed. In FY 1986, DOE focus shifted to developing advanced-cycle PFB systems that would build upon the current PFBC program in extending the technology to develop substantially higher payoff, high-risk PFBC systems. Performance goals for advanced PFBC systems include process efficiency approaching 45 percent and cost of electricity reduction at least 20 percent below conventional pulverized coal boilers with flue-gas desulfurization.

The prime objectives of the PFBC Program are twofold, namely:

- *To develop a U.S. technology base for scientific and engineering technology data through proof-of-concept that supports private sector efforts to demonstrate and commercialize PFB systems for electric power generation with initial entry in the early 1990's time frame*

- *To extend the state-of-the-art by developing advanced PFB systems that offer substantial improvement in cycle performance (approaching 45 percent) and reduction in COE by at least 20 percent over conventional coal-fired power plants with flue-gas desulfurization to enable industry to proceed with pilot scale testing by the mid-to-late 1990's. Advanced PFB systems would also be capable of providing economic modular increments to minimize field erection and shorten construction time (thereby lowering financial requirements).*

The following sub-objectives were established to develop a technology base that would support private sector efforts to demonstrate and commercialize PFB systems for electric power generation by the early 1990's. The data thus developed would be in sufficient detail so that the private sector could decide whether or not to proceed in PFB demonstration to verify process reliability and maintainability under utility operating conditions and to show significant economic advantage over conventional coal-fired utility plants with flue gas desulfurization while meeting or exceeding all environmental constraints.

- *METC to conduct, by October 1989, a preliminary in-house assessment of PFBC technology potential for industrial and cogeneration applications as well as the utility sector. If the preliminary study results show promise for these PFBC applications, a more extensive assessment will be made under competitive procurement to address this technology potential.*

- *Continue development of a PFB technology repository of past, present, and future R&D results, design specifications, and operating data, and update them on a continuing basis. The contents will be in the format and the detail required for industry's use in demonstrating and commercializing the technology.*

The following sub-objectives were established to extend the state-of-the-art by developing the technology base for Advanced PFB concepts.

- *Initiate by October 1986 conceptual design and cost estimates of an advanced PFB utility plant and identify and prepare a test program addressing those key critical technology areas required to confirm proof-of-concept. (Accomplished)*

- *Complete the conceptual design and cost estimates and initiate by March 1988 a subsystem test program of those critical technology developmental areas needed to confirm proof-of-concept. This subsystem testing program is to be completed by September 1990.*

- *Initiate by December 1990 the design and operation of an integrated test facility to verify proof-of-concept. This integrated test program, as well as a modified conceptual design and cost estimate, will be completed by March 1993. These data will be incorporated in the PFB technology data base.*

- *Complete by December 1989 an alternative advanced concept system having the project goal of modularity as well as process efficiency approaching 45 percent and cost of electricity reduction of at least 20 percent below present systems.*

- *Initiate by September 1990, advanced component development to evaluate advanced systems based on the results of the Foster-Wheeler and M.W. Kellogg projects.*

- *Initiate by September 1990, advanced third generation high efficiency concepts with emphasis on N_2O, CO_2, etc. emissions suppression.*

The research and development activities supporting the program are embodied in two categories: PFB technology development and advanced cycle systems. These activities are summarized below.

PFB Technology Development

Projects are being directed to develop a U.S. technology base through proof-of-concept to support private sector efforts to demonstrate and commercialize first entry PFB systems for electric power generation. The current PFB program that supports development includes the following R&D activities:

-- Test program to develop pilot scale data on performance of an updated U.S. designed heat exchanger using a coal slurry feed at Grimethorpe is complete. Data analysis and report preparation are in progress. The U.S. DOE will also obtain data from the core National Coal Board program as well as from the EPRI sponsored advanced hot gas cleanup test program.

-- METC in-house activities include systems evaluation, PFBC data base activities, and combustion performance, as well as testing of in-house reactors (both hot and cold).

-- Metal wastage studies at METC and other organizations to include erosion/corrosion (in-bed heat exchangers, gas turbine blades) experimental testing, including experiments and predictive modeling.

-- Hot Gas Cleanup: Contract negotiations are under way between METC/AEP to have AEP include the filter element scope in the contract. The scope would include conceptual design consideration of four devices. The activities are being addressed under a separate hot-gas cleanup program plan. Details of the hot gas stream cleanup R&D program that supports PFB activities are contained in the Hot Gas Cleanup Program Plan.

Advanced Cycle Systems

Advanced-cycle projects build upon the current PFBC program by extending the technology to develop higher performance, more economical PFBC systems. Performance goals for second-generation advanced PFBC systems include process efficiency approaching 45 percent and cost of electricity reductions of at least 20 percent below conventional pulverized coal boilers with flue gas desulfurization.

Higher turbine inlet temperature, high bed pressures, gas reheat, and intercooling are among the possible approaches. Advanced gas turbines offering high performance are expected to be available in the 1990's. PFB cycles matched to those machines will be one of the potential candidates for high efficiency, low COE technology.

The technical description of the PFBC Program is provided in a Legend of Events in Exhibit 1.

Exhibit 1

PFB LEGEND OF EVENTS

Number	Event	Date
1.	Initial PFB Program.	Circa 1972
2.	Completed preliminary analyses and decision to proceed with R&D.	Circa 1974
3.	Initiate scientific R&D test rigs; initiate IEA/Grimethorpe.	Circa 1974-1976
4.	Complete generic R&D testing at DOE test rigs and identify technical problem areas for further R&D.	12/84
5.	Complete R&D program of problem areas.	12/89
6.	Complete data analysis of problem area R&D; transfer generic R&D to data base.	1990
7.	Complete scientific PFB Technology Data Base.	1992
8.1	Complete operations of IEA/Grimethorpe.	4/84
8.2	Identify problem process areas at IEA/Grimethorpe.	6/84
8.3	Transfer title of IEA/Grimethorpe to NCB.	8/84
8.4	Decision for follow-on testing at Grimethorpe to resolve key problem areas.	10/84
8.5	Complete evaluation of IEA/Grimethorpe operating data and published final reports.	12/84
9.	Initiate follow-on program at Grimethorpe.	4/86
10.	Completed coal-slurry feed system and updated heat exchanger testing at Grimethorpe.	11/87
11.	Complete follow-on R&D at Grimethorpe and prepare final reports.	12/89
12.	Complete METC Industrial Applications Study aimed at evaluating the potential of PFBC in the industrial sector.	9/91
13.	Initiated Advanced PFB systems program; release RFP.	5/85
14.	Selected contractor for Advanced PFB systems program.	5/86

Exhibit 1 (continued)

Number	Event	Date
15.	Initiated Phase I - System Definition and Conceptual Design.	10/86
16.	Completed Phase I - System Definition and Conceptual Design.	7/88
17.	Initiated Phase II - Component Development and Testing.	4/88
18.	Complete Phase II and initiate Phase III - Integrated Subsystem Testing for Proof-of-Concept.	5/91
19.	Complete Phase III and identify technical problem areas for follow-on resolution; transfer data to technology data base.	5/93
20.	Released RFP for Alternative Advanced PFB Systems Conceptual Designs.	4/88
21.	Awarded contract(s) for Alternative Advanced PFB Systems Conceptual Studies.	9/88
22.	Complete Alternative Advanced PFB Systems Conceptual Studies.	12/89
23.	Initiate advanced third generation concepts.	9/90
24.	Initiate advanced component development.	9/90
24.1	Select TIDD HGCU slip stream device.	2/90
24.2	Complete TIDD HGCU slip stream construction.	10/91
24.3	Start TIDD HGCU slip stream testing.	1/92
24.4	Complete TIDD HGCU slip stream testing.	12/93

6.0 PROGRAM MANAGEMENT

The development of PFBC technology is under the overall direction of the Assistant Secretary for Fossil Energy. DOE Headquarters is responsible for program development, evaluation, planning and policies, developing budget requests, and obtaining funding. Under the decentralized management approach, the Morgantown Energy Technology Center (METC) is the field center responsible for program implementation to achieve program technical goals through directing and managing specific projects within the PFBC Program area.