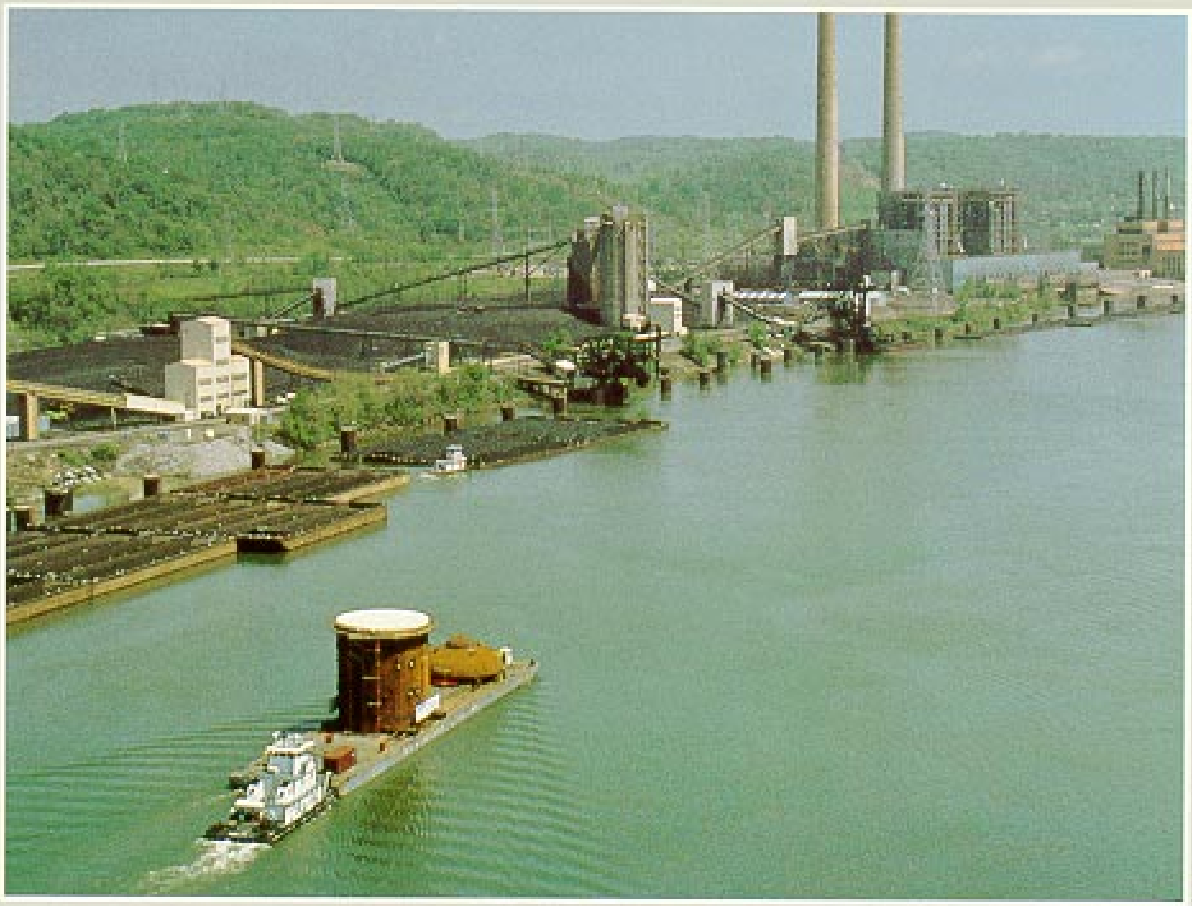
TOPICAL REPORT NUMBER 1

MARCH 1990

CLEAN COAL

TECHNOLOGY



Tidd:
The Nation's First PFBC Combined-Cycle Demonstration

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Tidd: The Nation's First PFBC Combined-Cycle Demonstration

Prepared jointly by:

U.S. Department of Energy
Assistant Secretary for Fossil Energy

American Electric Power Service Corporation

Contents

Cover photo:
Shipped up the Ohio River, the pressure vessel passes AEP's Cardinal plant as the barge nears Tidd, the red brick power plant at the far right, ushering in a new era for clean coal technologies.

Foreword

Coal's abundance makes it one of the nation's most important strategic resources in building a more secure energy future. However, the characteristics of coal tend to inhibit its greater use as a fuel.

For coal to reach its full potential, economically competitive and advanced coal-using technologies and systems must be developed— and they must be responsive to diverse energy markets, varied consumer needs, and stringent environmental requirements.

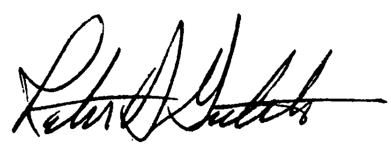
If there is one effort that can best define our unique opportunity to merge technological know-how with goals for a cleaner environment and continued economic prosperity, it is the Clean Coal Technology Demonstration Program.

A government-industry partnership, this program is demonstrating, at commercial scale, a new generation of innovative coal-utilizing processes in a series of "showcase" plants across the country. For many technologies, these demonstrations are the culmination of 15 to 20 years of research and development efforts that have yielded major improvements in the environmental and economic performance of coal-based energy technologies. For U.S. power and energy industries, the demonstration projects represent the final step over the threshold between the research laboratory and the commercial market.

This final step will occur only if the concepts and equipment developed in the demonstration projects are replicated and successfully deployed into the marketplace. Such deployment can occur only if decision makers are fully informed about their options.

With this first issue of *Clean Coal Technology,* a new series of topical reports on the demonstration program, we hope to forge an essential link with potential users of the technologies and the many decision makers who play important roles in determining the commercial applicability, viability, and success of innovative and new energy technologies. This series will provide a forum for communicating the potential of the technologies and the status and accomplishments of the projects.

Innovative clean coal technologies offer tremendous potential as a part of the solution to the many complex and integrated problems we face in our rapidly changing energy arena. This series of topical reports will be one of the many efforts undertaken to communicate vital information from the demonstration program about technological opportunities that could significantly reduce or perhaps eliminate the threat of acid rain damage in the future, while at the same time create the capability to solve the anticipated problems in meeting long-range energy requirements.



Robert H. Gentile
Assistant Secretary
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Preface

The Clean Coal Technology Demonstration Program is a unique joint venture of industry and government. It is a cost-shared effort to develop advanced coal-based technologies that offer numerous options for addressing a wide range of energy issues, including acid rain, global warming, improved energy efficiency, energy security, and environmental quality,

In nearly every phase of the program's implementation, precedent setting procedures have been implemented in joining government requirements to the commercial requirements of industrial participants, who by law pay at least half the costs. Cooperation has been essential in preparing procedures that enable both government and industry to pursue mutual and separate goals. In the relationships established, industry is the performer, the owner, and the implementer. The government shares in the cost, provides recommendations, and ensures that the program's ultimate goal— commercialization of a suite of advanced coal-using technologies— is achieved,

Some of the demonstration projects are approaching the stage where useful design, construction, or operational data are being generated. The time is opportune for communicating these results to the industrial community and to those who will participate in key decisions concerning the commercial application of clean coal technologies. However, a balance must be achieved between the government's responsibility to see that the public reaps full value for its share of the funding and the industrial participant's concerns about inadvertent release of proprietary data and controlled operational information.

Clean Coal Technology, a series of topical reports, is one means to achieve these goals.

Prepared jointly by the industrial participant and the government's program and project managers, these reports will establish a communication link among industry, federal and state government, and the public. Each report will contain sufficient information to track a project's progress, determine its status, and evaluate its potential. Each report lists sources of indepth information on commercial aspects.

This topical report features PFBC, or *pressurized fluidized-bed combustion technology,* and describes the status of one of the most advanced demonstration projects in the program. The project as well as the report are outstanding examples of what can be achieved through the cooperation of industry and government. This first issue introduces a new concept for distributing information as it is produced from the demonstrations.

The *Clean Coal Technology* series is designed to stimulate interest in the program, facilitate technology transfer, and encourage commercialization by those most interested and prepared to do so. The series is an evolving concept with the flexibility to be refined so that the information can remain relevant and satisfy user needs.

Dr. C. Lowell Miller
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Tidd: The Nation's First PFB C Combined- Cycle Demonstration

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Tidd, an electric generating station in Brilliant, Ohio, will have the nation's first pressurized fluidized-bed combustor (PFBC) to operate in a true combined-cycle mode. And for the first time in the U.S., this emerging clean coal technology will power an operating, commercial-scale plant. Almost all facets of the project involve pioneering efforts. Tidd will be the first PFBC facility in the U.S. to:

- Burn high-sulfur coal in full compliance with existing environmental requirements
- Be designed in accordance with U.S. codes and standards
- Have the pressure vessel and combustor internals assembled off-site and shipped via barge to the site as a complete module
- Use cyclones to clean up hot gas for an operating gas turbine
- Demonstrate the ability of in-bed tube bundles and gas turbine blades to survive in a large-scale, coal-fired, operating plant
- Demonstrate the ability to control an integrated combined-cycle system in utility operation.

Government and industry are jointly funding the $1 85-million project. The American Electric Power Company, Inc. (AEP) is providing $114.8 million, and the State of Ohio's Coal Development Office is contributing an additional $10 million, for a total of $124.8 million from industry sources. To this amount, the U.S. Department of Energy (DOE) is adding $60.2 million.

The project involves modernizing a 46-year-old power plant with technology that can burn coal efficiently while removing sulfur and significantly reducing nitrogen pollutants, both thought to contribute to acid rain. Repowering Tidd offers the added advantage of boosting power output while lowering emissions.

The owner of the Tidd plant is the Ohio Power Company (OPCo), an AEP

The project site is AEP's deactivated Tidd power plant on the Ohio River near Brilliant, Ohio. The PFBC vessel is housed in the new building (black walls, white roof) adjacent to the plant.

subsidiary. Electricity produced at Tidd will be dispatched by AEP into its will be dispatched by AEP into its transmission system. The American Electric Power Service Corporation (AEPSC), another AEP subsidiary, is serving as the utility's agent and is managing the project. The PFBC-related equipment is being supplied by ASEA Babcock, a partnership between The Babcock & Wilcox Company (B&W) and ASEA Brown Boveri Carbon (ABB Carbon).

Benefits of PFBC Technology

A clean coal technology (CCT) capable of burning high-sulfur coal to generate electricity efficiently and eco-nomically, PFBC can do so while meet-ing stringent New Source Performance Standards (NSPS). Compared to a conventional pulverized coal-fired plant, a PFBC combined-cycle plant offers several major advantages:

- Low SO_2 and NO_x emissions
- Lower capital and operating costs
- Increased thermal efficiency
- Fuel flexibility
- Modularity

More than 90% of the sulfur released while burning coal can be removed in the PFBC process. NO~ can be reduced by *50%* to 70%.

Capital and operating costs for PFBC are lower than for conventional coal fired boilers with flue gas scrubbers. Typical savings are roughly 10% of costs. Factors contributing to these savings include higher heat transfer rates in the boiler, smaller unit size, higher plant efficiency, elimination of costly add-on pollution control equipment, and easier solid waste disposal.

In PFBC, the rate at which heat is transferred from the bed to the tubes is four to five times greater than in a conventional coal-fired boiler. PFBC combined-cycle technology offers the potential to achieve thermal efficiencies as high as 45%, a significant improvement over the 36% efficiency of today's coal-fired plants.

The fuel flexibility offered by a PFBC boiler enables a plant to burn a wide range of coal, regardless of its quality (e.g., its heat, ash, and sulfur content, or its fusion temperature).

Modularity makes PFBC combined cycle technology an attractive option for either repowering or new applications. PFBC modules, available in two sizes, can be installed individually or in multiples. The modules are suitable for installation in existing facilities, where a PFBC module would replace a unit's

Pressurized Fluidized-Bed Combustion

In a fluidized-bed combustor, crushed coal with limestone or dolomite (called "sorbents") is suspended by jets of air. This "bed" of coal and sorbent actually floats inside the boiler, tumbling in a way that resembles a boiling fluid, hence the name "fluidized." Inside a PFBC boiler, pressures are up to 16 times higher than normal atmospheric pressure.

As the coal burns, sulfur is released. The limestone acts like a chemical "sponge" to capture the sulfur before it can escape the boiler. The sulfur-laden sorbent forms a dry waste. Some of the waste is removed with the bed ash through the bottom of the boiler. Smaller ash particles, or "fly ash," are carried out of the boiler and captured by cyclone dust collectors.

Also, because the tumbling motion of the coal enhances the burning process, combustion temperatures can be kept relatively low— to less than 1,600 ^{0}F, or almost half that of a conventional boiler. This is also the temperature range within which the reaction of SO_2 with limestone and dolomite is most effective. Furthermore, this range is lower than the temperature at which substantial amounts of NO~ are formed.

To maintain bed temperature within the desired range, heat is extracted continuously by immersing cooling tubes in the fluidized bed. Water (or another working fluid) flows through the bundle of tubes, changes to steam as it is heated, and is routed through a steam turbine to generate electricity.

Hot, pressurized flue gases from the combustor flow through "cyclone d ust collectors" to remove particulate matter that could foul, corrode, or erode the blades of the gas turbine. After cleaning, the hot gases are routed to a gas turbine and expanded to generate electricity.

boiler, or in new plants, where one or more modules would be installed,

In repowering, the old boiler is replaced while most of the remaining facilities are retained, although some may be refurbished. Because the facility has already been sited, built, and connected to the power grid, repowering can be an economical alternative to constructing a new power plant.

Repowering with combined-cycle PFBC technology enables an existing plant, such as Tidd, to meet environmental constraints while at the same time producing more power than the original plant. Depending on the application, the capacity of the existing plant can be increased by up to *25%* with PFBC combined-cycle technology.

When a new power plant is built, PFBC modules can be installed incrementally in phases, making it easier for a utility to manage capital investment without sacrificing economies of scale. Staged, modular expansion shortens construction time and lowers the costs required to bring new capacity on line, In addition, the reliability of a string of parallel modules is typically higher than for a single, large unit.

In sum, the many features of PFBC combined-cycle systems are expected to make this technology an attractive and highly competitive option in the suite of emerging clean coal technologies.

Need for the Demonstration

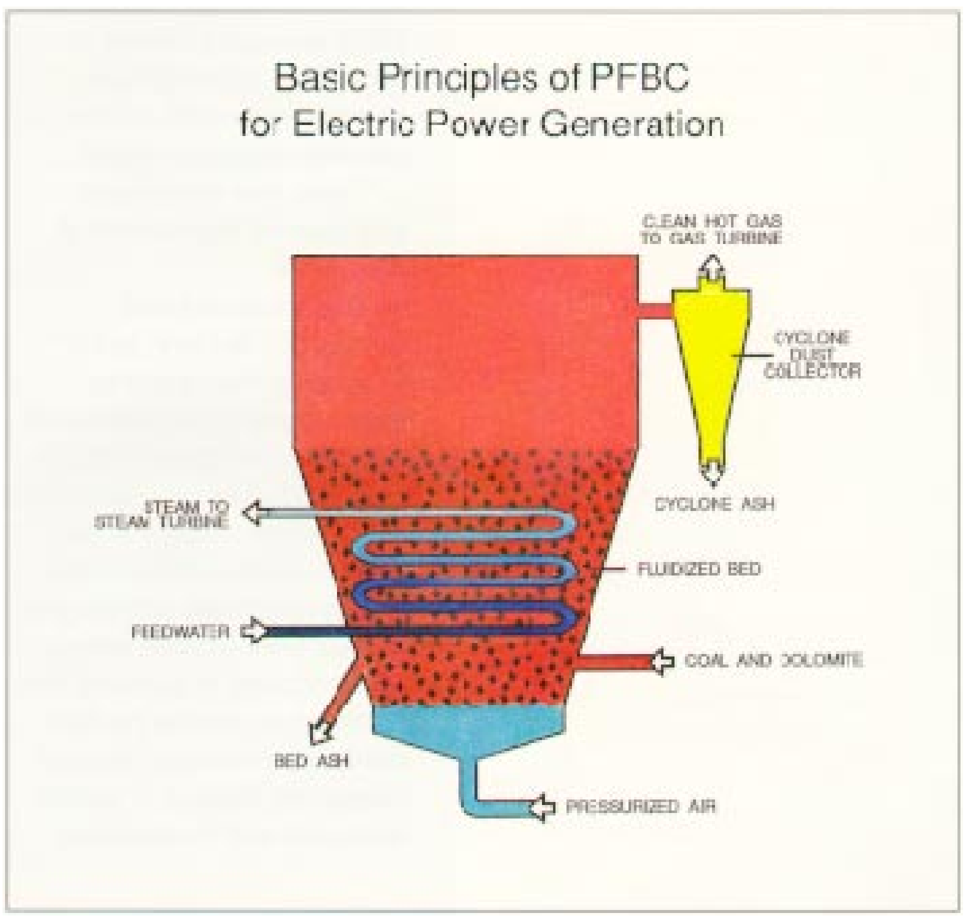
Never before has PFBC technology been employed in the U.S. in a commercial facility. Previous tests have been conducted at far smaller scales and in controlled settings. Expectations about the performance of PFBC systems at larger sizes have been based on these earlier tests and engineering estimates. Without actual operating experience, however, uncertainty and risk are inherent, and this risk can be a barrier to commercial acceptance.

The purpose of the Tidd PFBC demonstration is to verify expectations about the technology's economic, environmental, and technical performance and to collect *actual* data from a utility-operated facility while it is subjected to "real world" conditions.

Potential users must be confident that the systems are not only technically feasible but also viable in the real world with all its attendant complexities.

In 1989, DOE's Innovative Control Technology Advisory Panel assessed impediments to the commercialization of clean coal technologies. The Panel

In fluidized-bed combustion, crushed coal mixed with sorbent burns while suspended by jets of air. Water flowing through tubes submerged in the hot, turbulent bed changes to steam which drives a steam turbine. The hot flue gases are cleaned in cyclone dust collectors and then routed to a gas turbine.



described a number of barriers relating to economic risks, regulatory concerns, and environmental problems.

Economic Risks

Economic problems and risks result from various market imperfections or failures such as unrecognized value of research and development, imperfect regulation, imperfect knowledge, environmental externalities, and unrecognized public needs,

There are costs associated with bringing a technology to full commercial maturity. A new technology can have a higher cost at first than the technology it is meant to replace. Typically, a first-of-a-kind facility will have comparatively higher development, testing, engineering and design, and fabrication costs than will subsequent plants. Consequently, the true cost savings offered by the new technology usually cannot be realized until the third to fifth plant has entered the marketplace.

Barriers to New Technologies

In its 1989 *Report to the Secretary of Energy Concerning Commercialization Incentives,* DOE's Innovative Control Technology Advisory Panel summarized barriers to clean coal technologies as follows:

"These new technologies face potential impediments of three types.

"First, because these technologies are new, and in many cases have yet to be demonstrated at the commercial scale, engineering estimates of actual cost and performance are still uncertain. Thus, it is too early to expect utilities or other firms to build these technologies on a commercial scale without some reduction of economic risk.

"Secondly, despite the best efforts of regulators to properly balance the interests of electric ratepayers and shareholders, institutional problems inherent in rate regulation today cause utilities to be reluctant to spend large amounts of money for new generation projects of any kind, including CCTs. Also siting and permitting regulations can be duplicative and overly complex.

"Some environmental air quality regulations may also potentially constrain new CCT demonstration and deployment, despite the fact that both the regulations and the CCT technologies have the goal of a cleaner environment. Some regulations or policies may create uncertainties because of lack of clarity, while others provide CCT demonstration with inadequate time for compliance. In addition, in some cases, environment permitting and/or approval may be subject to delays which increase project uncertainty and/or costs."

Developers of "pre-commercial" CCT plants risk higher than expected project capital costs and operating costs and lower than expected performance.

Regulatory Concerns

Protecting ratepayer interests while at the same time providing a reasonable business environment for utilities is a complex and difficult task, one in which balance is very hard to achieve,

The Innovative Control Technology Advisory Panel observed that problems faced by utilities and other regulated developers of CCT projects tend to involve electricity rate regulation and/or the state siting and project approval process.

Rate regulation can significantly impede CCT investment if developers are concerned or uncertain about the potential for cost disallowances, inadequate rates of return, financial effects of delayed construction projects, and regulatory lag. In addition, complex and lengthy siting and project approval processes may be concerns.

Environmental Problems

Ironically, CCT demonstrations are subject to a number of environmental impediments. The problem is not due to the intent of the environmental regulations but occurs during implementation or enforcement.

Environmental permitting processes can be long and costly, and delays tend to increase borrowing costs of a project. Time limits in some environmental and construction permits increase a developer's uncertainty and costs if repeated applications are required.

Uncertainty in the definition or enforcement of regulations or in the future status of the regulations can have a major impact on CCT projects. Developers may be reluctant to proceed if uncertain about how current regulations will be enforced or unsure as to whether or not the project would comply with future regulations.

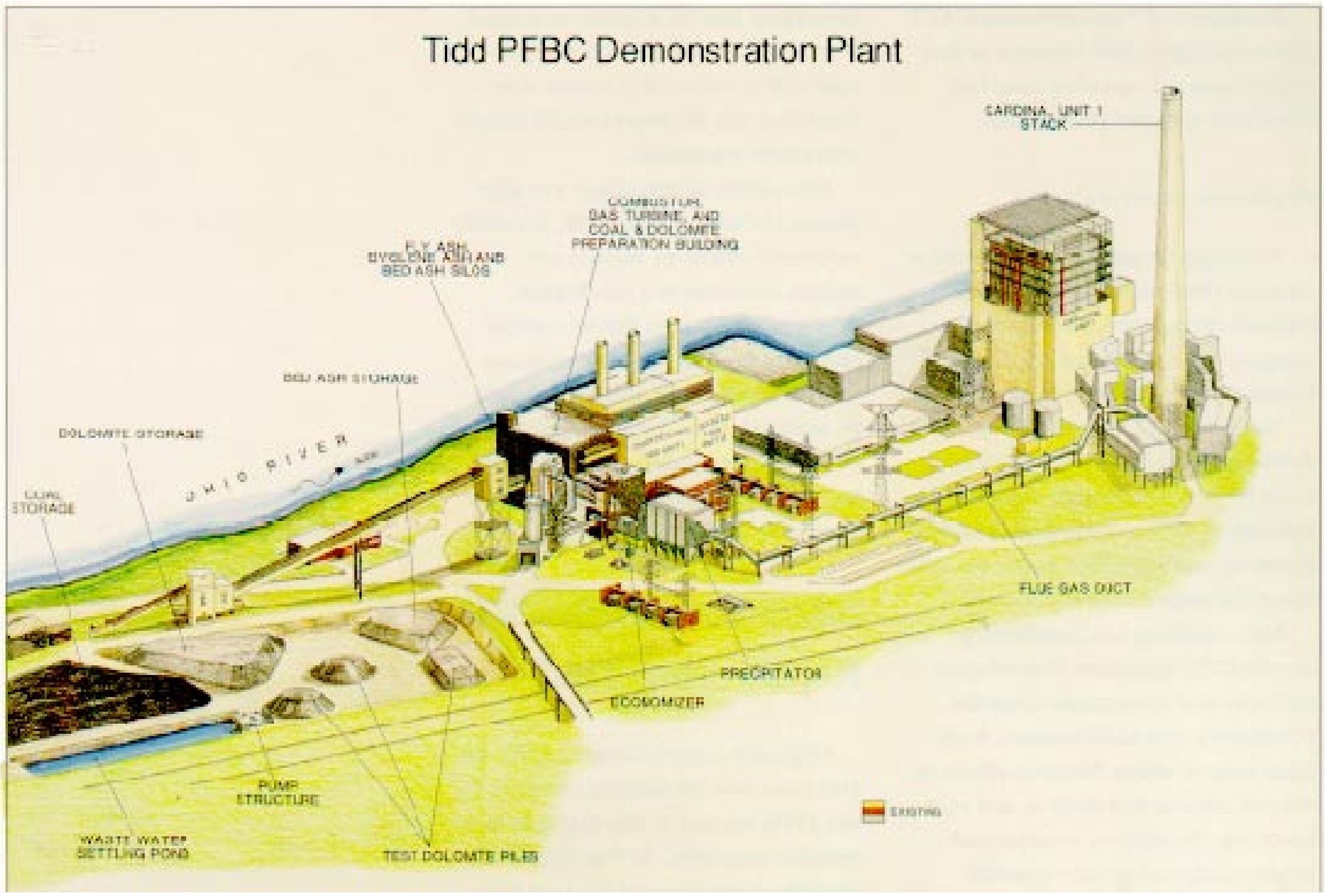
Inflexibility of regulations can also present barriers. For example, if a utility *voluntarily* improves controls and reduces emissions at a power plant, requirements for even tighter controls could be triggered. Because emission waivers might not be allowed or might be restricted, units that just miss complying with newer, tighter standards could be faced with substantial added expense in order to comply.

Repowering Tidd

Originally commissioned in *1945,* the Tidd plant was prematurely retired in the late 1 970s because it was unable to meet emission standards. At that time, OPCo determined that it would not have been economical to retrofit the plant with the necessary controls to meet the standards. However, Tidd is now being repowered with an emerging clean coal technology. The old pulverized coal-fired boiler is being replaced with a PFBC boiler, and a gas turbine is being added. The PFBC combined-cycle system is being used to repower Unit 1, one of two 11 0-MWe units at the Tidd site.

Much of the original equipment is being refurbished. The plant's steam cycle is utilizing many of the existing components, including the steam turbine generator as well as condensate and feedwater heaters and pumps.

Many of the service buildings, control systems, and piping systems also are being incorporated. The existing structures for storing and handling coal and dolomite are also being used, as well



Many existing facilities at Tidd are being refurbished and reused, such as the steam cycle, fuel storage and handling facilities, and switchyard. A new building adjacent to Tidd Unit 1 houses the PFBC pressure vessel, gas turbine, and other new systems.

as a 138,000-volt switchyard from which power will be sent into AEP's transmission system.

Major new equipment being installed includes the PFB combustor and related components (including the boiler, bed ash reinjection system and cyclones), the gas turbine, coal and sorbent preparation and injection systems, the economizer, the electrostatic precipitator, ash removal and disposal systems, and electrical components (including transformers and switchgears). It also has been necessary to construct new foundations, buildings, and piping and electrical systems needed to integrate the PFBC system with the balance of the plant.

The new PFBC power island, which includes the combustor, gas turbine, and coal and sorbent systems, is located in a new building next to the wall of Tidd Unit 1 in one of the original ash ponds.

The new economizer, electrostatic precipitator, ash silos, and electrical vessel, control building are located nearby. This layout allowed maximum use of existing Tidd facilities.

Tidd Power Island

The Tidd PFBC Demonstration Project will be the nation's first PFBC plant to operate in a true combined-cycle mode, with both a gas turbine and a steam turbine generating electricity. Tidd's new PFBC power island, which is being incorporated into the existing conventional steam cycle, will have a steam flow of 440,000 pounds per hour at 1,300 psia and 925 ^{0}F and a gross electrical output of 74 MWe (58 MWe from the steam turbine and 16 MWe from the gas turbine).

The Tidd plant will demonstrate a pressurized bubbling fluidized-bed operating at about 175 psia. Pressurized combustion air is supplied by the gas turbine. In the combustor, air fluidizes and entrains bed materials consisting of the fuel (a coal-water paste), coal ash, and dolomite sorbent.

After leaving the boiler, the hot gases and entrained ash particles pass into a two-cyclone train. The cyclones remove 98% of the entrained ash. The clean, hot gases leave the pressure vessel via a coaxial pipe and are expanded through a high-pressure turbine and a low-pressure turbine, then sent to the turbine exhaust gas economizer. The gas is further cleaned in an electrostatic precipitator and then emitted to the atmosphere.

The steam cycle is a Rankine cycle with a once-through boiler. Condensate (from a condenser) is heated in three stages of low-pressure heaters and the gas turbine intercooler as it is pumped to the deaerator. The feedwater pressure is then increased to 820 psia and further heated. The flow is then further pressurized to 2,000 psia by the feedwater pump and directed to the economizer, where it is preheated to 480^{0}F by the gas turbine exhaust before being routed to the boiler.

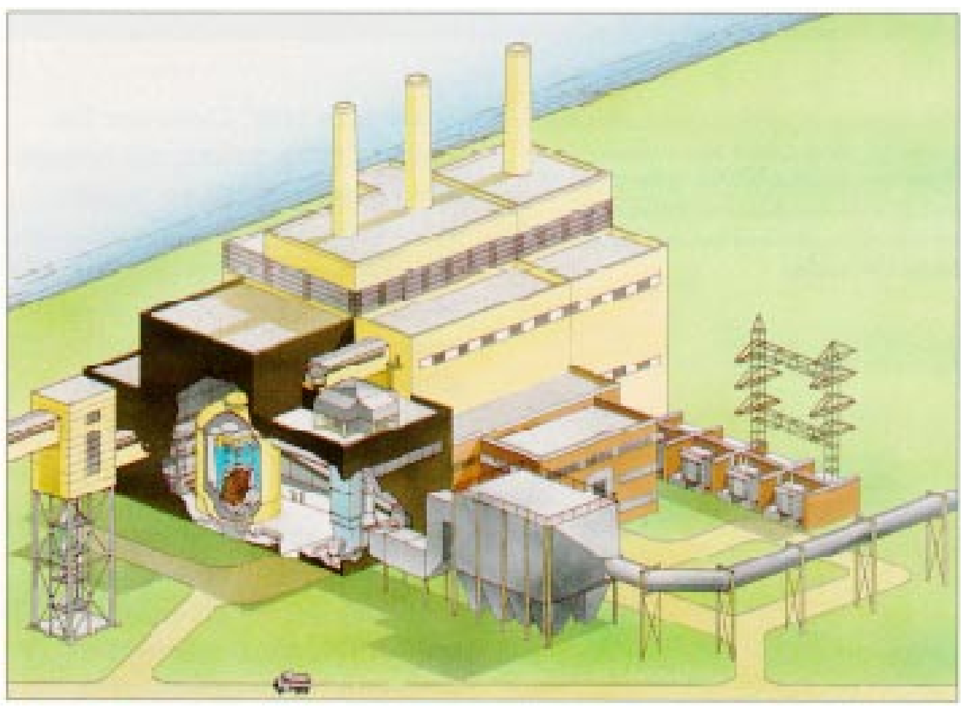
The feedwater passes through the boiler bottom zone and into the in-bed evaporator surface. Here, steam is formed and conveyed to the vertical separator. The steam is two-phase up to about 40% load and slightly superheated at full load. After the steam enters the in-bed primary superheater, spray attemperation (which is temperature adjustment by dilution) controls the final temperature of steam exiting the boiler. After passing through the in-bed secondary superheater, the steam exits the boiler at 1,335 psia and 925 ^{0}F.

During start-up and in the event of a steam turbine trip, a *50%* bypass system to the condenser and a pressure control valve to the atmosphere serve to dispose of excess steam while controlling the boiler pressure-temperature decay. In the event of a loss of plant power or the boiler feed pumps during operation, a backup feedwater injection system maintains water flow to the boiler circuits contained in the slumped bed and thus exposed to heat.

Plant Systems

One of the key objectives of the Tidd demonstration project is successfully scaling up the PFBC system from pilot plant size to the 200-MWt Tidd plant. The 15-MWt integrated pilot plant,

Tidd's new PFBC power island includes the combustor vessel, gas turbine, and fuel preparation system. Other related equipment, such as the economizer, electrostatic precipitator, ash silos, and electrical controls, also were added.



This scale model of Tidd's pressure vessel shows (1) the dolomite feed system, (2) boiler tubes suspended in the fluidized bed, (3) coal feed lines, (4) vessel wall, (5) two-stage cyclone train, and (6) bed ash reinjection vessel.

located at the PFBC Component Test Facility (CTF) in Sweden, was designed to test components, process variables, and control systems at near-commercial size. The testing performed at the CTF has enabled AEP to verify the design conditions projected for the Tidd PFBC demonstration plant.

Pressure Vessel

A single cylindrical pressure vessel contains the boiler, cyclones, cyclone ash coolers, and bed ash reinjection system. This arrangement allows the components within the vessel to be designed for a relatively low differential pressure even though the process pressure is relatively high.

The pressure vessel is externally insulated and is designed for internal operating conditions of 590^{0}F and 170 psia. It consists of a vertical cylindrical shell about 70 feet high and 44 feet in diameter with elliptical heads.

The pressure vessel heads include removable service openings that allow for the removal of internal components. In addition, internal and external service platforms, lifting devices, and access doors are provided to permit service and maintenance of both the internal and external systems.

PFBC Boiler

The PFBC boiler enclosure is designed with membrane water wall construction. At normal operating loads, the boiler is a sub-critical, once-through unit. There are three major sections in the boiler— the boiler bottom, the bed zone, and the freeboard.

The boiler bottom consists of fluidizing air ducts arranged on top of a pair of membraned water wall hoppers. The hoppers, which remain full of ash during operation, direct the spent bed ash to the bed ash removal system.

The boiler's bed zone is designed as a deep (10.5 feet), tapered, fluidized bed in which the superheater and evaporator sections are submerged. At full load, all of the evaporator and superheater surfaces are submerged within the bed. At reduced loads, the bed level is lower, thereby exposing portions of the surface. The surface above the bed convectively cools the gases feeding to the gas side, because the convective heat transfer rates are lower than those within the bed.

In the freeboard section, excess air in the hot gas is controlled to 25%. The freeboard is sized to minimize the elutriation (separation) of fly ash by the gas flow and is internally insulated to cut heat loss on the way to the gas turbine,

Critical design variables for the boiler were bed temperature and area, operating pressure, and residence time,

Bed temperature strongly influences the process and is related to gas-side corrosion. Experience at the CTF indicated that gas-side corrosion should not be a problem if bed temperature is kept between 1,500 and 1,600 ^{0}F. Above this temperature range, there is greater risk that high levels of alkali constituents will form in the gas stream, The Tidd plant is designed to operate at a bed temperature of 1,580 ^{0}F, which is within the acceptable range.

In scaling up bed area, experience has shown that boiler tube geometry and proper air distribution are the most significant parameters relating to bed temperature distribution. Increased bed area is not expected to be a problem, especially since the larger bed area minimizes the effects of wall cooling.

Earlier research has also indicated that between 150 and 300 psia, operating pressure does not significantly influence process results. At 170 psia, Tidd's bed will operate well within this range.

Residence time, another critical scale-up variable, strongly influences sulfur removal and combustion efficiency. Residence time is a function of fluidizing velocity and bed depth. Because these two parameters are

Component Testing for Commercial Scale-Up

Technical risks associated with scaling up technology to commercial sizes are reduced by testing the proposed designs and systems in an integrated facility. Testing of PFBC-related equipment and systems for Tidd was conducted at the Component Test Facility (GTE) in Sweden. This facility is owned and operated by ASEA Brown Boveri Carbon (ABB Carbon; formerly known as Stal-Laval and then ASEA Stal). ABB Carbon is one of the partners in ASEA Babcock, the PFBC supplier for Tidd.

Operational since 1982, the GTE is an integrated PFBC pilot plant. Its 1 5-MWt combustor can be operated at pressures of up to 235 psia. The GTE incorporates key PFBC-related systems and components needed for a corn-mercial power station.

Key technological and developmental breakthroughs made at the GTE include:

- Successful continuous removal of cyclone ash in a dry state
- Successful utilization of hot bed ash reinjection
- Successful test of a rotating gas turbine cascade
- Successful gas cleaning through a two-stage cyclone train
- Successful feeding of coal as a paste with less than 25% total water content.

similar for both the CTF and Tidd, scale-up problems are not expected.

Another area of technical concern in the development of PFBC technology has been in-bed tube erosion. The design of the tube bundle for the Tidd plant takes advantage of experience from the CTF, and it is anticipated that tube erosion rates will prove to be acceptable for commercial applications,

Bed Ash Reinjection System

Bed level is the main controlling parameter in the PFBC boiler. The bed ash reinjection system permits rapid change in the unit load by transferring bed material to and from a pair of reinjection vessels located inside the combustor pressure vessel. Special handling devices are used to admit bed material stored in the reinjection vessels into the bed, thus increasing load. To decrease unit load, bed material is pneumatically transported from the bed to reinjection vessels,

Air from the combustor pressure vessel transports the bed material to and from the reinjection vessels. The transport air flow is separated from the ash and vented outside the combustor into the main combustion flue gas. The reinjection vessels are normally at the same pressure as the boiler; however, during load decreases, they are at a slightly lower pressure.

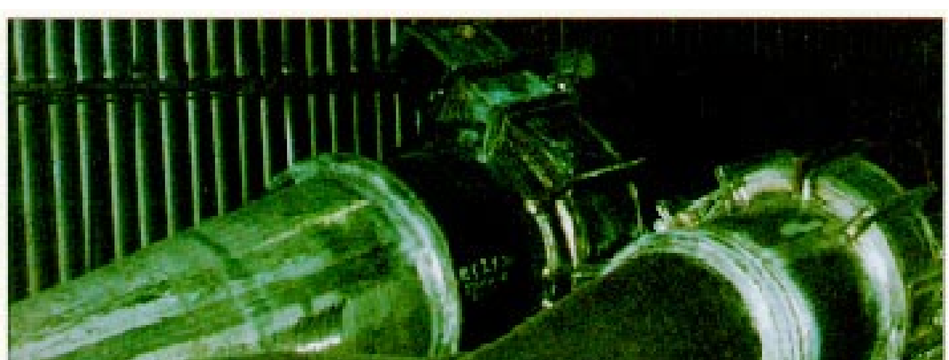
Ash Removal System

Fine ash collected in the cyclones is continuously removed by a pneumatic transport system. The ash is cooled and a portion of the heat is recovered in the combustion air. Depressurization requires no lockhoppers or valves. Granular bed ash is continuously removed by gravity from the boiler bottom hoppers in order to maintain the desired fluidized-bed level. Two parallel lockhoppers, each serving one of the bottom hoppers, are filled and emptied independently. When full, the lockhoppers are depressurized by venting and are emptied by gravity into a common atmospheric-pressure hopper. From here the ash is fed onto an enclosed conveyor system and transported to the storage silo.

Cyclones

To reduce particulates flowing to the gas turbine, the exhaust gas leaving the upper part of the boiler freeboard passes through a series of cyclones. At Tidd, there are seven parallel strings of cyclones, each with two stages of separation. The gas is conveyed from the boiler to the first-stage cyclones through connecting flues. Gas flows from the second-stage cyclones to a manifold and then exits the pressure vessel. It then makes its way through

Cyclones clean particulates from hot flue gases to prevent fouling and erosion of the gas turbine. The Tidd pressure vessel contains seven parallel strings of cyclones, each with two stages. Pictured are both stages of cyclones, prior to installation inside the pressure vessel,



the inner portion of a coaxial pipe and past the hot gas intercept valves on its way to the gas turbine. The cyclones and gas collecting pipe are insulated to minimize gas temperature loss.

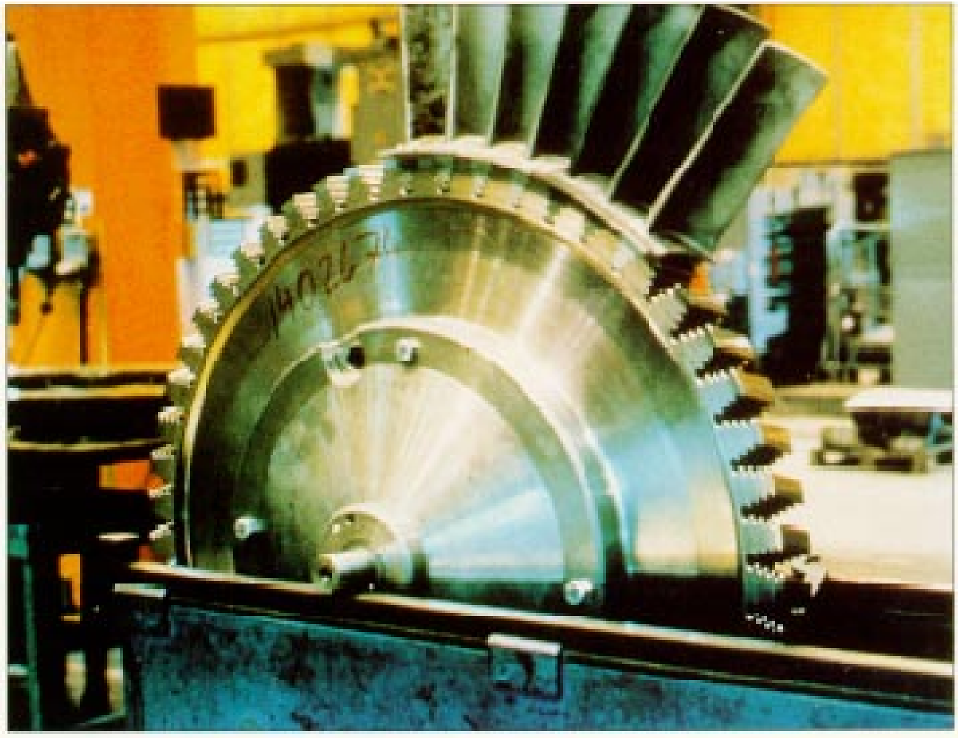
Gas Turbine Generator

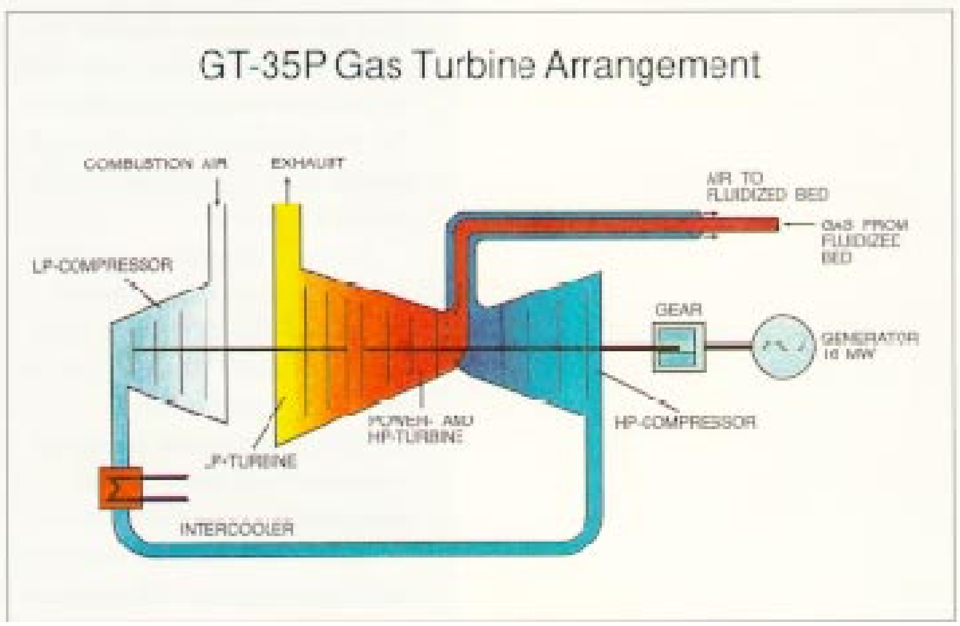
The new gas turbine being used for the demonstration project, the GT-35P, is a modified ASEA Stal GT-35 that is uniquely suitable for PFBC applications. This turbine is arranged in-line on two shafts. The variable speed, low-pressure compressor is mechanically coupled to its driving low-pressure turbine on one shaft. The high-pressure turbine drives both the constant speed high-pressure compressor and the electric generator. Anepicyclic gear reducer couples the electric generator to the high-pressure shaft.

temperatures fall when unit load is cut because the lower bed height exposes more steam generator tubes. As gas

temperature drops, the low-pressure shaft slows, lessening the pressure and flow of combustion air. Thus the free-spinning low-pressure shaft allows the air flow to vary with unit load.

The gas turbine in a PFBC combined cycle system is subjected to very harsh conditions— and the Tidd demonstration is no exception. Thus measures have been taken to ensure the integrity and operating life of the turbine. At Tidd, the gas is precleaned using cyclones, and Turbine erosion and corrosion as well
Turbine erosion and corrosion as well
as deposition phenomena have been researched extensively. An important aspect of the program at the CTF was investigation of the gas-cleanup and gas-turbine interface. In testing at turbine inlet temperatures to 1,526^{0}F, no blade erosion was found. Selection of





Assembly of the high-pressure turbine stage is shown in the photo (top). Tidd's gas turbine is arranged in-line on two shafts: the variable speed, low-pressure (LP) turbine on one and the constant speed, high-pressure (HP) turbine on the other.

Hot Gas Cleanup R&D Planned

The Tidd demonstration offers a unique opportunity for developing further advances in PFBC components and systems. An agreement between AEP and DOE to test advanced hot gas cleanup (HGCU) filtration devices is an example of the synergism possible between demonstration and R&D activities.

Historically, gas turbines have been fueled from natural gas or oil; however, Tidd's gas turbine will generate electricity from coal. The key element at Tidd that allows the gas turbine to be coal-fired are *cyclones-devices* that impart a swirl to gases laden with fly ash and remove over 98% of the ash particles before the high-temperature, high-pressure gas enters the turbine,

Although this gas is expected to be clean enough to prevent damage to the gas turbine from particle erosion, the gas must be further cleaned to meet particulate emissions standards. A conventional electrostatic precipitator accomplishes this.

Ideally, an HGCU device could be located between the combustor and the gas turbine to remove sufficient particulate matter to eliminate the need for the electrostatic precipitator; however, this approach would require a very efficient filter capable of operating under comparatively severe conditions of over 1,500 ^{0}F and 180 to 250 psia.

Even though there has been extensive development in advanced HGCU filtration, AEP concluded that advanced HGCU technology was not yet ready to be implemented into the design of Tidd, but that provisions should be included at Tidd to test such a device in the future.

The 5-year, $20-million HGCU research project will test filtration devices in a "slipstream." About one-seventh of the combustor exhaust gas— 100,000 pounds per hour at full load— will be diverted through this slipstream.

Various types of filters will be evaluated and one or two tested. Four types of filters are under study: ceramic crossflow, moving screenless granular bed, ceramic candle, and ceramic tube filters.

All use ceramic material configured in various shapes and sizes. Ceramic is used as the particulate barrier because it can withstand harsh conditions.

The filters trap virtually all particulate matter by acting as an impermeable barrier, in microscopic pores in the ceramic, or in a moving bed of granules as the gas flows from the fluidized bed to the gas turbine.

Testing is scheduled to begin in early 1992 and will be conducted during the second and third years of Tidd's operational phase. During this period, up to 7,000 hours of test runs are planned for the HGCU devices.

the two-cyclone train for gas cleanup at Tidd was based on work at the CTF and the cyclone manufacturer's experience.

Design modifications made in the gas turbine to improve reliability in PFBC applications include decreasing loading on the first turbine stage by adding an extra stage and increasing stability by connecting the high-pressure shaft to the power turbine shaft by using a gear train.

Economizer

A new, once-through, turbine exhaust gas economizer will be used at Tidd. An economizer recovers heat from the gas turbine exhaust for preheating the feedwater. Tidd's economizer is a modular design with the flue gas flowing horizontally across vertical, in-line, spirally finned water tubes. It is in series with the condensate heaters and replaces existing high-pressure feedwater heaters.

Electrostatic Precipitator

After leaving the economizer, the gas enters the electrostatic precipitator. Here, the gas is further cleaned of particulates to the NSPS level of 0.03 pounds per million Btu. The gas is then released to the atmosphere via the flue gas stack.

Steam Turbine Generator

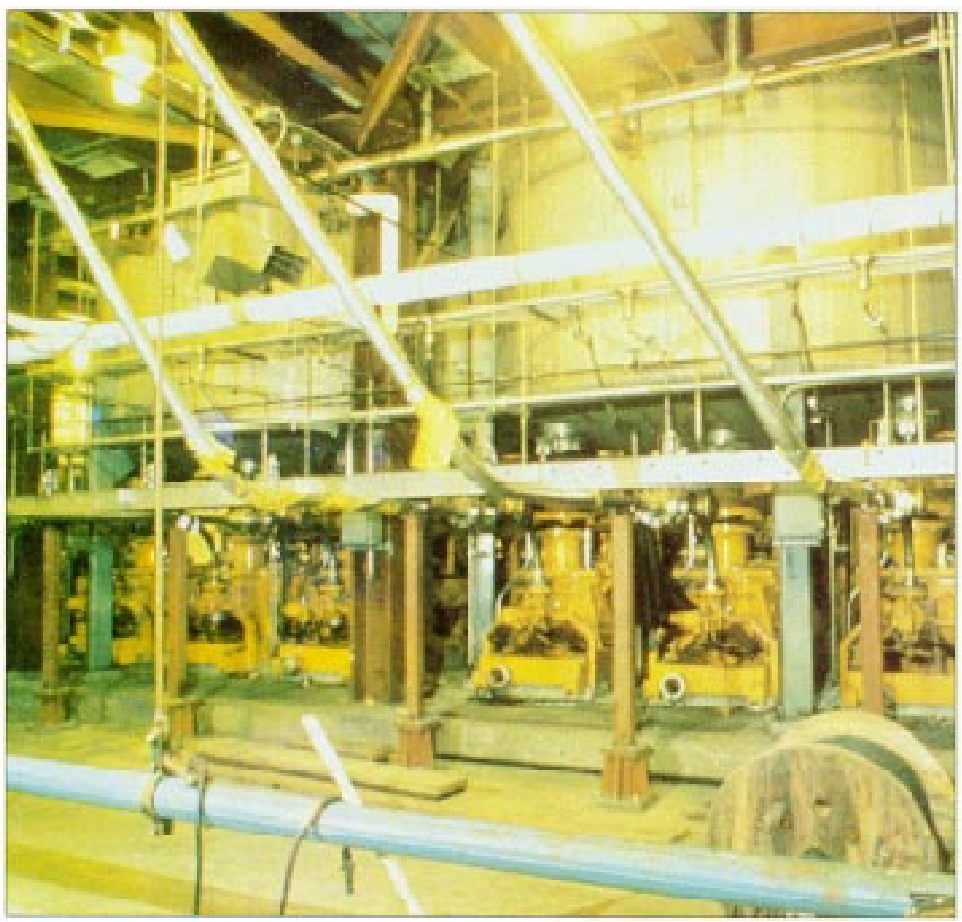
The original Tidd plant steam turbine generator is being refurbished and will operate at half of its original rating to generate 75% of the plant's 70-MWe capacity. Both the turbine rotor and generator field for the steam cycle were on reserve as system spares at another AEP power plant. Refurbishing the turbine involves replacing the first-stage wheel and updating the former water seal system with a more effective, new steam seal system.

Coal Feed System

A paste feed system is being used. It was chosen because of its operating ease, lower capital cost, better flow control, and better expected availability than alternative methods. Also crushed rather than pulverized coal is being used because small particles will elutriate (separate) from the bed. This would be undesirable as it would reduce the residence time needed for efficient combustion and sulfur absorption and would also cause excessive loading of dust within the cyclones.

To form the paste, uncrushed 1-inch coal stored in a 45-ton capacity surge hopper is fed into a double-roll crusher. A system of conveyors then transports the crushed coal (1/4-inch) onto a three-deck screen to eliminate oversized pieces and into a pugmill-type mixer,

A coal-water paste fuels Tidds PFBC boiler. Feed hoppers supply six parallel, hydraulically operated coal-injection pumps. Feed lines leading from each pump carry the paste upward and into the boiler.



The fuel is pumped as a coal-water paste which is 25% water. A specific distribution of coal size is used to eliminate inter-particle motion and to make pumping the paste easier. The coal's moisture is measured on the weigh feeder and water is added to the mixer to prepare the paste. It then goes directly into a fuel feed hopper which has a 1-hour storage capacity.

The feed hopper supplies six parallel, hydraulically operated coal injection pumps that deliver the fuel to the boiler. Each pump feeds fuel into the boiler through a dedicated fuel nozzle,

Sorbent Feed System

Sorbent (dolomite), stored in a 70-ton capacity surge hopper, is first fed into an impact dryer mill. The size of the sorbent (1/8-inch) is controlled by a vibrating screen and heated air flowing through the mill. The sized material is swept from the mill by the hot air and then sorted by a cyclone separator and a baghouse. A vibrating screen located at the outlet to the cyclone separator diverts oversized material back to the mill. The final product is transported by conveyor into a 200-ton sorbent storage hopper. The hopper has two outlets to feed the sorbent injection system.

Lockhoppers receive the prepared sorbent at atmospheric pressure. When full, the lockhoppers are isolated from the storage vessel and pressurized more than the combustor. Variable-speed rotary feeders meter the flow of sorbent to pneumatic conveying pipes. When the lockhoppers are empty, they are isolated from the combustor and are vented to the atmosphere through a bag filter. When completely depressurized, they are then ready to be refilled.

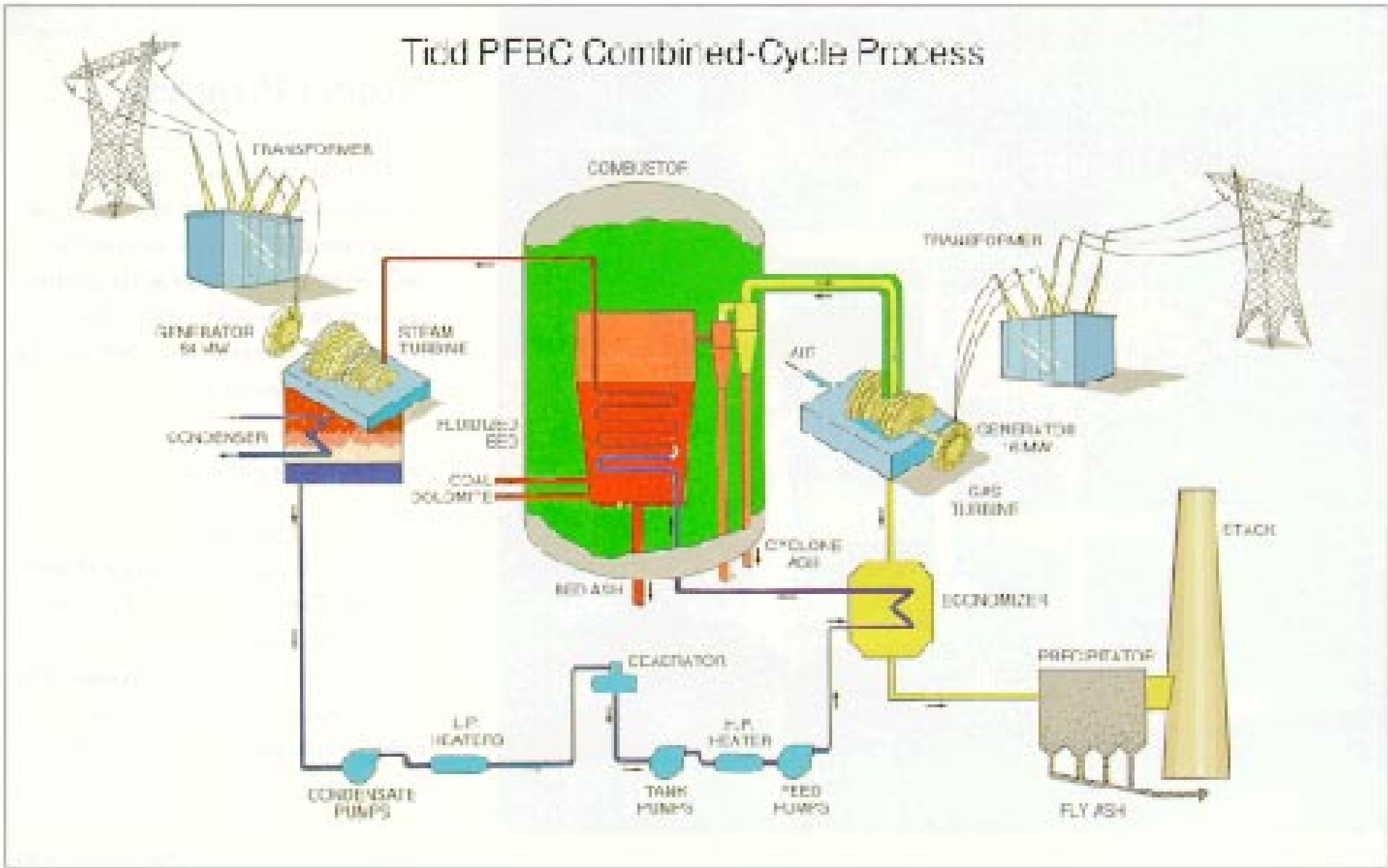
The PFBC combined-cycle system is integrated using eight process control units located in a central control room, shown under construction.

Control System

A distributed programmable logic system is being used to collect signals and measurements. The control system, a Bailey NET-90, uses eight process control units divided into the following nodes: gas turbine, combustor, steam turbine, balance of plant, and safety.

These units perform the control of individual plant items and also most of the coordinating control, interlocking, and automatic functions involving groups of related items.

The control system will operate as an integral-plus-proportional system. It integrates the combined-cycle system through a megawatt-demand signal. The system determines the necessary fuel flow, water flow, air flow, and bed level based on predicted values and biased by feedback loops.



Tidd PFBC Combined-Cycle Demonstration Project

Description:

A PFBC combined-cycle system is being used to repower a moth-balled pulverized coal-fired power plant. Off gases from the combustor are expanded through a GT-35P gas turbine with a steam turbine bottoming cycle. A new PFBC power island is being installed. Existing steam turbine and site utilities are being refurbished.

Participants:
Ohio Power Company
American Electric Power Service Corporation
Ohio Coal Development Office
U.S. Department of Energy

Funding:

DOE	$ 60,200,000
Industry	$124,800,000
Total	$185,000,000

Electrical output:

Net	70 MWe
Gross	74 MWe
Steam turbine	58 MWe
Gas turbine	16 MWe

Fuel and sorbent:
Pittsburgh #8 (3.4% sulfur)
Dolomite (Ca/S of 1.6)

Environmental performance:

SO_2 abatement	90%
NOx abatement	70%
Particulates	0.03 lb/10^6 Btu
Solid waste	32.8 lb/10^6 Btu

Combustor vessel:

Operating temperature	590 ^{0}F
Operating pressure	170 psia
Diameter	44 ft
Height	70 ft
Weight (total)	1,400 tons

Combustion:

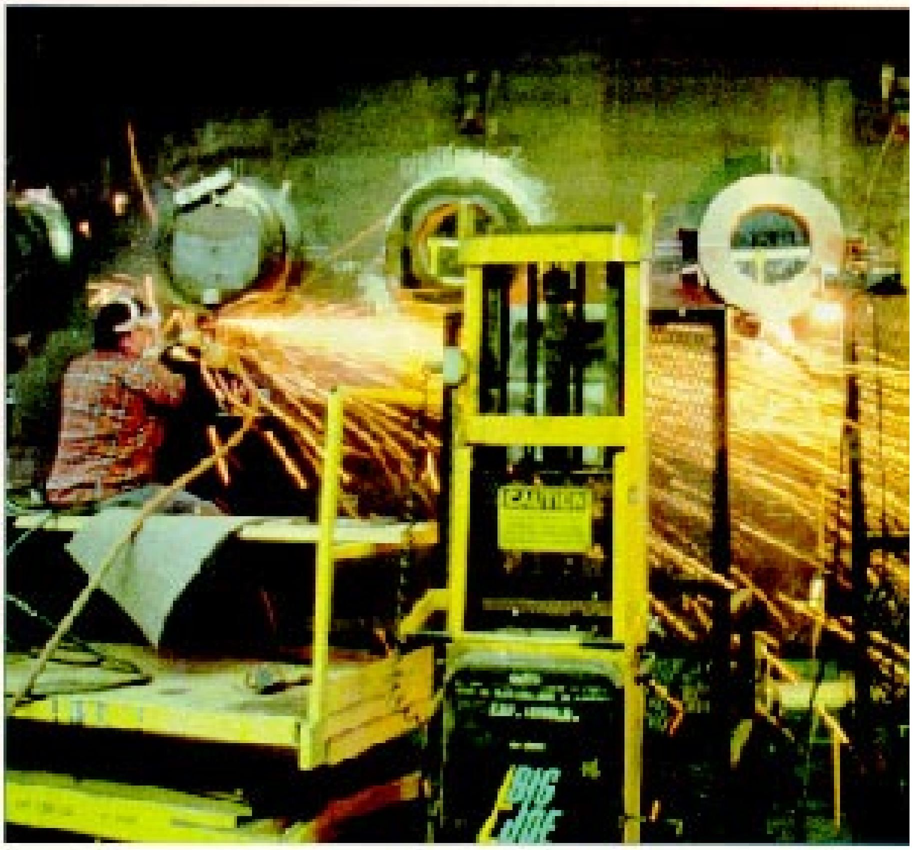
Temperature	1,580 ^{0}F
Pressure	170 psia

Steam flow:

Temperature	925 ^{0}F
Pressure	1,300 psia
Flow rate (lb/hr)	440,000

Schedule for Project Phases

I. Design & permitting
II. Procurement, construction & start-up
III. Operation, data collection, reporting & disposition




Sparks fly as a worker grinds the edges of a service opening (top). A steel plate 3 inches is bent to form a section of one of the three steel rings that were welded together to the pressure vessel shell (bottom). Prefabricated at B&W's facility in Mt. Vernon, Indiana, the pressure vessel stands ready for removal of the top head and installation of internal components (opposite).

Project Progress

The Tidd cooperative agreement between AEP, DOE, and the Ohio Coal Development Office was executed in 1987. Formal ground breaking ceremonies were held in April 1988. The project is on schedule, and plant start-up is set for October 1990.

Proceeding on Schedule

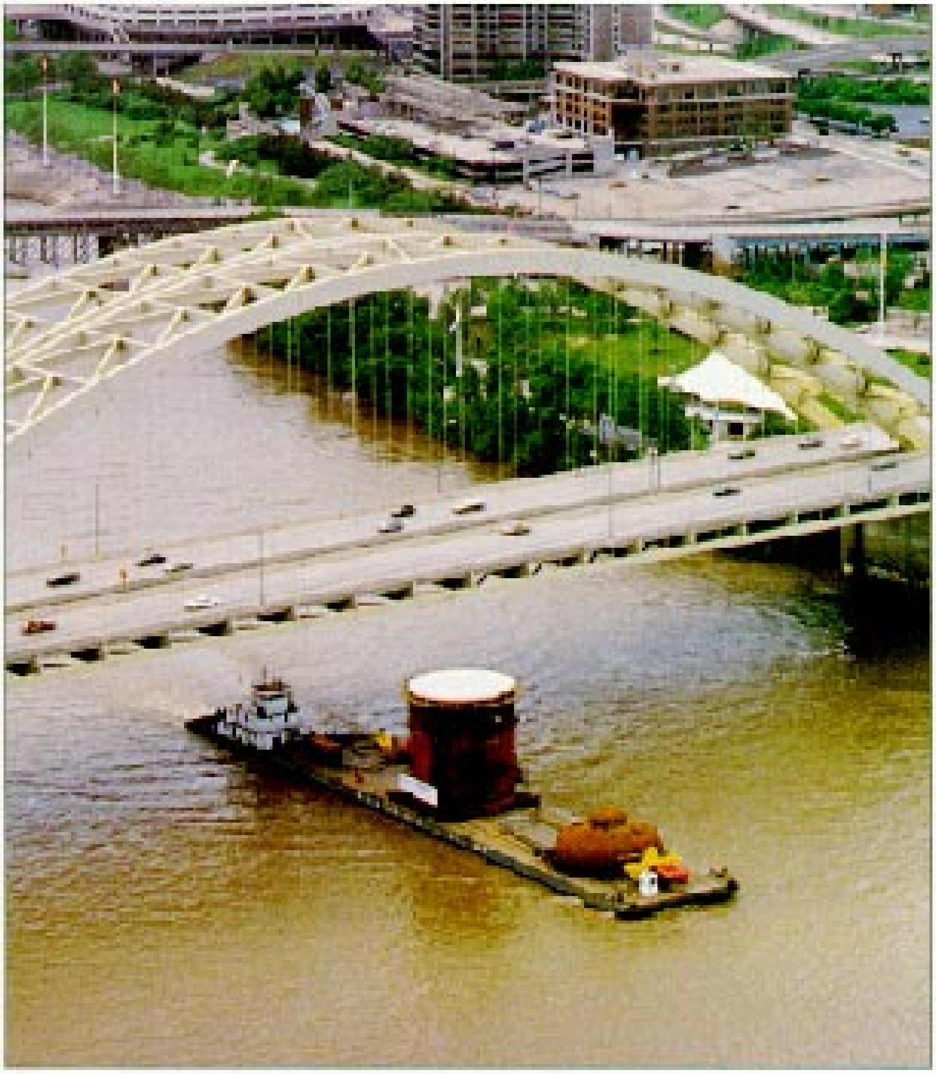
Phase I (Design and Permitting) started in February 1987. Phase II (Pro-curement, Construction, and Start-up) began in December 1987.

Construction is nearly complete. The new combustor building has been erected and contains the entire PFBC pressure vessel. All of the major components have been constructed and installed, including the coal feed system, pressure vessel, economizer, electrostatic precipitator, and ash silos. The gas turbine is in place and ready to be hooked up, and all new piping and electrical work is almost completed. Refurbishment of the steam turbine began with disassembly in early 1988 and was completed in late 1989.

Moving the Pressure Vessel

The immense size of most utility boilers requires that they be custom assembled at the plant site. A PFBC boiler, however, can be designed as a modular unit. It is compact enough to be fabricated at the manufacturer's plant and then transported to the plant site.

Tidd's prefabricated pressure vessel is as tall as a seven-story building. The thick pressure vessel was shipped by barge make nearly 750 miles up the Ohio River to the plant site.



The vessel, head, internal items, and transport equipment, weighing a total of 2,200 tons, were loaded onto a 276-foot barge and shipped 750 miles up the Ohio River. After departing Mt. Vernon (bottom), the loaded barge passed under 49 bridges, including those at Cincinnati (top).

The combustor vessel was built over a 2-year span at B&W's fabrication facilities in Mt. Vernon, Indiana. The 44-foot diameter, 70-foot tall combustor vessel is the largest "shop-built" vessel in B&W's history. By building the vessel and shipping it intact, considerable cost and time savings were realized.

The vessel holds the fluidized-bed enclosure with boiler tubes and other associated equipment. These items were also constructed as modules for easy assembly into the vessel after being shipped to the Tidd plant. The fluidized-bed boiler modules were built at B&W's facility at West Point, Mississippi, and shipped via the Mississippi and Ohio Rivers to Mt. Vernon for placement inside the cylindrical pressure vessel.

In May 1989, the completed pressure vessel was loaded onto a 276-foot barge for the river trip to the Tidd site. With the 17-foot high hemispherical head removed, the vessel stood 53 feet. The vessel assembly and head weighed a total of 1,392 tons. The entire cargo, consisting of the vessel with internal items, head, transport trailer, and other moving apparatus, totaled 2,200 tons.

The barge passed through 13 locks and under 49 bridges on its voyage through Indiana, Kentucky, Ohio, and West Virginia to Brilliant, Ohio.

High water from late spring rains necessitated the addition of water ballast in the barge to clear a railroad bridge at Henderson, Kentucky. Even more ballast was added shortly thereafter to improve stability and provide adequate clearance under another bridge.

Project engineers had calculated that a suspension bridge at Wheeling, West Virginia, would pose the tightest squeeze of the trip. In the end, the combustor had a 10-foot clearance as it passed under this bridge. The combination of the ballasted barge and greater water depth made it possible to follow the river's sailing channel under the bridge.

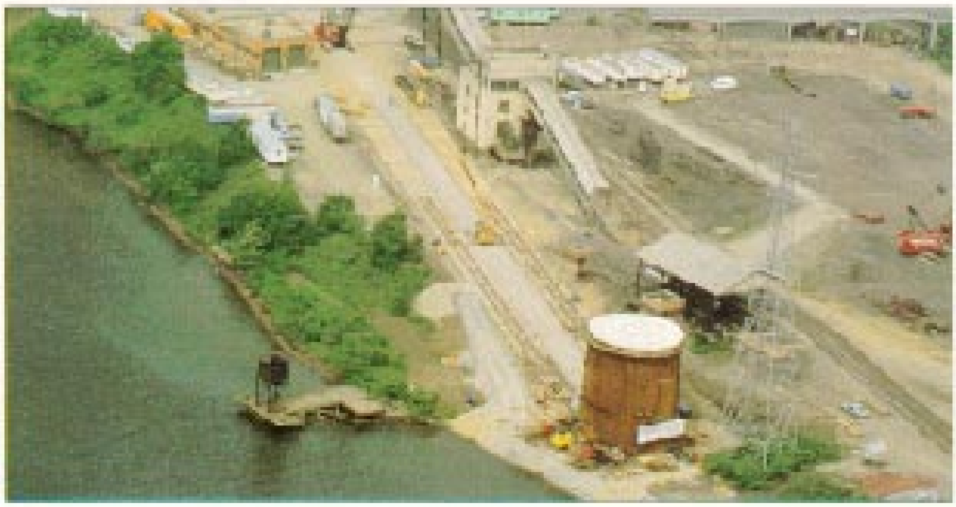
Nine days after its departure from Indiana, the combustor vessel arrived at the landing area on the Tidd plant site. Two crawler cranes helped hold the barge in place against the landing area while enough ballast was added to place the barge level with the shore.

Once in position, with the tugboat providing an extra push from behind, a power unit was hitched to the trailer carrying the 150-ton combustor vessel head. The giant truck and cargo left the barge and turned 900 to make the slow trip up the 900-foot haul road to a spot in front of the combustor building.

As soon as the combustor head left the barge, workers began to prepare the 1,242-ton combustor assembly for transport using hydraulic push jacks, 10,000 psia each, along a steel-plate track system. Tons of fill material had been placed in the haul road, 12 feet deep in some places, to support the load. On the trip up the haul road, workers alternated pushing the vessel one day with moving and welding the track system ahead of the cargo the next day.

In late July 1989, the pressure vessel head was hoisted by two crawler cranes and placed into position. Then the entire vessel was pushed into the combustor building. Once the vessel arrived over its pedestal, the contractor performed a final rotation and centering move. The pressure vessel was placed on its pedestal in early August and was in its precise location four days later.

The construction, shipping, and installation of the combustor vessel are pioneering efforts. Almost every facet— from the new technology and its modular construction to moving the vessel itself— represents a challenge that will benefit future PFBC plants.



With the barge docked at Tidd, the crew gets ready to oft-load the head, detached for clearance under bridges (top). The vessel shell was moved up a 900-foot haul road, over a steel plate track laid on timber mats (center). With major internal components installed and the head repositioned, the pressure vessel is ready for the final move into the building (bottom). Once in position, the head will be arc welded in place.

Tidd Test Program

During the 3-year operational phase, plant performance and operation will be carefully monitored and analyzed to verify technical performance of the plant and its components. Tests will establish the reliability, load following capability, and operating and maintenance costs.

Although the Tidd demonstration plant is not expected to be economical or operate at a high level of availability, the performance and test data collected during its operation are essential for confirming technical feasibility and economic viability. With this data, more accurate forecasts of the cost of electricity from a PFBC combined-cycle plant can be developed.

Acceptance Testing

Acceptance testing will demonstrate the technical feasibility of PFBC combined-cycle technology at the 70-MWe scale. Of primary interest are the

Parameters Continuously Monitored

During Tidd's operation, plant performance will be monitored continuously. Detailed analysis of the data collected will yield information about the deterioration of plant performance over time and will be used to ascertain preferred operating conditions and to improve future designs.

Major parameters being tracked are listed below:

1. Fluidization conditions (temperature, bed height)
2. Fluidized-bed air flow, gas flow, temperature distribution, excess air factor, bed ash removal rate, elutriation rate
3. Combustor mass flow, temperature, pressure, and heat transfer
4. Calcium-to-sulfur molar ratio
5. Gas turbine efficiency and output
6. Economizer mass flow, pressure, temperature, effectiveness, and heat transfer
7. Fly-ash mass flows, particle size distribution, and chemical analysis
8. Bed-ash mass flows, particle size distribution, and chemical analysis
9. Cyclone dust removal efficiency and pressure loss
10. Coal and sorbent mass flows, particle size distributions, and chemical analyses
11. Coal and sorbent feed system consumption of water and transport gas
12. Coal heat input
13. Auxiliary power needs for all PFBC-specific systems
14. Total combustor heat transfer efficiency.

combustor, gas turbine, and economizer, Test results will be used in a thorough assessment of the actual performance of the equipment. These results will be compared to design expectations. The information also will serve as a baseline for performance tests.

Performance Monitoring

Beginning with the initial start-up of the unit and continuing through the end of the project, plant performance will be monitored continuously. Engineers will look for indications that equipment performance might be deteriorating with time. A maintenance history for the PFBC-related equipment will be developed and the impact of plant operating conditions on this equipment determined. All plant effluents and gaseous emissions will be monitored, Manned test stations will sample fuel, sorbent, ash, and particulate emissions for laboratory analysis.

Detailed study of the test data will yield preferred operating conditions for the PFBC combined-cycle concept and also provide the information necessary for improving the equipment's design for use in future commercial facilities.

Information will be available in real time and in an historical data base for assessing trends. Operators and test engineers will be able to make on-line calculations of system performance-information needed to assure that test conditions are being met.

Physical Equipment Inspections

The third part of the testing program involves periodic inspection of the major PFBC-specific equipment. Erosion,corrosion, and other wear characteristics will be measured and evaluated. A primary goal is to confirm the reliability and controllability of a gas turbine operated in a combined-cycle mode with PFBC. Therefore, special attention will be paid to the materials in the gas turbine to detect any deterioration that might be caused by high-temperature PFBC effluents.

Another goal of the inspections is to develop better RAM (reliability, availability, and maintainability) data for the combustor and related equipment. Data analysis will provide PFBC equipment manufacturers with information needed to develop a reliable, cost-effective, commercial plant design.

System Response Testing

Finally, system response testing will be performed to verify the dynamic behavior of combined-cycle PFBC systems. Various control strategies will be tested and evaluated to find out how PFBC plants can be best integrated with existing utility networks. Steady-state testing will be conducted over the load range of the unit, and transient studies will be conducted during load changes and trips. Process parameters also will be varied to optimize emission reductions and plant economics. Several coals and sorbents also will be tested.

Control principles being evaluated during system response testing include:

- Unit load control by bed level, which is controlled by bed ash removal and reinjection
- Bed temperature control by fuel injection
- Excess air control by air flow
- Steam outlet temperature control by attempenition (temperature adjustment) and feedwater flow
- Steam outlet pressure control by turbine valve position.

Comparison of the Environmental Perfoemance Selected Clean Coal Technologies

Clean Coal Technologies	Heat Rate (Btu/kWh)	SO_2 Removal **(%)**	NOx Removal **(%)**
Pulverized coal-fired with FGD	9,320	90+	0
Circulating FBC	9,230	90	50
Gasification combined-cycle (GCC)	9,500	98	
Advanced GCC	8,140	99+	95+
PFBC	8,510	90+	50+
Advanced PFBC	7,820	95+	80+

SO_2 and NO~ Emissions Reductions

Two critical air pollutants are emitted when coal is burned—sulfur dioxide (SO_2) and nitrogen oxides (NOr). Emission levels of these pollutants are regulated by the Environmental Protection Agency's New Source Performance Standards (NSPS). A primary goal of the Tidd project is to demonstrate the ability of PFBC technology to meet these standards, even when burning high-sulfur coal.

Sulfur is removed by adding an alkali sorbent to the fluidized bed. Dolomite (calcium magnesium carbonate), a form of limestone, is the sorbent being used at Tidd.

If enough sorbent is used while burning coal, it is possible to capture up to 95% of the sulfur released during combustion.

To meet NSPS, the Tidd PFBC system is designed to use a calcium-to-sulfur molar ratio of 1 .6. This level is expected to capture 90% of the sulfur released by high-sulfur (4%) coal.

NO~ emissions are a function of the combustion temperature and the amount of excess air supplied to the combustion process. NO~ emissions from a PFBC system are expected to be 50% to 70% lower than those from a conventional pulverized coal-fired boiler. This decrease in NO~ occurs because of the relatively low combustion temperature in a fluidized bed.

The Tidd plant is expected to emit only 50% of the NO~ that would be emitted from a conventional coal-fired plant.

Environmental Monitoring

Throughout Tidd's operational phase, emissions and other aspects will be monitored to ensure compliance with environmental regulations. Environmental data being collected to comply with applicable permits and regulations should also provide the necessary data for PFBC commercialization activities. Nevertheless, supplemental monitoring will provide additional data for use in designing future PFBC systems. Compliance monitoring activities at Tidd will include stack gas monitoring of SO, NO, and opacity. Other required performance testing will measure 50_2, NOx and particulates in the duct leading from thecombustor and downstream of the precipitator.

Supplemental testing forparticulates and determination of particle size will be conducted on the emissions from the combustor at a location downstream of the gas turbine and upstream of the precipitator. The coal, sorbent feed, bed ash, fly ash, and exhaust stream to the stack will be checked for trace metals.

The solids stream will be monitored and analyzed daily. Measurements will be taken of coal moisture, sulfur, ash, and Btu content. Supplemental monitoring of the solids stream will develop data for characterization of fly ash and bed ash, evaluation of combustion process performance, and additional analysis of the coal and sorbent.

The Road to Commercial Application

The origin of FBC technology can be traced to the Winkler gasifier developed in Germany during the 1920s. By the second world war, the technology was being used commercially in German coal gasification and metal refining industries,

The U.K. began developing FBC in the 1950s, with the goal of making use of locally available, low-grade coals. At the same time, several countries were developing a coal-fired gas turbine. However, early turbine-firing methods proved unacceptable, at least partly because of problems associated with the high combustion temperatures.

Because of its relatively low combustion temperatures, PFBC came under study in the mid-1960s as a new means of firing a gas turbine with coal. Plant-scale PFBC testing began in 1968 at the British Coal Utilization Research Association's Coal Utilization Research Laboratory (CURL) in England.

From the mid-i 970s to the early 1980s, several small-scale PFBC facilities were constructed. These units, built by Exxon, Curtiss-Wright, General Electric, New York University, Argonne National Laboratory, NASA's Lewis Laboratory, the U.K.'s National Coal Board, and ABB Carbon (then Stal-Laval), have provided tens of thousands of hours of test data.

U.S. interest in PFBC technology intensified in the 1970s in response to stringent air quality regulations and a need for an economical and environmentally acceptable way to burn high-sulfur domestic coal.

In 1980, testing began on a wide range of design and operating conditions at the International Energy Agency's Grimethorpe PFBC test facility, operated and jointly financed by the U.S., the U.K., and West Germany. The facility has provided pilot-scale data on technical and environmental performance, process monitoring and control, the behavior of regional coals and sorbents, and component performance and reliability. From 1986 to 1988, DOE participated in follow-on tests at Grimethorpe. An updated, U.S. designed heat exchange bundle was used to develop pilot-scale data on coal feeding and combustion performance.

In 1980, ABB Carbon designed the Component Test Facility (CTF). Operational since 1982, this integrated PFBC pilot plant has been used to test and evaluate components and systems designed for the Tidd demonstration plant.

AEP's Philip Sporn Plant in West Virginia will be the world's largest PFBC power plant. Two 1 50-MVJe pulverized coal-fired units will be replaced with one 330-MVJe PFBC combined-cycle system.

Sporn PFBC Demonstration Project

AEP's Philip Sporn Plant in West Virginia will be the site for construction of the world's largest PFBC power plant. The Sporn project is the next logical step in developing PFBC technology and would be the world's first large-scale repowering of a conventional coal-fired plant.

The system used at Tidd is being scaled up to 330 MWe, a size more typical of U.S. commercial utility applications, With a goal of extending Sporn's plant life by 25 years, reliability and maintainability will be important considerations in designing the repowered plant.

Currently Sporn consists of five pulverized coal-fired units—four identical units of 150 MWe each and a 450-MWe unit. Two of the smaller units will be replac-ed with a single PFBC module. Capacity will be increased from 300 to 330 MWe and net thermal efficiency from 36.5% to 38%.

The existing boilers for Sporn Units 3 and 4 will be replaced by a single P-800 PFBC module that will supply steam to both of the existing steam turbines.

The combustor for the P-800 unit will be enclosed in a pressure vessel about 64 feet in diameter and 140 feet high. The operating pressure will be about 235 psia, the combustion temperature about 1,580 ^{0}F. The system's gas turbine, a modified GT-140P, has an output of about 72 MWe.

After repowering, Sporn will be able to use 4%-sulfur coal instead of the 1 %-sulfur coal currently burned to meet emissions require-ments. The repowered unit is expected to burn 374,500 tons of high-sulfur coal per year.

Commercialization

Commercialization and marketing of PFBC combined-cycle systems will be performed by private industry. Equipment manufacturers, engineering firms, and many other businesses are expected to play key roles in the sale, design, construction, operation, and maintenance of commercial PFBC systems.

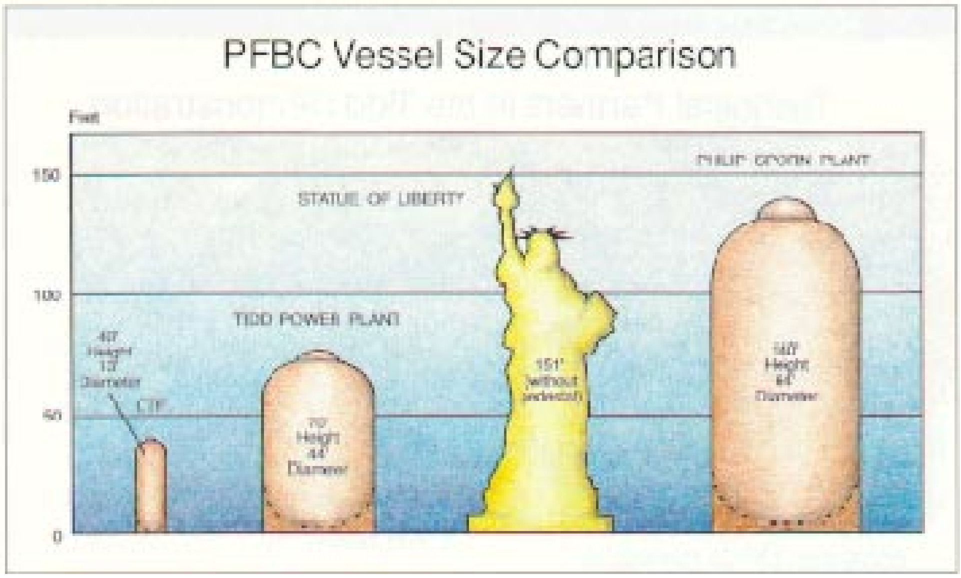
Potential buyers, consisting of utilities and other industries, will base their decisions on whether or not to nstall PFBC systems in a particular facility on the merits of this technology compared to other conventional and emerging technologies.

The Tidd demonstration project is expected to yield data and operating experience useful in improving the design, operation, and economics of subsequent commercial-scale PFBC plants. In addition, successful demonstration of the 70-MWe PFBC unit at Tidd is expected to comfirm the commercial feasibility of this technology for power generation units of under 100 MWe, a size typical of many installations worldwide.

However, according to ASBA Babcock, the best applications for PFBC technology are likely to be forrepowering and adding new capacity increments in medium (100-400 MWe) and large (over 400 MWe) generating units. With this in mind, AEP and ASEA Babcock are currently negotiating another Clean Coal Technology Demonstration Project with DOE that would address this market segment.

A single 330-MWe combined-cycle PFBC system would be used torepower two existing I 50-MWe generating units at the Philip Sporn Plant in New Haven, West Virginia. With a capacity more than four times that of Tidd, Sporn would demonstrate the feasibility of repowering with PFBC at a size more typical of commercial utilityapplications in the U.S. and internationally.

The potential PFBC market can be divided into therepowering and new capacity markets. There are an estimated 400 to 500 candidates forrepowering with PFBC, with a cumulative capacity of over 70,000 MWe. Only 7% of these units currently have SO_2 removal systems. Candidate plants are 20 to 40 years old, have a capacity of between 40 and 360 MWe, an existing



Scaling Up PFBC Technology

	CTF	Tidd	Sporn
Bed height (ft)	11 .5	10.5	12
Scale of bed area	1	16	24*
Bed pressure (atm)	12to16	12	16
Bed temperature (^{0}F)	1580	1580	1580
Fluidizing velocity (ft/sec)	3	3	3
Gas turbine inlet temperature (^{0}F)	1454	1526	1526
Scale of cyclones	1	1 .3	1 .3
Steam pressure (psia)	1440	1335	2015
Steam temperature (^{0}F)	990	925	1050/1 000
Thermal input (MWt)	15	200	800

* The commercial plant module has two beds, each at this scale

Technical Partners in the Tidd Demonstration

American Electric Power Company

Two key participants in the Tidd project, OPCo and AEPSC are wholly owned subsidiaries o the American Electric Power Company, Inc. (AEP), an electric utility holding company. An investor-owned electric utility company, OPCo generates, purchases, transmits, and distributes electric power to over 625,000 customers in Ohio; Tidd is one of OPCo's power plants. OPCo customers annually consume over 33 billion kWh.

As AEP's management, technology, and professional services organization, AEPSC is designing, engineering, and managing construction of the Tidd demonstration plant. AEPSC also will provide technical services to OPCo throughout the operating life of the Tidd plant.

One of the largest U.S. users of coal, AEP burns more than 40 million tons of coal per year to generate about 89% of its electricity. The AEP system, which annually generates over 100 billion kWh, ranks as the nation's second largest investor-owned producer of electric power. The system includes 10 power plants with a capacity of 1,000 MWe or more; among these are six of the world's largest operating units (each 1,300 MWe).

ASEA Babcock

AEPSC subcontracted with ASEA Babcock for construction of the Tidd PFBC island. ASEA Babcock is a business partnership between ABB Carbon and B&W formed to commercialize PFBC technology,

B&W is a supplier of steam generating equipment and has been designing, engineering, and constructing fluidized-bed technology for over 30 years.

ABB Carbon develops and manufactures steam and gas turbines and other equipment for energy conversion. ABB Carbon owns and operates the Component Test Facility.

coal-fired boiler, and steam turbine pressure of at least 1,300 psia.

PFBC is expected to be competitive also with the atmospheric fluidized-bed boiler in utility applications and could eventually capture a significant share of the market for replacing pulverized-coal plants using flue gas desulfurization.

It is expected that PFBC will be commercially available by the year 2000 and that repowering with PFBC technology could increase capacity by up to 20,000 MWe by the year 2010.

In the new capacity market, B&W forecast that orders for all technologies in the first half of the 1990s could total 60,000 MWe and then increase to 75,000 MWe by the second half of the decade. During the 1990s, utilities are projected to order or repower between 200 and 300 power plants and buy between 250 and 300 cogeneration units.

The ability of PFBC to service both the new plant and life-extension markets is expected to provide a basis for steady penetration of the utility market. A substantial market is also expected to exist for the 80-MWe PFBC modules in cogeneration applications.

ASEA Babcock has determined that two standard-size PFBC modules would best meet the requirements for both new and repowering markets. These two modules are called:

- P-200, an 80-MWe module
- P-800, a 340-MWe module.

These modules could be combined to suit a wide range of plant sizes, such as 80 MWe, 160 MWe, 340 MWe, and 680 MWe. These sizes would enable utilities to add small, moderate, or large increments of power in relatively short time intervals.

The P-200 module is the type installed at Tidd. Engineering studies to support the development of the P-800 unit are in progress, and an assessment of manufacturing facilities required for the large pressure vessel is planned. The design philosophy of the P-800 involves multiples of hardware and equipment that will be proven on the P-200.

In supporting the commercialization of PFBC technology, especially for use in future power generation applications, AEP plans to share the operational information gained from the Tidd demonstration with other electric utilities and industries. Except for contractual restrictions, AEP does not intend to identify as "proprietary and confidential" any information about the project. Successful operation and commercial demonstration of the PFBC combined-cycle system at Tidd may encourage U.S. manufacturers to provide equipment that is applicable to PFBC technology. Such equipment might involve fuel preparation and feeding, ash removal, and hot gas cleanup.

In addition to Tidd and Sporn, two other PFBC projects are also under way— one at the Escatron plant in Spain and one at the Vartan plant in Sweden.

ENDESA, the Spanish state-owned utility, is repowering Unit 4 of the Escatron power plant with a P-200 PFBC module, the size of the unit used at Tidd. ENDESA produces about 25% of Spain's electricity mainly by burning coal and lignite. Spain has large reserves of black lignite which contain 4% to 8% sulfur, 25% to 45% ash, and about 20% moisture. ENDESA chose PFBC over other technologies because of its promise in burning this type of coal.

The Escatron plant is designed to burn Spanish black lignite with 36% ash and 6.8% sulfur, and a moisture content of about 20%. Limestone will be used to capture at least 90% of the sulfur.

In Sweden, StockholmEnergi, a municipal utility, has constructed a new PFBC cogeneration power plant in the center of Stockholm. Steam from the plant will be used for district heating The Vartan plant uses two P200 PFBC modules and a single steam turbine. The plant will have a net output of 135 MWe of electricity and more than 225 MWt of heat— while meeting extremely stringent emissions requirements. Low-sulfur (1% or less) coal will be burned; and Swedish dolomite or limestone will be used as the sorbent.

Start-up tests began in late 1989. With commissioning proceeding ahead of schedule, full commercial operation is now expected by the end of 1990.

The vartan PFBC plant is located in the center of Stockholm (top). Low-sulfur coal will fire two P-200 units, the same size used at Tidd, to cogenerate electricity and steam for district heating. Spain's Escatron plant sulfur black lignite; a sorbent will capture at (bottom) will use PFBC to burn very high-least 90% of the sulfur. The Escatron pressure vessel is being constructed on site; the head and steel rings are ready for assembly.

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