Status of B&W's Low-Emission Boiler System Development Program

Dennis K. McDonald (MCDONALD@pgg.mcdermott.com; (330) 860-6175)
Utility, Environmental and Industrial Division
The Babcock & Wilcox Co.
20. S. Van Buren Ave.
Barberton, Ohio 44203

Abstract

Since 1992, Babcock & Wilcox, under contract to the U.S. Department of Energy's (DOE) Federal Energy Technology Center (FETC) in Pittsburgh (DE-AC22-92PC92160), has been developing a Low-Emission Boiler System (LEBS) under their Combustion 2000 program. With direction from Mr. Anthony E. Mayne, FETC Contracting Officer's Representative, B&W is achieving the objective of the LEBS program which is to develop a Commercial Generating Unit (CGU) design, for deployment in the year 2000, which produces ultra-low emissions and a net plant efficiency greater than 42% at or below the cost-of-electricity (COE) of a conventional PC plant designed to meet current New Source Performance Standards (NSPS).

To meet the challenging emissions targets, B&W has developed advanced environmental control technologies which testing has shown to be capable of achieving emissions of 0.1 lb NO_x /MBtu within the combustion process itself (no SCR or SNCR), 0.1 lb SO_2 /MBtu and 0.005 lb particulate/MBtu, which are far below current NSPS. B&W's new E-LIDS™ process has also captured over 95% of thirteen air toxic elements measured, including mercury, and virtually all of the acid gases HCl and HF during Phase II tests at 100 MBtu/hr scale. To achieve a net plant efficiency of 42.27%, B&W and our subcontractor Raytheon Engineers and Constructors of Denver, Colorado, have developed an advanced steam cycle and boiler. Phases I through III have now been completed and B&W is anticipating Proof-of-Concept (POC) demonstration of these technologies in Phase IV.

During Phase I, completed in 1994, several advanced steam cycle, boiler and emission control technologies were reviewed and what was believed to be the lowest cost combination which could meet the performance goals was selected. Through engineering analysis, numerical modeling, pilot-scale tests and 2200 hours of testing at our 100 MBtu/hr Clean Environment Development Facility (CEDF) the selected technologies have been developed as subsystems during Phase II. The results have resolved the major uncertainties and provided the technical basis for a Commercial Generating Unit design which meets or exceeds all program objectives. In addition, B&W's new DRB-4Z™ ultra-low-NO_x burner and the E-LIDS™ process promise to offer improved emissions in retrofit applications as well as in greenfield installations.

During Phase III, these results were applied to produce the design and cost estimate for the Proof-of-Concept Demonstration facility and the Commercial Generating Unit. Phase IV, scheduled to begin in the fall of 1997, is an essential and critical step toward commercialization which focuses on integrated plant control, operability, performance and reliability of these subsystems under

utility power plant conditions while varying load and firing several different coals. This paper describes the key results of our extensive subsystem testing, B&W's resulting Commercial Generating Unit design and summarizes our plans for Phase IV's Proof-of-Concept Demonstration.

Introduction

Coal will undoubtedly remain the world's primary fuel for power generation well into the 21st century. The International Energy Agency reports about 970,000 MW_e of coal fired capacity in operation today[1], with about one third located in the United States. The Energy Information Agency of the DOE reports about 51% of the domestic electricity generated in 1995 was generated using coal. In spite of a significant projected increase in oil and gas fired capacity, the Energy Information Agency's "Annual Energy Outlook" for 1997 projects coal will still represent over 47% of the electricity generated in the U.S. in the year 2015.

Internationally, about 300,000 MW_e of coal-fired capacity is expected to be ordered over the next decade, mostly in Asia and the Pacific Rim[2] . Though present domestic market conditions are depressed, U.S. Utilities have announced a need for over 13,000 MW_e of coal-fired capacity by 2005[3] consisting of 6,788 MW_e of new capacity additions and 6,300 MW_e of repowering.

U.S. suppliers are now competing in a world-wide economy and the international demand for coal-fired capacity is large. However, the greatest needs are in countries such as China where technologies which are proven, reliable, low-cost, and easy to operate are presently favored. Emission limits in these markets are presently unchallenging. However, pressure from the world community exerted through financing institutions is rapidly forcing stricter emissions limits which is also shifting attention to more sophisticated coal-fired technologies. In areas such as Europe and Japan, emission restrictions and/or high fuel cost have already made high efficiency, low emission advanced technologies attractive.

In the U.S. the economic uncertainties of deregulation have created an almost non-existent market for new installations. In addition, a traditional industry aversion to risk has created a business climate that limits resources to finance the risks associated with new technologies such as pressurized fluidized bed combustion (PFBC) or integrated gasification combined cycle (IGCC). Simultaneously, recent improvements in transmission capabilities, interconnection of power grids allowing regions with excess power to supply to regions whose demand exceeds their supply, and demand-side conservation have significantly diminished the need for new domestic equipment. While about 647 units representing 74,000 MWe of capacity in the U.S. will be over 40 years old by the year 2005[1] and potentially ready for retirement, it is currently more economical to maintain, repair, upgrade and repower these existing plants rather than construct new facilities.

As the Clean Air Act Amendments of 1990 are implemented domestically, emission limits for SO_2 and NO_x, particulate and air toxics are becoming progressively more stringent. There is also growing pressure from global environmentalists to reduce the amount of greenhouse gasses such as CO_2 being discharged to the atmosphere. As a result, equipment suppliers are under severe pressure to deliver improving performance (efficiency and emissions) under extremely competitive pricing conditions.

All of these factors contribute to the inclination of the domestic power generation industry to improve performance with equipment and technologies that carry as low a risk on the investment as possible. In order to gain acceptance, any new coal based technology must (1) achieve high net plant efficiency and very low emissions, and (2) minimize the risks inherent in the first units at (3) a cost-of-electricity competitive with conventional coal-fired technology.

In response to these global conditions, B&W contracted in 1992 with the U.S. Department of Energy's (DOE) Federal Energy Technology Center (FETC) in Pittsburgh to participate in the Combustion 2000 program to develop a Low Emission Boiler System (LEBS) design. Built upon B&W's unequaled pulverized coal-fired boiler experience, our design integrates an advanced low NO_x combustion system, which innovatively extends current combustion technology, and enhanced limestone injection dry scrubbing (E-LIDS™), composed of three commercial technologies operating synergistically, into a once-through double-reheat steam generator operating at ultra-supercritical steam conditions (4500psi, 1100°F/1100°F/1100°F).

Program Objectives

The objective of the Combustion 2000 LEBS program is to develop a pulverized coal-fired Commercial Generating Unit (CGU) design to be commercially available in the year 2000 that will achieve aggressive efficiency and emissions targets while keeping the cost-of-electricity at or below that of a current conventional plant designed to meet New Source Performance Standards (NSPS). The program performance objectives are shown in Table 1 and the structure of the program is summarized in Table 2.

Table 1: LEBS Performance Objectives

	NOx Emissions (lb/MBtu)	SO_2 Emissions (lb/MBtu)	Particulate Emissions (lb/MBtu)	Air Toxic Emissions (% Capture)	Net Plant Efficiency (%)
Program Goal	0.2	0.2	<0.015	in compliance	>38
Program Target	0.1	0.1	<0.01	in compliance	>42

Table 2: U.S. DOE's Combustion 2000 LEBS program Summary

Phase	Status of B&W Program	Objective	Time Frame
I	Successfully Completed	Assess potential technologies for reducing emissions and improving efficiency to arrive at the most promising technologies, resulting in a conceptual CGU design and preliminary costs which meet the program performance and cost goals.	1992-1994
II	Successfully Completed	Further develop technologies through engineering analysis, detailed subsystem design and testing of complete subsystems to produce a more substantial basis for the CGU design.	1995-1997
III	Successfully Completed	Update the CGU design and costs and the detailed facility design, operational test plan and cost estimate for the Phase IV Proof-of-Concept (POC) demonstration facility.	1995-1997
IV	Proposal Due August 1997	Construction and operation of the Proof-of-Concept Demonstration Facility	1997-2000

B&W has successfully completed Phases I through III and in Phase IV a Proof-of-Concept demonstration facility will be constructed and operated based upon our existing Clean Environment Development Facility (CEDF), located at McDermott Technology Inc. (Formerly the Alliance Research Center) in Alliance, Ohio which was originally constructed with funds from DOE, the Ohio Coal Development Office (OCDO) and B&W. The Combustion 2000 LEBS program schedule is shown graphically in Figure 1.

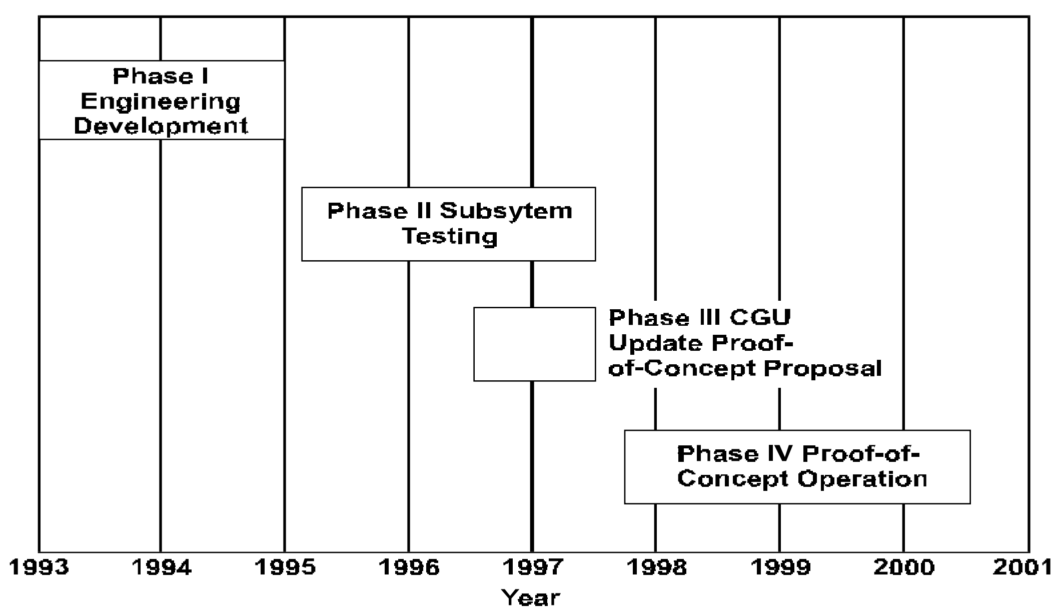

Figure 1: Combustion 2000 LEBS Schedule

Approach

During Phase I, completed in 1994, several advanced steam cycles, boiler and emission control technologies were reviewed and what was believed to be the lowest cost combination to meet the performance goals was selected. During Phase II, five subsystem teams were formed to focus on each of the technologies selected in Phase I; NO_x, E-LIDS™, Boiler, Controls & Sensors and Balance-of-Plant (BOP). These subsystem teams further developed the technologies through engineering analysis, including extensive numerical modeling, almost 1100 hours of pilot-scale testing at B&W's 5 MBtu/hr Small Boiler Simulator (SBS) and nearly 2200 hours of testing in B&W's 100 MBtu/hr Clean Environment Development Facility (CEDF). The CEDF is a state-of-the-art facility allowing testing of both combustion and a variety of emissions control technologies in a facility specifically designed to represent commercial plant characteristics. Figure 2 shows the CEDF arrangement and major equipment.

For reduction of NO_x emissions, a new burner named the DRB-4Z™ was developed. To remove sulfur, particulate, air toxic elements, and acid gases from the flue gas, B&W's Enhanced Limestone Injection Dry Scrubbing system (E-LIDS™) was refined. As a result of this immense amount of development and testing, B&W has improved the equipment and system designs and acquired substantial performance data with several fuels for use in predicting emissions performance and defining optimum operating parameters.

During Phase III a detailed CGU design was developed based on the results of subsystem testing combined with additional numerical modeling, laboratory and field testing conducted in Phase II which was directed at specific issues such as controls, sensor development and corrosion. This data along with the steam cycle and plant design expertise of Raytheon Engineers and Constructors of Denver Colorado (RE&C) and B&W's boiler's design experience were used to generate a detailed CGU plant design which meets or exceeds the performance objectives of the program. A capital cost estimate of the CGU design and an analysis of the constant dollar levelized busbar cost were made and compared with the capital and busbar costs for a state-of-the-art conventional subcritical pulverized coal-fired (PC) plant achieving 37.5% net plant efficiency, 95% sulfur removal and 0.46 lb/MBtu NO_x emissions (better than current NSPS).

Also during Phase III a detailed design and cost estimate was made for Phase IV's Proof-of-Concept facility. The fourth and final phase of this important national program is dedicated to Proof-of-Concept demonstration of the designs developed and tested in prior program phases. In Phase IV the readiness of B&W's LEBS design for commercial application as an integrated system will be demonstrated. Phase IV is a critical step toward commercial application in that it provides a means of gaining the experience of integrated operation of the combustion system, including individual burner coal-air flow control, and the E-LIDS™ system in a facility configured and operated like a utility plant. It will also provide operational data over the load range and during dynamic load changing which are essential to control system development and performance optimization.

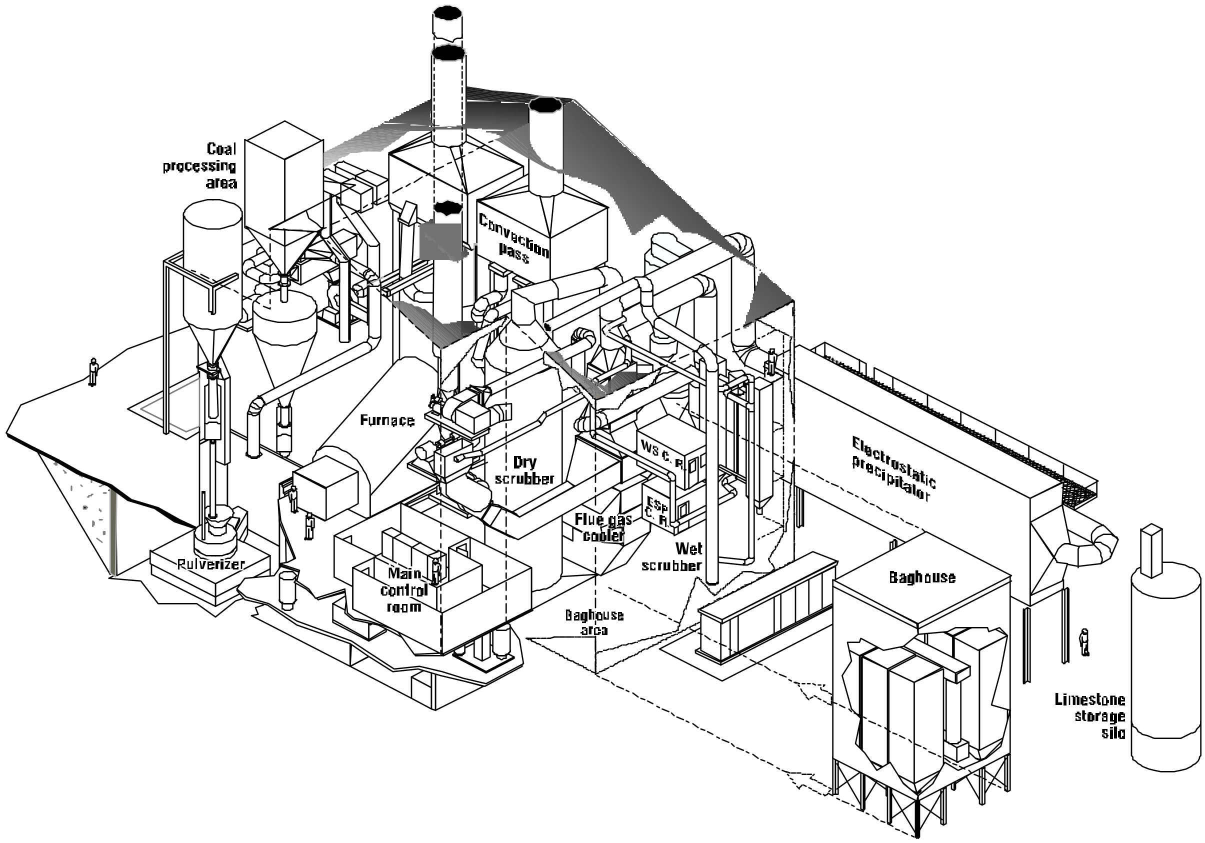

Figure 2: B&W's 100 MBtu/hr Clean Environment Development Facility

Technology Description and Results

B&W's CGU is based on a net 400 MW electrical output consisting of an advanced steam cycle, a once-through supercritical boiler employing opposed wall fired DRB-4Z™ burners with over-fire air integrated with in-furnace limestone injection and the E-LIDS™ system. Figure 3 shows the CGU schematically and a summary description of the technologies and components employed follows.

Steam Cycle **-** Net Plant Efficiency depends on many factors which vary greatly with the site conditions and fuel. The level of efficiency which can be achieved technically must also be balanced against the cost of the equipment, sophistication of operation and other risks to establish the most economical plant design. To address some of these variables, DOE specified a Kenosha, Wisconsin site, Illinois #6 fuel and the key cost parameters. The objective then was not simply to achieve 42% net plant efficiency, but to achieve it at a life-cycle cost of electricity at or below that of a conventional pulverized coal plant of the same net output designed to meet current NSPS.

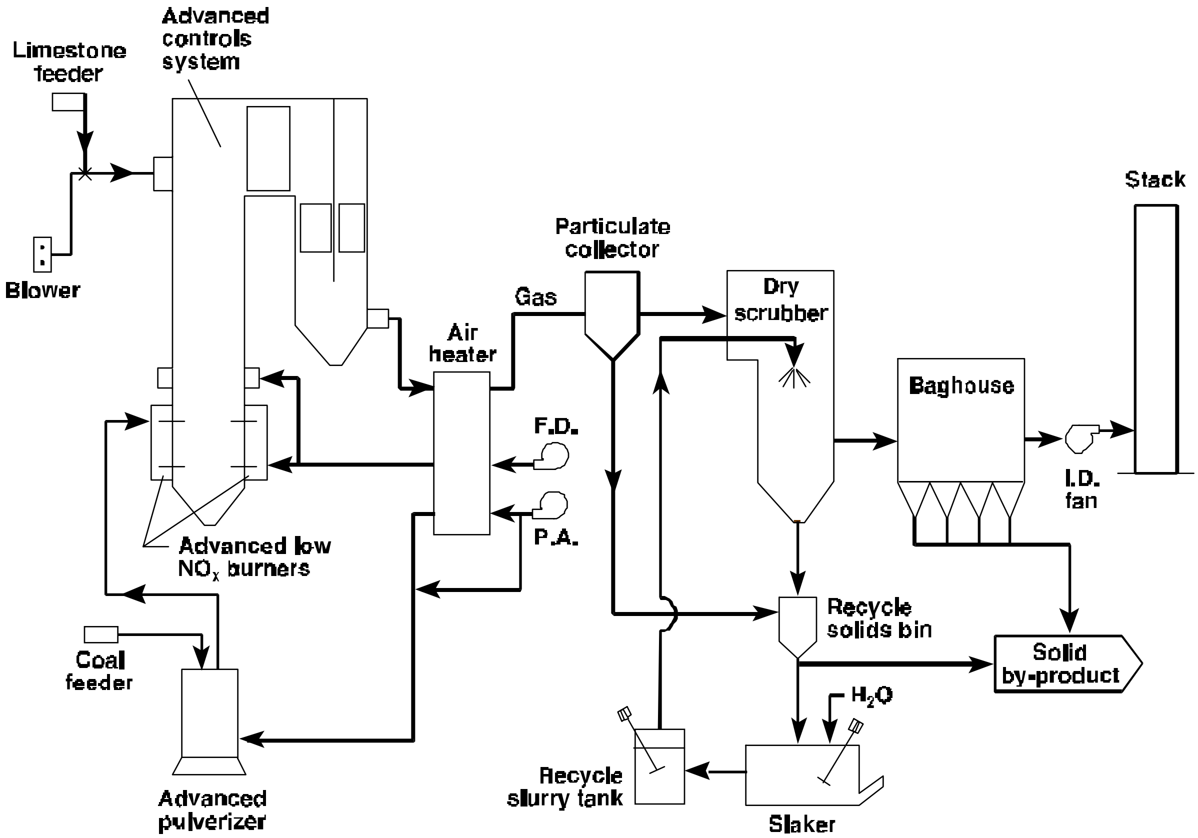

Figure 3: B&W's Commercial Generating Unit Schematic

After careful consideration in Phase I, B&W selected a 4500 psi, 1100°F double reheat steam cycle to accomplish the objective. With our subcontractor Raytheon Engineers & Constructors, a cycle incorporating two high pressure desuperheating feedwater heaters into the feedwater train was selected. In addition, state-of-the-art steam turbine characteristics were incorporated and a steam cycle was developed that achieves a turbine cycle heat rate of about 6811 Btu/kWh (50.1% turbine cycle efficiency). Because of the improved turbine cycle efficiency and reduced power requirements of the E-LIDS™ system, B&W's Commercial plant design achieves a net plant efficiency of 42.27% (8073 Btu/kWh heat rate HHV) at 100% load after incorporating all other plant losses. This cycle efficiency is comparable to other advanced coal-fired technologies such as IGCC and PFBC without the development and first-of-a-kind risks and costs.

Figure 4 shows the cycle arrangement. The steam turbine layout consists of four (4) casing sections; one combined Very High Pressure (HP)/High Pressure (HP2) turbine casing, one Intermediate Pressure (IP) turbine casing and two double flow Low Pressure (LP) turbine casings.

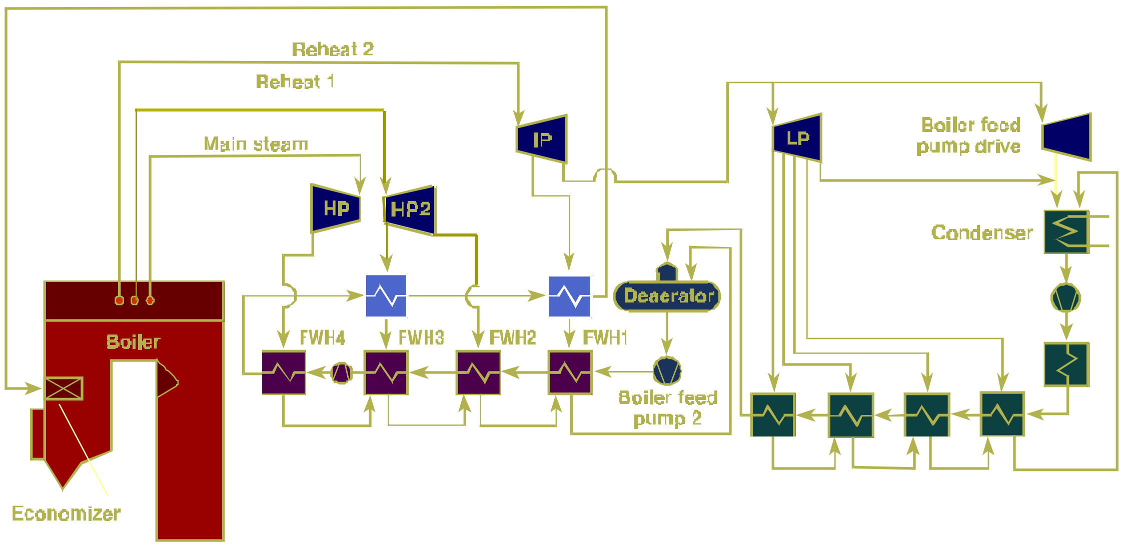

Figure 4: B&W's Commercial Generating Unit Steam Cycle Schematic

The feedwater heating system consists of nine (9) stages of extraction heating. There are two (2) desuperheating heat exchangers, four (4) high pressure (HP) feedwater heaters, a deaerator and storage tank and four (4) low pressure (LP) feedwater heaters. The top desuperheating heaters before the economizer enable a final feedwater temperature of 583°F to be attained with extractions from the HP and IP turbines. Steam exiting the top heaters cascades to two of the four HP feedwater heaters.

Boiler Design -To develop a state-of-the-art boiler design which accommodates the emission control technologies and achieves advanced steam conditions, B&W applied over 40 years of once-through boiler design experience. B&W's boiler design incorporates experience from over 80 supercritical boilers supplied in the U.S., 15 of which employ double reheat cycles, and our knowledge of state-of-the-art once-through Benson™ boiler technology licensed from Siemens. A new, advanced vertical tube furnace design, which provides a natural circulation characteristic at low loads, was developed analytically, compared to the currently applied spiral wound circuitry, and selected based on superior performance and lower cost. B&W's latest materials technologies have been applied to select materials resistant to corrosion of the high temperature surfaces in the superheater and reheaters due to the coal ash and of the furnace walls when operating substoichiometrically with staged combustion. Much of this corrosion work was completed during Phase II of this program.

The boiler is a dry hopper bottom, once-through, once-up, double reheat steam generator operating under balanced draft conditions in the furnace. The furnace incorporates deep staging in order to meet the NO_x emission goal of 0.10 lbs/MBtu using overfire air ports located on both the front and rear walls above the top burner row. The boiler convection pass configuration is a B&W parallel downpass design arranged with two parallel gas paths. Control dampers located at the bottom of each downpass bias the flue gas flow through each of the gas paths to control reheat outlet steam temperature throughout the load range. Feedwater flow/firing rate ratio and spray attemperation are used for controlling main steam temperature.

Combustion **-** B&W's Low-Emission Boiler System (LEBS) utilizes DRB-4Z™ advanced low-NO_x burners and air staging for NO_x control (no backend cleanup). The DRB-4Z™ burner concept has been meticulously engineered and designed using advanced numerical modeling, over 550 hours of pilot-scale testing at 5 MBtu/hr and nearly 1400 hours of full scale 100 MBtu/hr testing. Aerodynamic partitioning of combustion air combined with knowledge of the near-flame turbulent flow structure and chemical kinetic rates were used to optimize the mixing of fuel and air streams, resulting in minimum pollutant formation and maximum combustion efficiency. The burner internals were designed to provide the desired air distributions to the flame front while minimizing pressure drop.

The DRB-4Z™ burner operates on the principle of delayed combustion. Air is diverted away from the core of the flame, reducing local stoichiometry during coal devolatilization, and thereby reducing initial NO_x formation. This "internal staging" or delayed mixing of some of the combustion air with the fuel allows the released nitrogen volatiles to combine to form molecular nitrogen instead of NO_x. In the reducing atmosphere produced by this internal staging, molecules of NO_x that do form can be more readily reduced back to molecular nitrogen.

A 100 MBtu/hr DRB-4Z™ burner was tested in Phase II in B&W's state-of-the-art CEDF. Figure 5 shows that when firing the Illinois #6 design coal, the NO_x goal of 0.2 lb/MBtu was met without external staging (1.17 burner stoichiometry). When externally staged to 0.86 burner stoichiometry, NO_x emissions of 0.12 lb/MBtu were achieved with a burner which **was not** optimally configured for external staged operation.

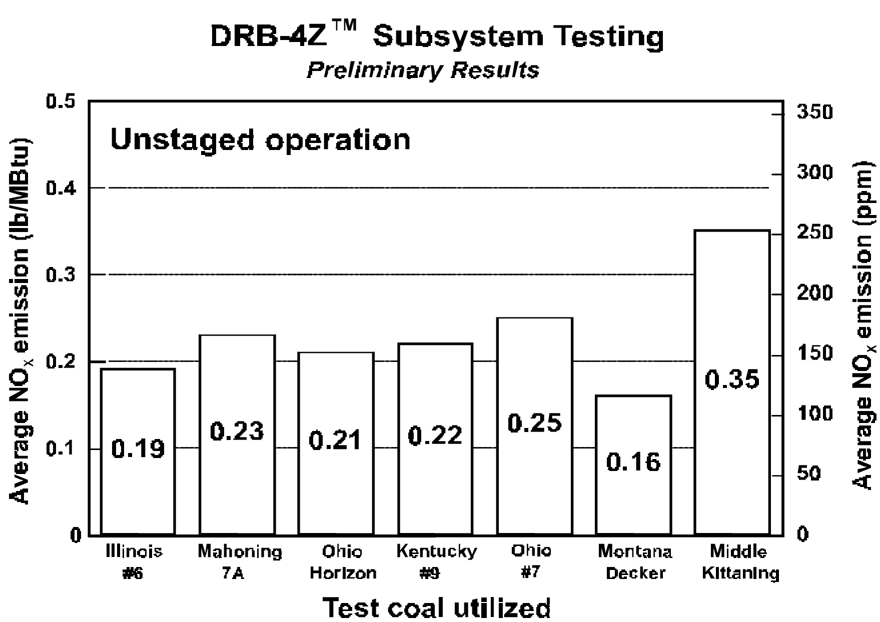

Figure 5: 100 MBtu/hr DRB-4Z™ Performance Unstaged

As illustrated in Figure 6, when externally staged to 0.75 burner stoichiometry, the DRB-4Z™ burner will achieve the project target of 0.1 lb NO_x /MBtu. This will be validated in Phase IV. Since all previous testing has involved a single burner, testing the DRB-4Z™ burner in a multiple burner configuration and control of individual burners via coal and air flow sensors and an integrated control system will also be demonstrated in Phase IV.

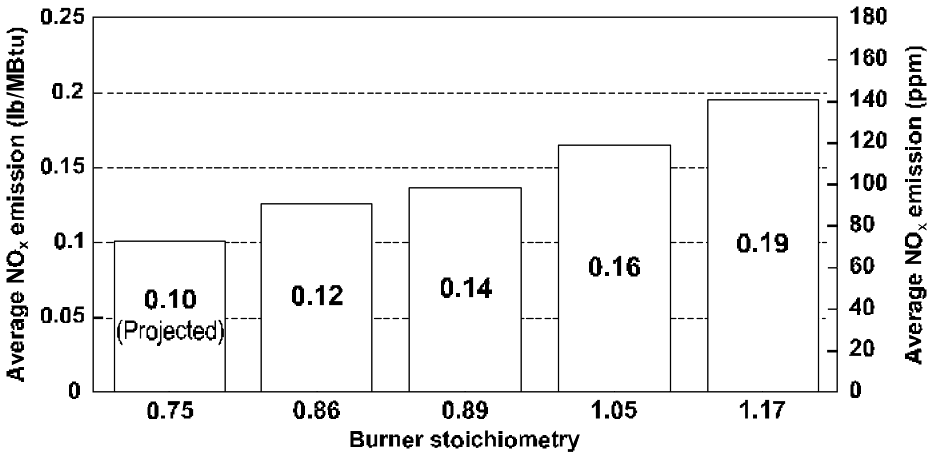

Figure 6: 100 MBtu/hr DRB-4Z™ Performance Staged (firing Illinois #6)

***E-LIDS™* -** To meet the SO_2, particulate, and air toxics emission objectives, B&W has developed an innovative Enhanced Limestone Injection Dry Scrubbing system (E-LIDS™, patent pending). The E-LIDS™ process comprises the cost-effective integration of three commercially-proven flue gas cleanup technologies: furnace limestone injection, dry scrubbing, and pulse-jet fabric filtration. Over 450 hours of testing at 5 MBtu/hr and over 610 hours of testing at 100 MBtu/hr has shown that more than 98% sulfur dioxide removal is achieved across the boiler furnace and convection pass, the dry scrubber, and the fabric filter. Figure 7 shows the removal by component.

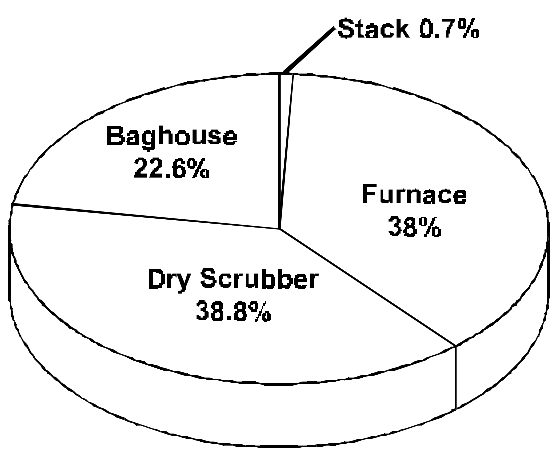

Figure 7: 100 MBtu/hr E-LIDS™ Sulfur Removal (firing Illinois #6)

Because air toxics capture is likely to be an important issue by the time a LEBS plant is commercialized, B&W has characterized the E-LIDS™ process with respect to the capture of air toxics species (mercury, trace metals, and acid gases). Figure 8 shows the air toxics removal efficiency for each element of interest. Note that the system averaged well over 95% removal of mercury.

E-LIDS™ has an additional advantage since it removes almost all of the acid gases HCl and HF and achieves greater acid mist control due to the limestone furnace injection process. Normally, airheater outlet temperatures must be kept above the SO_3 acid dew point temperature to avoid condensation and corrosion in the airheater and downstream flues. Removing the SO_3 upstream

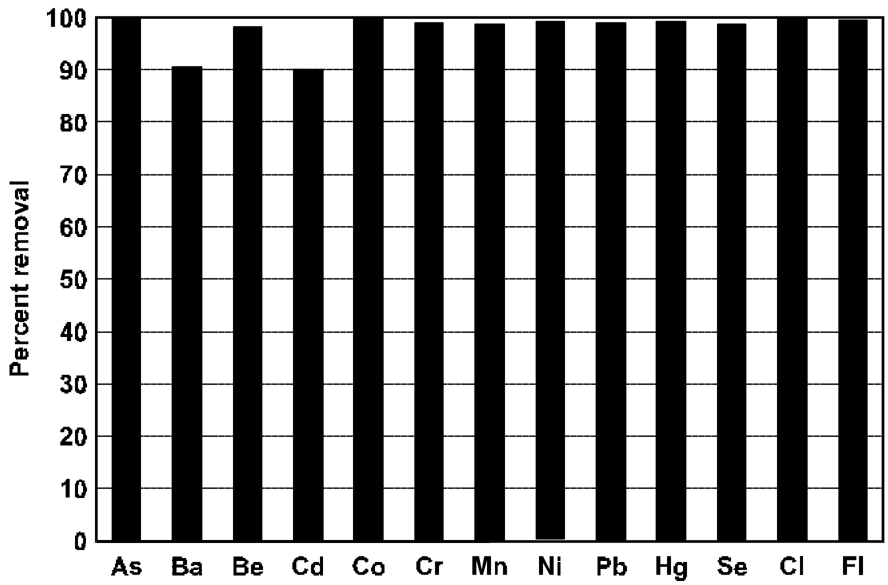

Figure 8: E-LIDS™ Average Air Toxics Removals

of the airheater allows the airheater flue gas outlet temperature to be reduced by 40°F or more. This reduction in temperature has a favorable impact on boiler efficiency. The overall impact of E-LIDS™ on the net plant efficiency is also favorable due to its significantly lower auxiliary power consumption relative to the state-of-the-art wet scrubber.

The particulate removal goal is accomplished through the use of the E-LIDS™ pulse-jet fabric filter. Phase II tests have shown that particulate emissions down to 0.005 lbs/MBtu can be achieved. The B&W LEBS system is also well-positioned to meet potential fine particulate (PM 2.5) regulations due to: 1) the use of a pulse-jet fabric filter for final particulate control, and 2) the ultra-high capture of SO_2, SO_3, and NO_x which can result in PM 2.5 precursors such as sulfates and nitrates if left uncontrolled.

Controls and Instrumentation - The CGU control system must couple sound mechanical design with excellent monitoring and control hardware and software so that total system performance is not compromised by off-design operation of individual subsystems. To accomplish this, the overall design philosophy for the CGU control system is to use state-of-the-art solutions wherever possible. Although the boiler is an ultra-supercritical double reheat design, control of the steam cycle is not considered new technology. New measurements, control elements, and algorithms are used in the CGU control system only where current methods would fail to meet the project objectives.

The most significant new solutions introduced into the CGU control system design concern the control of emissions and unburned carbon. The overall strategy for NO_x control is to create three distinct combustion zones in the furnace: an ignition zone where a stable flame is established, a reducing zone where NO_x formed in the ignition zone is reduced to molecular nitrogen or hydrocarbon species, and an oxidation zone where combustion is completed and nitrogen contained in hydrocarbon species is reduced to molecular nitrogen. Therefore, the general objective of the control system is to control mixing rates of fuel and air to establish a time-temperature history which will minimize NO_x formation. Similarly, high sulfur removal by the E-LIDS™ system depends on maintaining the close approach to saturation temperature at the outlet of the dry scrubber. The control system must be responsive to changes within the combustion process if sulfur removal efficiency is to be maintained.

Benefits

B&W's CGU design not only meets or exceeds LEBS emission targets at a net plant efficiency greater than 42% but its cost-of-electricity (COE) is slightly less than the COE of a state-of-the-art conventional subcritical plant achieving an excellent 37.5% net plant efficiency, 95% sulfur removal and 0.46 lb/MBtu NO_x emissions. For a conventional plant with a typical efficiency designed to meet NSPS, B&W's LEBS plant has a noticeably greater advantage. The health and economic value (credits) of reduced SO_2, NO_x and CO_2 emissions is another significant advantage of the LEBS plant.

Since B&W's approach has been to make significant advancements based on processes already utilized and accepted by the industry rather than developing emerging processes, such as PFBC and IGCC or new ones such as the Kalina cycle, its market entry is expected to be considered lower risk. Commercialization of B&W's LEBS design will provide both domestic and international power producers with an option that has lower cost and lower emissions than current conventional PC technology and lower risk than any other high efficiency technology presently under development.

Future Activities

To prove commercial readiness, controllability and operability, the advanced subsystems developed in Phases I through III must be demonstrated in a fully integrated facility of significant size operating for longer periods of time. Phase IV will provide the needed opportunity to integrate the subsystems and gain the operational and control experience to permit commercial deployment of these technologies for greenfield applications as well as retrofit systems and components in existing plants to improve performance and reduce emissions. Phase IV is essential in developing the experience necessary to offer an integrated, advanced power station that will achieve outstanding efficiency and emissions at a competitive price.

Integrated operation of the entire POC facility involves understanding of the relationships, and ultimately the control algorithms, to manage both the combustion and post-combustion emissions systems simultaneously at optimum conditions. In addition, an understanding of their interactive behavior during transient conditions, such as load changes, must be gained. Advanced control schemes will be demonstrated which integrate operation of individual burners, controlling their individual operation in concert with the overfire air system to minimize NO_x production and unburned carbon loss. The issues addressed with this configuration will include: the integration of multiple burners, the ability to control their individual air/fuel flows and operating characteristics, further optimization of coal particle size and primary air-to-coal ratio, staging to 0.75 stoichiometry and optimization of a complete overfire air system in association with the burners. Furthermore, the ability to control NO_x emissions while maintaining unburned carbon levels and CO emissions will continue to be addressed, along with the concerns of maintaining a stable flame while at low burner stoichiometries. The effect of turn-down will also be addressed during Phase IV.

The combustion system does not stand alone in a commercial power plant and its operation can have profound effects on other plant systems such as E-LIDS™. E-LIDS™ alone has challenging control requirements. Maintaining the 10^{o}F approach to saturation temperature at the dry scrubber outlet during load changes and combustion changes (burners in and out of service) will require an advanced approach.

Numerous phenomena can occur during extended operation that will impact ability to maintain optimum conditions which minimize emissions and maximize efficiency. Issues such as process and control response times, variations in fuel and sorbent chemistry, cleanliness of heat transfer surfaces, deposition in the dry scrubber and elsewhere and their impact on stack emissions must be better understood before commercial guarantees can be considered. The various changes in performance resulting from such factors will be identified and studied to determine how best to mitigate degradation of plant performance. The data obtained burning different coals under varying operating conditions will increase the database from which commercial guarantees will be established. Although considerable data was obtained during Phase II testing, additional data is needed to confirm the emissions targets can be met at a commercial scale. Particulate capture down to PM2.5 and additional air toxics data will also be obtained in Phase IV and solid by-product utilization applications (products) will be demonstrated.

Modern utility plants operate with minimal human intervention. State-of-the art Distributed Control Systems are capable of managing all power plant equipment and processes. One objective of B&W's POC Demonstration is to provide the hardware and sufficiently develop the control software to allow fully automatic control of the main facility not only at full load but through load changes.

Originally B&W intended to construct a demonstration facility at an electric utility generating site, but after consideration of the cost and benefits, budget constraints, and several other factors it was decided that modification of B&W's existing CEDF could fulfill the program objectives much more effectively. Not only is the total cost much lower but most of the cost will be expended for actual operation of the facility rather than on equipment, construction and shakedown. Therefore, B&W's proven CEDF will be modified into the 10 MW_e scale LEBS Proof-of-Concept Test Facility. Modification of the CEDF to create the fully integrated POC facility offers the LEBS program use of an existing $20 million facility at a fraction of what the total POC facility would cost.

The anticipated Phase IV program main tasks and schedule are shown in Figure 9. Just as B&W has consistently met or exceeded every objective of LEBS so far, we are anticipating a successful Phase IV program and commercial application of our highly efficient, low cost and low emission design in the year 2000.

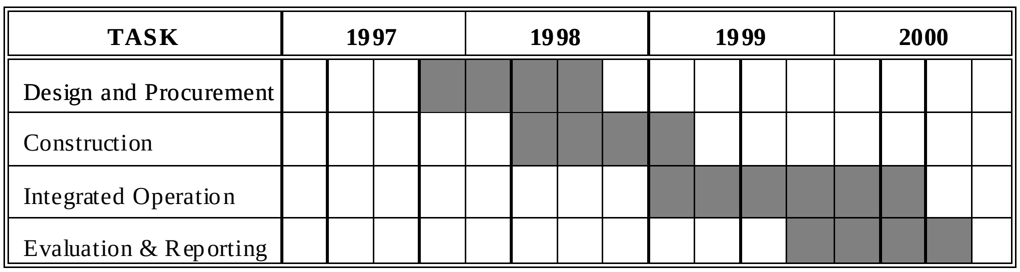

Figure 9: B&W's Phase IV Schedule

Acknowledgments

Babcock & Wilcox wishes to express thanks to the U.S. Department of Energy's (DOE) Federal Energy Technology Center (FETC) in Pittsburgh, and to Mr. Anthony E. Mayne, FETC Contracting Officer's Representative, for their continued support of B&W's LEBS team's efforts.

References

1. C.W. Maude, et al., "Worldwide Coal-fired Power Systems" (3 volumes), International Energy Agency Coal Research Reports 66, 67 and 70, London, 1994.

2. McCoy Power Reports, Boilers Worldwide, April, 1995.

3. DRI/McGraw-Hill "World Energy Service, U.S. Outlook" Spring-Summer 1995 from tables 65 and 78.