TOPICAL REPORT NUMBER 5 SEPTEMBER 1996

CLEAN COAL TECHNOLOGY

Reducing Emissions of Nitrogen Oxides via Low-NO_x Burner Technologies

Reducing Emissions of Nitrogen Oxides via Low-NO_X Burner Technologies

A report on projects conducted jointly under cooperative agreements between:

The U.S. Department of Energy and
- The Babcock & Wilcox Company
- Southern Company Services, Inc.
- Public Service Company of Colorado

CLEAN COAL TECHNOLOGY

Reducing Emissions of Nitrogen Oxides via Low-NO_X Burner Technologies

Cover image:
Inside a wall-fired boiler.

Introduction and Executive Summary

Summary of Demonstration Projects

Boiler Type	Wall-Fired	T-Fired	Vertically Fired	Cell Burner
Technology	LNB	LNB	LNB + OFA	LNB
Utility	Georgia Power	Gulf Power	Public Service of Colorado	Dayton Power & Light
Power Plant	Hammond	Smith	Arapahoe	J.M. Stuart
Unit No.	4	2	4	4
Size, MWe	500	200	100	605
NO_X Reduction at Full Load, %	48	37	69	55

The Clean Coal Technology (CCT) Demonstration Program is a government and industry co-funded effort to demonstrate a new generation of innovative coal utilization processes in "showcase" projects conducted across the country. These projects are on a scale sufficiently large to demonstrate commercial worthiness and generate data for design, construction, operation, and technical/economic evaluation of full-scale commercial applications.

The goal of the CCT program is to furnish the U.S. energy marketplace with advanced, more efficient, and environmentally responsive coal-utilizing technologies. These technologies will mitigate some of the economic and environmental impediments that limit the full utilization of coal as a continuing viable energy resource.

To achieve this goal, a multi-phased effort consisting of five separate solicitations was administered by the U.S. Department of Energy (DOE). Projects selected through these solicitations have demonstrated technology options with the potential to meet the needs of energy markets and respond to relevant environmental requirements.

Part of this program is the demonstration of technologies designed to reduce emissions of oxides of nitrogen (NO_x) from existing coal-fired utility boilers. NO_x is an acid rain precursor and a contributor to atmospheric (i.e., tropospheric) ozone formation, which is a health hazard and is also related to smog formation. NO_x emissions are regulated under the provisions of the Clean Air Act and particularly the Clean Air Act Amendments (CAAA) of 1990.

This report discusses CCT demonstration projects that reduce NO_x emissions by combustion modifications using low-NO_x burners (LNBs). In some cases. LNBs are used in conjunction with overfire air (OFA). Separate projects involve use of LNBs with four different boiler types: wall-fired, tangentially fired (T-fired), vertically fired, and cell burner units. All of these boiler types are subject to CAAA regulations. These CCT projects have been administered by DOE through its Pittsburgh Energy Technology Center (PETC).

Summary of Results

The results of these demonstration projects are summarized in the table above.

Several of the LNB technologies tested in these demonstration projects are being used successfully in commercial retrofits and new boilers.

Economics have been estimated by the project participants for the cases involving wall-fired, T-fired, and cell burner boilers. The economics assume a baseloaded power plant with a 65% capacity factor and a 15-year project life. The estimated capital cost for these technologies is less than $10/kW and the levelized cost on a current dollar basis is in the range of $100 - $125/ton of NO_x removed. The costs for application of LNBs to vertically fired boilers are expected to be significantly higher than for wall-fired, T-fired, and cell burner units as a result of the extensive boiler modifications required.

Reducing Emissions of Nitrogen Oxides via Low-NO_X Burner Technologies

Overview

The CCT Program NO_X reduction projects discussed in this report involve the use of LNBs, either alone or in combination with other technologies. These projects provide retrofit alternatives to reduce NO_X without the need to replace the boiler or install expensive post-combustion controls. The results obtained from these projects have been reported to the utility industry, to the public, and to EPA to guide them in establishing NO_X control regulations and selection of technology options.

The technology applications are: (1) a wall-fired boiler project at Plant Hammond, operated by Georgia Power Company; (2) a T-fired boiler project at Plant Smith, operated by Gulf Power Company; (3) a vertically fired boiler project at Arapahoe Station, operated by Public Service Company of Colorado; and (4) a cell burner boiler project conducted by Babcock & Wilcox at J. M. Stuart Station, operated by Dayton Power & Light. Projects 1 and 2 were conducted by Southern Company Services.

Background

The Clean Coal Technology (CCT) Demonstration Program, which is sponsored by the U.S. Department of Energy (DOE), is a government and industry co-funded technology development effort conducted since 1985 to demonstrate a new generation of innovative coal utilization processes. In a parallel effort, the U.S. Environmental Protection Agency (EPA) is in the process of promulgating new regulations, authorized by the 1990 Amendments to the Clean Air Act (CAAA), concerning emissions from a variety of stationary sources, including coal-burning power plants.

A major issue of concern is emissions of nitrogen oxides (NO and NO_2, collectively referred to as NO_X). Low-NO_X burners (LNBs) are one means of effectively reducing NOx emissions. This report describes a variety of LNB technologies demonstrated under the CCT Program.

The CCT Program involves a series of "showcase" projects, conducted on a scale sufficiently large to demonstrate commercial worthiness and generate data for design, construction, operation, and technical/economic evaluation of full scale commercial applications. The goal of the CCT Program is to furnish the U.S. energy marketplace with advanced, more efficient, and environmentally responsive coal-utilizing technologies. These technologies will mitigate some of the economic and environmental impediments that inhibit utilization of coal as a viable energy source.

The CCT Program also has opened a channel to policy-making bodies by providing data from cutting-edge technologies to aid in formulating regulatory decisions. DOE and participants in several CCT projects have provided the EPA with data to confirm NO_X emissions targets for coal-fired power plants subject to compliance under the CAAA.

NO_X Control Technologies

NO_X Emissions Regulations

Current and proposed EPA regulations for NO_X emissions are summarized on page 3. As noted, separate limits apply to the different boiler types covered in this report.

Combustion Modifications for Reducing NO_X Emissions

NOx control can be achieved by: a) boiler combustion controls, b) post-combustion controls, or c) a combination

NO_X Regulations under the Clean Air Act Amendments of 1990

NO_X emissions are generated primarily from transportation, utility, and other industrial sources. They are reported to contribute to a variety of environmental problems, including acid rain and acidification of aquatic systems, ground level ozone (smog), and visibility degradation. For these reasons, NO_X emissions are regulated in many ways by different levels of government throughout the country.

Table 1. Coal-Fired Boiler NO_X Emissions Limits, lb/10^6 Btu (Title IV)

	Phase I	Phase II
Implementation Period	1996-2000	2000+
Status of Regulations	*Promulgated*	*Proposed*
Group 1 Boilers		
Dry Bottom Wall-Fired	0.50	0.45
Tangentially Fired	0.45	0.38
Group 2 Boilers		
Wet Bottom Wall-Fired	NA	0.86
Cyclone-Fired	NA	0.94
Vertically Fired	NA	0.80
Cell Burner	NA	0.68
Fluidized Bed	NA	0.29

NA = Not applicable

Ozone Non-Attainment

Title I of the CAAA requires the states to apply the same limits to major stationary sources of NO_X as are applied to major stationary sources of volatile organic compounds. In general, these new NO_X provisions require (1) existing major stationary sources to apply reasonably available control technologies (RACT), (2) new or modified major stationary sources to offset their new emissions and install controls representing the lowest achievable emission rate, and (3) each state with an ozone nonattainment region in it to develop a State Implementation Plan (SIP) that, in most cases, will include reductions in stationary source NO_X emissions beyond those required by the RACT provisions of Title I. These requirements apply in certain ozone nonattainment areas and ozone transport regions.

Mobile Sources

Title II of the CAAA calls for reductions in motor vehicle emissions. Emission limits for new vehicles constitute the majority of reductions from vehicles. Emission limits for various classes of vehicles will be implemented throughout this decade.

Acid Rain

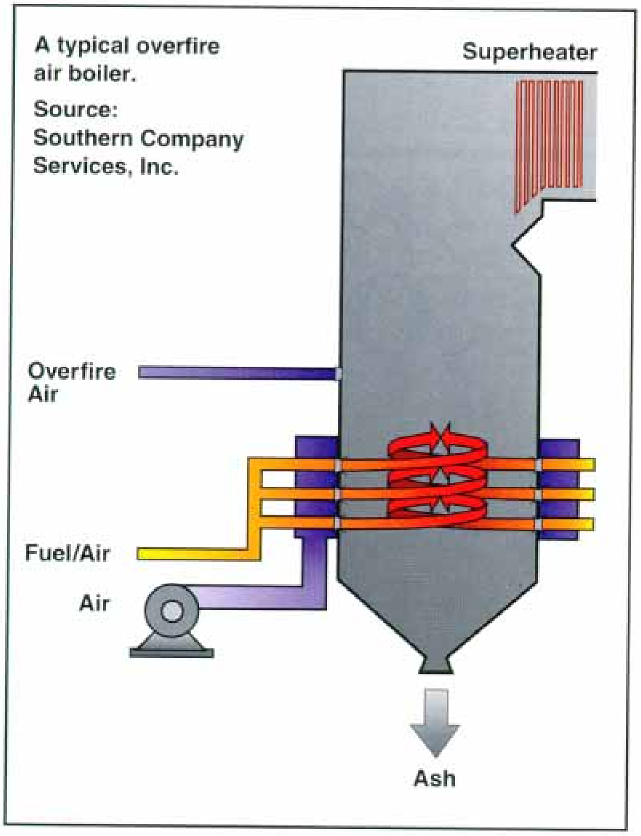
Title IV of the CAAA focuses on a particular set of NO_X emitting sources—coal-fired electric utility plants—and uses a two-part strategy to reduce emissions. The first stage of the program, promulgated on April 13, 1995, will reduce NO_X emissions in the United States by over 400,000 tons/yr between 1996 and 1999 (Phase I). These reductions are achieved by dry bottom wall-fired boilers and tangentially fired (T-fired) boilers (Group 1). In Phase II, which begins in 2000, EPA may establish more stringent standards for Group 1 boilers and establish regulations for other boilers known as Group 2 (boilers applying cell-burner technology, cyclone boilers, wet bottom boilers, and other types of coal-fired boilers). Currently, EPA has proposed a rule that would set lower Phase II, Group 1 emission limits and establish limits for Group 2, resulting in an additional reduction of 820,000 tons/yr.

Implementation

The table outlines Title IV NO_X emissions limits. The EPA has established emissions limits for the 169 Phase I, Group I, boilers (110 plants) identified for control in the CAAA. These limits will not change in Phase II. Emissions limits for the 195 Group 2 boilers will be established in Phase II. In addition to the 169 Phase I, Group 1 boilers, there are another 580 tangentially fired and wall-fired boilers that must meet the applicable NO_X emissions limits by January 1, 2000.

As shown above, the emission limitations proposed by EPA under Title IV for Phase II, Group 1 boilers are more stringent than the Phase I standards. EPA states that this is because more effective NO_X reduction technology has become available since promulgation of Phase I regulations. The statute requires that emission control costs for Group 2 be comparable to those for Group 1.

EPA has the authority to set Title IV NO_X limitations at higher levels if a utility can demonstrate that a boiler could not meet the standard by using LNB technology. The regulations also allow for emissions averaging in which the emissions levels established by EPA are applied to an entire group of boilers owned or operated by a single company. Averaging is not limited geographically.

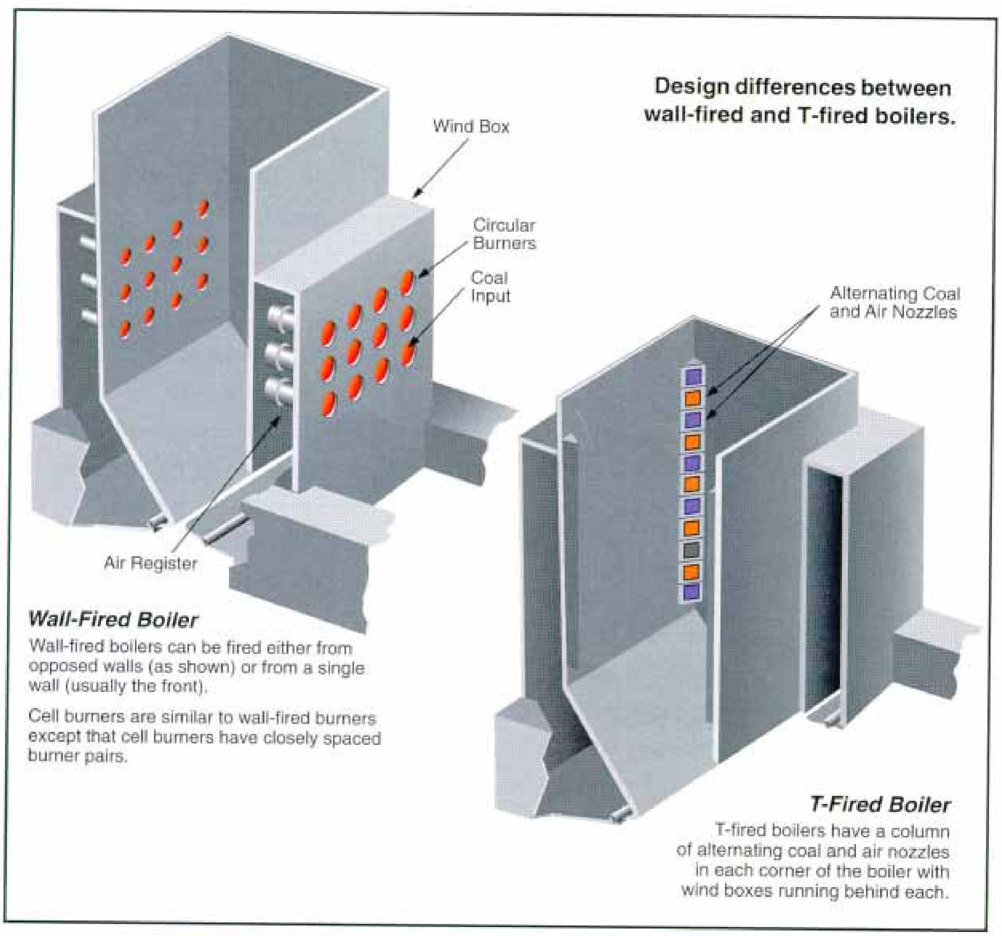


of these techniques. Post-combustion control processes being studied in the CCT Program include selective catalytic reduction (SCR) and selective noncatalytic reduction (SNCR). The present report focuses on combustion controls.

Low-NO_X combustion systems are designed to reduce the availability of oxygen in the primary combustion zone. This is achieved either by staged combustion using LNB or LNB in combination with overfire air (OFA). In addition, supplemental fuel can be used (coal, oil, or natural gas). This is referred to as reburning.

Staged combustion minimizes the formation of NO_X by reducing the amount of combustion air going to the burners. The remaining air, required for complete combustion, is introduced either in the burner as secondary (and possibly tertiary) air, or above the burner as overfire air. Conventional coal-fired burners operate with 15 to 20% excess air (compared to the theoretical, or stoichiometric, requirement). Staging involves reducing the percentage of excess air in the primary combustion zone.

Reburning decomposes NO_X once it is formed. The majority of the coal is burned in the primary combustion zone at or near stoichiometric conditions. Additional fuel is injected, and further burning occurs in another zone higher in the boiler with additional air; under the reducing conditions in the reburn zone, some of the NO_X, already formed is converted to molecular nitrogen.



Wall-Fired Boiler
Wall-fired boilers can be fired either from opposed walls (as shown) or from a single wall (usually the front).
Cell burners are similar to wall-fired burners except that cell burners have closely spaced burner pairs.

T-Fired Boiler
T-fired boilers have a column of alternating coal and air nozzles in each corner of the boiler with wind boxes running behind each.

Boiler Types

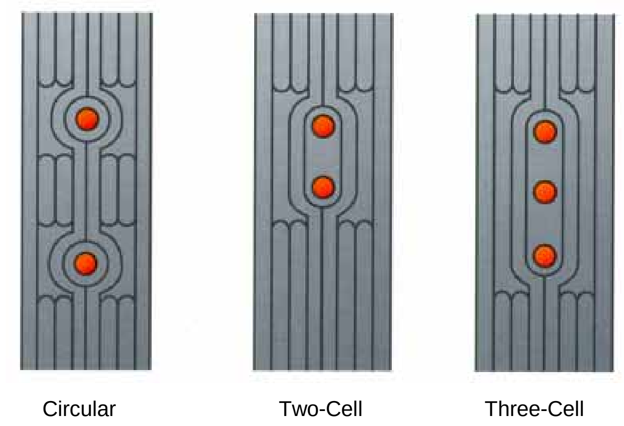
This report discusses NO_X emissions reduction for four types of boilers: wall-fired, T-fired, vertically fired, and cell burner units, using LNBs (with or without OFA) as the NO_X control technology. Wall-fired boilers most commonly use circular burners, in which each burner nozzle is surrounded by water tubes. Cell burners represent a variation in which two (or occasionally three) circular burners are grouped closely together, surrounded with water tubes. Wall-fired burners produce an intense, turbulent flame, with consequent high levels of NO_X formation. T-fired boilers consist of a vertical array of coal nozzles and air ports mounted in each corner of the furnace. The resulting lower temperature and diminished turbulence lead to inherently lower NO_X formation than is the case in wall-fired burners.

These differences in design cause different boiler systems to produce varying levels of uncontrolled NO_X. Because the boilers studied were designed and built before the establishment of New Source Performance Standards (NSPS) in 1971, they are referred to as pre-NSPS boilers.

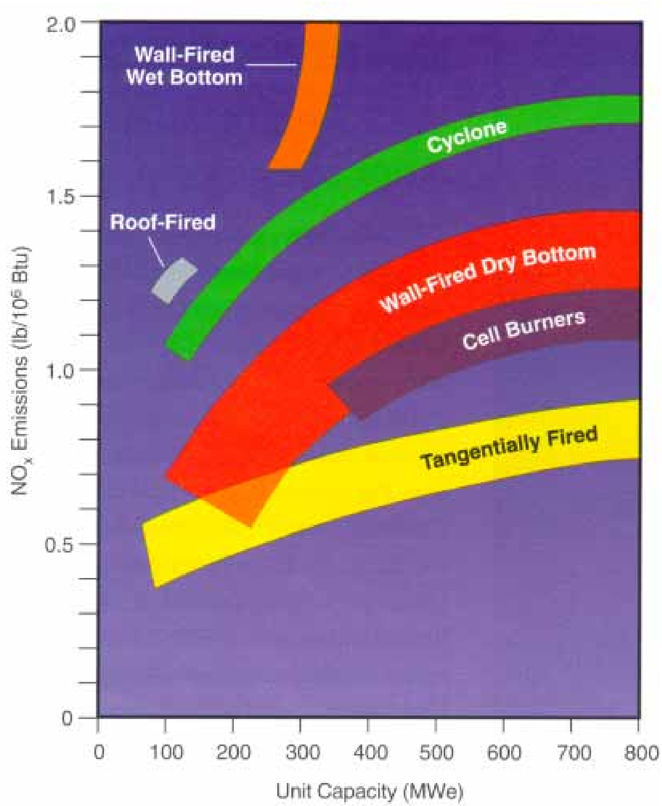
Most of these units produce levels of NO_X well above the current Title IV emissions regulations. These differences are important for retrofit technologies because a majority of the 192,000 MWe pre-NSPS coal boiler capacity consists of boilers that produce the highest levels of NO_X (e.g., wall-fired dry and wet bottom boilers, cyclone boilers, and cell burners). T-fired boilers constitute 43%, wall-fired 26%, cyclone 13%, and cell burners 13% of the pre-NSPS boiler population in the United States. The remaining 5% consist of other boiler types. In addition, over 70,000 MWe of U.S. boiler capacity is subject to NSPS requirements. Cyclone and cell units represent more than 50% of the NO_X generated by pre-NSPS coal-fired boilers.

Low-NO_X Burners

The principle of LNB operation involves decreasing the amount of air introduced into the primary combustion zone, thereby creating a fuel-rich, reducing environment and lowering the temperature, both of which generally suppress NO_X formation. The remaining air required for complete burnout of combustibles is added after the primary combustion zone, where the temperature is sufficiently-low so that additional NO_X formation is minimized. All of the combustion air is delivered to the furnace via the LNBs.



Arrangement of circular and cell burners in the furnace wall. Source: IEA



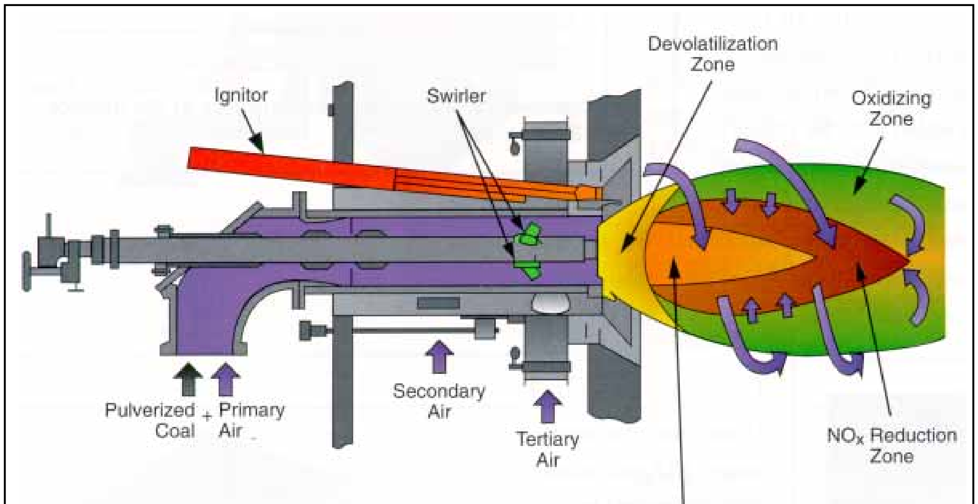
Full-load NO_X emissions for pre-NSPS coal-fired U.S. utility boiler configurations.

Overfire Air (OFA)

Under circumstances where NO_X emissions exceed desired levels despite the use of LNBs, it may be necessary to more deeply stage combustion, followed by introduction of the remaining air required for combustion through separate ports at higher elevations in the boiler, again at lower temperatures, thus limiting production of additional NO_X. This is the principle of OFA operation.

Potential Problems with Low-NOX Burners

Operation of LNBs with reduced air in the primary combustion zone can lead to economic losses as a result of increased amounts of unburned carbon (UBC), increased slagging in the combustion zone, and accelerated corrosion. To counteract these tendencies, UBC losses can be minimized by increasing coal fineness and by careful control of air/fuel distribution.



Example of an advanced low NO_x burner.
Source: IEA

Burner design, arrangement, and operation can be modified to minimize UBC, slagging, and corrosion. Also, tubes in the burner zone can be coated with corrosion-resistant materials. Increased UBC can impact the performance of particulate control systems. The expected increase in UBC is a function of boiler design and operating parameters and the coal burned. Increased carbon levels change the electrostatic properties of the fly ash, adversely affecting the performance of electrostatic precipitators (ESP). The marketability of the fly ash is also limited by UBC levels. Fly ash can be sold for use in cement manufacture and as road construction material, provided that the UBC content is below prescribed levels.

In any given retrofit application of NO_X reduction technologies, the available burner opening must be taken into account. Insufficient space can require additional boiler modifications at increased cost.

Wall-Fired Boiler Applications

The CCT project at Georgia Power Company's Plant Hammond Unit 4 was designed to demonstrate two combustion control techniques for NO_X reduction in wall-fired boilers: advanced overfire air (AOFA) and LNB. These technologies were tested both singly and in combination. The project was managed by Southern Company Services (SCS) on behalf of DOE and the project's industry co-funders, Southern Company and the Electric Power Research Institute (EPRI). The project has been expanded to include a study of the effects of advanced instrumentation and intelligent control on NO_X reduction performance. This extension is discussed in the section on artificial intelligence.

Test Site

Hammond Unit 4, a pre-NSPS unit having a gross rating of 500 MWe, was placed into commercial operation in 1970. The boiler, designed by the Foster Wheeler Energy Corporation (FWEC), is fired from opposed walls. Design steam conditions are 2500 psig and superheat/reheat temperatures of 1000°F/1000°F. The unit was designed for pressurized-furnace operation but was converted to balanced draft operation in 1977.

The unit is equipped with a cold-side electrostatic precipitator (ESP) and utilizes two regenerative preheaters each for the primary and secondary air. Prior to the LNB retrofit, six FWEC Planetary Roller and Table type mills provided pulverized coal to 24 pre-NSPS, Intervane burners, arranged in a matrix of 12 burners on opposing walls. The fuel is an eastern bituminous coal having 33% volatile matter, 10% ash, 4% moisture, 1.7% sulfur, and 1.3% nitrogen with a higher heating value of 12,900 Btu/lb on an as-received basis.

Advanced Overfire Air (AOFA)

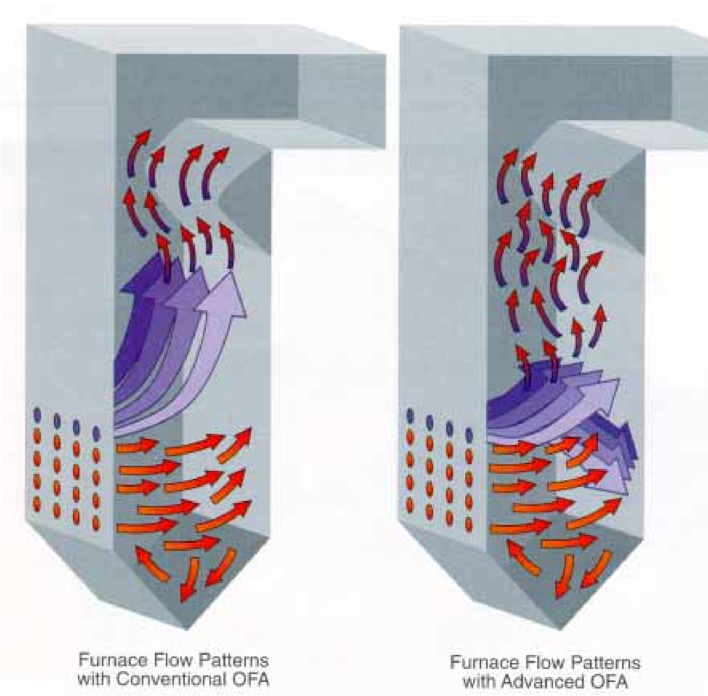
AOFA incorporates two principles for achieving NO_X reduction: (1) depletion of the air from the flame core of the burner zone to form a fuel-rich, reducing environment to minimize NO_X formation; and (2) better mixing and control of OFA with the furnace gases above the flame zone to achieve complete combustion.

For this project, FWEC designed an eight-port AOFA system. This system diverts air from the secondary air ductwork and incorporates four flow-control dampers at the corners of the OFA windbox and four OFA ports on both the front and rear furnace walls. To improve mixing, the AOFA system increases the velocity of OFA injection compared with other types of OFA systems.

How NO_X Is Formed in a Boiler

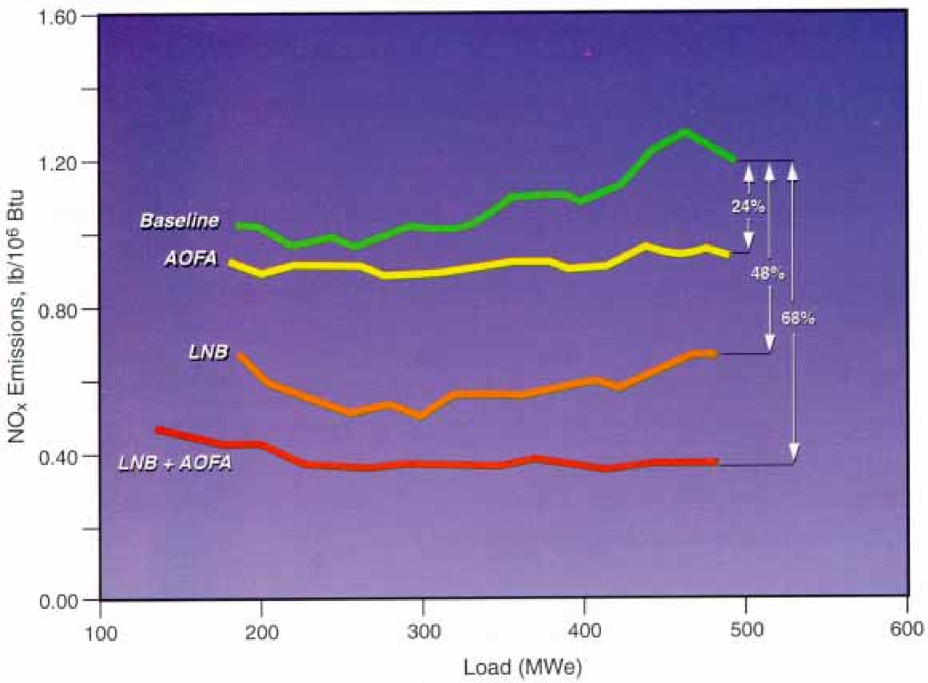
Most of the NO_X formed during the combustion process is the result of two oxidation mechanisms: (1) reaction of nitrogen in the combustion air with excess oxygen, referred to as thermal NOx; and (2) reaction of nitrogen that is chemically bound in the coal, referred to as fuel NO_X. Thermal NO_X generally represents about 25% of the total and fuel NO_X about 75%. In addition, minor amounts of NO_X are formed through complex interaction of molecular nitrogen with hydrocarbons in an early phase of the flame front; this is referred to as prompt NO_X.

The quantity of NO_X formed depends primarily on the "three t's:" temperature, time, and turbulence. In other words, flame temperature and the residence time of the fuel/air mixture, along with the nitrogen content of the coal and the quantity of excess air used for combustion, determine NO_X levels in the flue gas. Combustion modifications delay the mixing of fuel and air, thereby reducing temperature and initial turbulence, which minimizes NO_X formation.

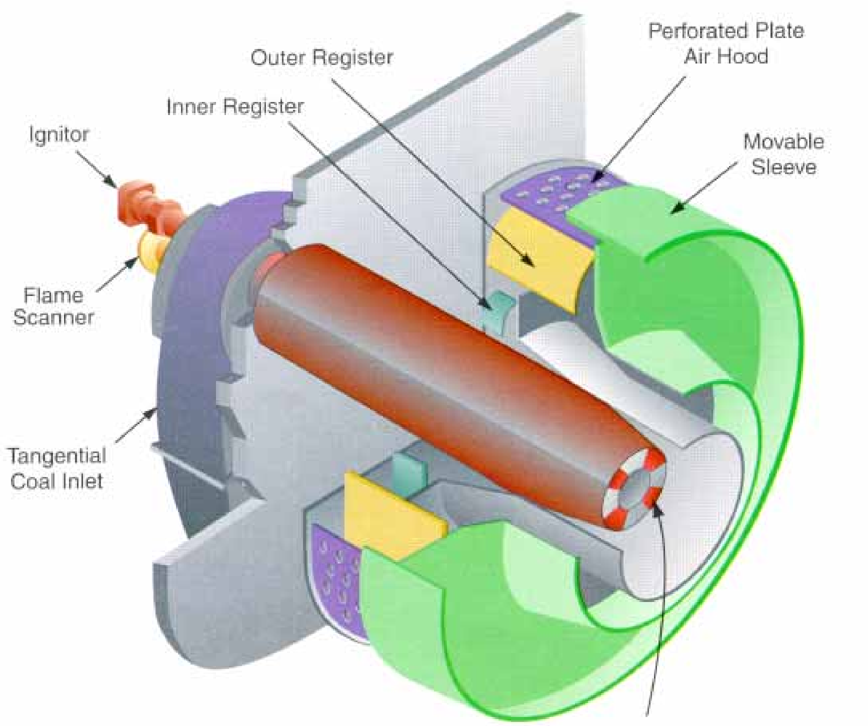


Effect of overfire air injection velocity.

Typically, OFA introduces air into the furnace in stages by diverting 10 to 25% of the total combustion air to ports located above the primary combustion zone. AOFA improves this approach by introducing the overfire air through separated ductwork at higher velocities and with more control. The resulting system provides staging of the



NO_X emissions results for wall-fired boiler.



Low-NO_X burner installed at Plant Hammond.

Split Flame Coal Nozzle (Variable Velocity)

combustion process, combined with accurate measurement of the AOFA flow.

To reduce slagging (deposition of molten mineral matter from coal on the furnace surfaces) and corrosion, the system is designed so that some of the combustion air is passed over furnace walls and tube surfaces. This provides a boundary of air that maintains an oxidizing atmosphere close to the boiler tube walls.

Low-NO_X Burners

The 24 existing Intervane burners were replaced with FWEC Controlled Flow/ Split Flame low-NO_X burners. In these burners, secondary combustion air is divided between inner- and outer-flow registers. A sliding-sleeve damper regulates the total secondary air flow entering the burner and is used to balance the air flow distribution among the burners. An adjustable outer register assembly divides the secondary air into two concentric paths and also imparts swirl to the air.

The secondary air that traverses the inner path flows across an adjustable inner register assembly that, by providing a variable pressure drop, apportions the flow between the inner- and outer-flow paths. The inner register also controls the degree of additional swirl imparted to the coal/air mixture in the near-throat region of the burner. The outer-air flow, which enters the furnace axially, provides the remaining air necessary to complete combustion. An axially movable inner sleeve tip provides a means to vary the velocity of the primary air while maintaining a constant mass flow.

The split-flame nozzle segregates the coal/air mixture into four concentrated streams, each of which forms an individual flame when entering the furnace. This segregation minimizes mixing between the coal and primary air, thereby assisting in staging of the combustion process to minimize the formation of NO_X.

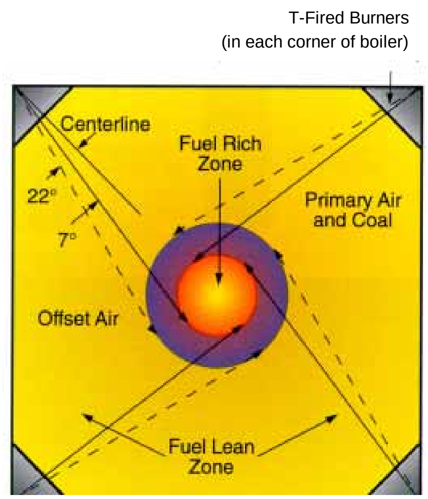
Test Results

With AOFA alone, the average longterm NO_X emissions were reduced by 24% from baseline values. For LNB alone, the reduction was 48%, while for LNB + AOFA the reduction was 68%. An unexpected consequence of installing LNBs was a decrease in furnace slagging and an increase in the amount of particulates (about 25%). Because of the reduced slagging, some portion of the mineral matter that would normally become molten slag in the boiler instead becomes fly ash. These factors had an adverse impact on ESP performance, leading to increased particulate emissions, which was a factor in the decision to install a new ESP at this site. Other sites may not require ESP replacement. Several on-line carbon-in-ash monitors are being evaluated as to their reliability, maintenance requirements, accuracy, repeatability, and suitability for use in this project. These instruments provide information that enhances boiler control capabilities.

T-Fired Boiler Applications

The SCS NO_X control project for T-fired boilers used an approach similar to that used on the wall-fired project. However, the T-fired technology is, by definition, different from the wall-fired system. The retrofits to this boiler involved installing air and coal inlet nozzles in three different configurations that change the way in which coal, primary air, secondary air, and OFA are injected into the boiler.

As indicated previously, conventional T-fired systems use vertical stacks of burners



Low-NO_X Concentric Firing System (LNCFS™).

The Clean Coal Technology Program

The Clean Coal Technology (CCT) Program is a unique partnership between the federal government and industry that has as its primary goal the successful introduction of new clean coal utilization technologies into the energy marketplace. With its roots in the acid rain debate of the 1980s, the program is on the verge of meeting its early objective of broadening the range of technological solutions available to eliminate acid rain concerns associated with coal use. Moreover, the program has evolved and has been expanded to address the need for new, high-efficiency power-generating technologies that will allow coal to continue to be a fuel option well into the 21st century.

Begun in 1985 and expanded in 1987 consistent with the recommendation of the U.S. and Canadian Special Envoys on Acid Rain, the program has been implemented through a series of five nationwide competitive solicitations. Each solicitation has been associated with specific government funding and program objectives. After five solicitations, the CCT Program comprises a total of 40 projects located in 18 states with a capital investment value of nearly \$6.0 billion. DOE's share of the total project costs is about \$2.0 billion, or approximately 34 percent of the total. The projects' industrial participants (i.e., the non-DOE participants) are providing the remainder- nearly \$4.0 billion.

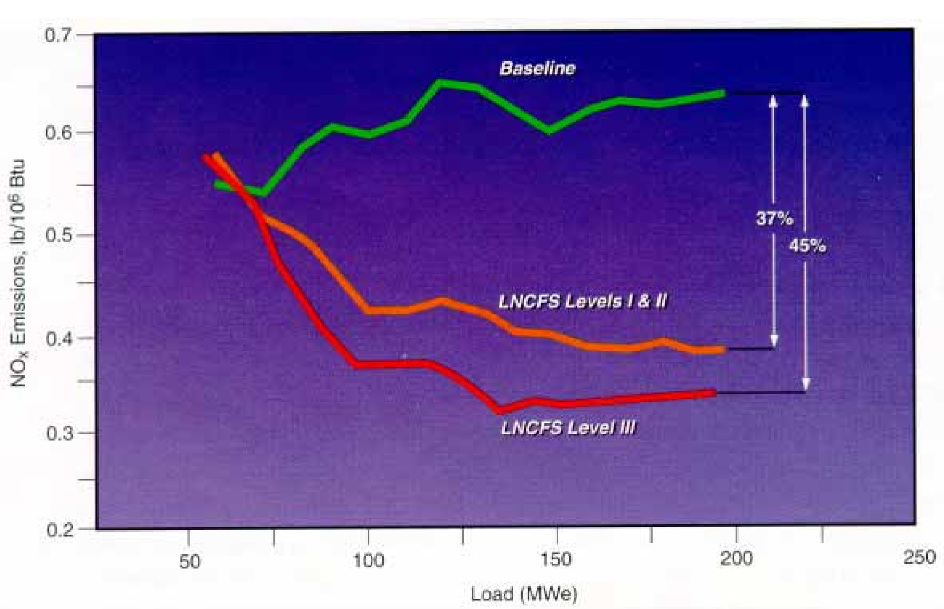
Clean coal technologies being demonstrated under the CCT Program are establishing a technology base that will enable the nation to meet more stringent energy and environmental goals. Most of the demonstrations are being conducted at commercial scale, in actual user environments, and under circumstances typical of commercial operations. These features allow the potential of the technologies to be evaluated in their intended commercial applications. Each application addresses one of the following four market sectors:

- Advanced electric power generation
- Environmental control devices
- Coal processing for clean fuels
- Industrial applications

Given its programmatic success, the CCT Program serves as a model for other cooperative government/industry programs aimed at introducing new technologies into the commercial marketplace.

at each comer of the furnace. The coal and air nozzles are alternated and angled to direct the air and fuel inward toward the middle of the furnace in a tangential firing circle. By offsetting the nozzles slightly, the combustion gases are made to swirl.

Southern Company Services' Plant Smith, site of a T-fired project designed to demonstrate three variations of LNCFS™ technologies for NO_X reduction.



NO_X, emissions results for T-fired boiler.

The nozzles can also be tilted vertically to control temperature throughout the furnace to meet steam requirements.

Test Site

The Plant Smith project consisted of retrofitting low-NO_X burners on a T-fired boiler at Unit No. 2, which has a capacity of 200 MWe. The boiler is an ABB/CE radiant reheat, natural circulation steam generator, with five elevations of burners. The unit was originally designed for pressurized-furnace operation, but was converted to balanced draft operation in 1976.

The fuel burned in the test program was an eastern bituminous coal with about 35% volatile matter, 8% ash, 9% moisture, 2.8% sulfur, and 1.4% nitrogen with a higher heating value of 12,000 Btu/lb on an as-received basis.

Low-NO_X Concentric Firing System (LNCF™)

LNCFS™ allows improved control of coal/air mixing by directing the secondary air in a circle outside of the circle formed by the coal and primary air. This configuration produces a stable flame front and a fuel-rich (oxygen-deficient) flame core in which coal-bound nitrogen is converted to molecular nitrogen.

LNCFS™ was specifically developed for retrofitting to T-fired furnaces. The major components of LNCFS™ are OFA, offset secondary air, and flame attachment coal nozzle tips. As defined previously, OFA refers to air introduced into the furnace above the top coal nozzle. Two types of OFA are employed in the LNCFS™ technology. Close-coupled overfire air (CCOFA) is introduced immediately above the top coal nozzle using the main windbox. Separated overfire air (SOFA) is introduced through a windbox and air nozzles separated from the main windbox.

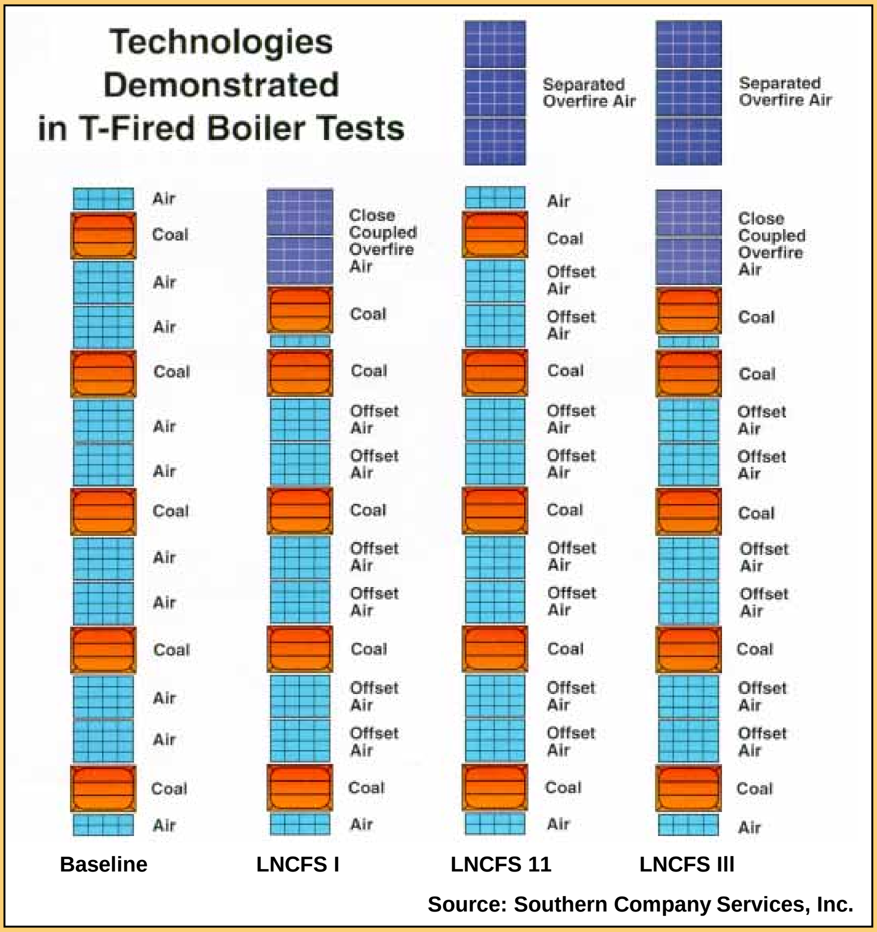
Offset secondary air is introduced between the coal nozzles. This air is injected through concentric auxiliary nozzle tips installed on the air nozzles in the main windbox. The angle of these nozzles can be adjusted both horizontally (yaw) and vertically (pitch). In general, these nozzles are adjusted to direct the air toward the furnace walls to reduce fouling and corrosion. This produces two concentric circular combustion regions. Most of the coal is contained in the fuel-rich inner zone, which is surrounded by a fuel-lean outer zone containing combustion air. The size of the outer zone can be varied by adjusting the yaw and pitch of the offset air nozzles.

Flame attachment tips are installed on the coal nozzles to stabilize and ignite the coal stream close to the nozzles to devolatilize the coal as quickly as possible and release the fuel nitrogen in an oxygen poor region of the flame. This helps minimize formation of fuel NO_X.

Test Results

All three levels of LNCFS™ technology were successful in lowering NO_X levels at full load of 200 Mew. Levels I and II averaged 37% reduction, while Level III averaged 45% reduction. As load was reduced, NO_X reduction remained relatively constant down to a load of about 100 MWe (about 50% of rated capacity). As load was further reduced, however, NO_X emissions rapidly increased, reaching baseline levels at 50-70 MWe.

LNCFS™ technology is potentially applicable to a wide range of T-fired utility and industrial boilers throughout the United States and abroad. There are nearly 600 U.S. pulverized-coal T-fired utility units. These units range in electric generating capacity from 25 MWe to 950 MWe. A wide range of coals, from low-volatile bituminous through lignite, are being fired in these units. LNCFS™ technology can be used in retrofit as well as new boiler applications.



Three variations of LNCFS™ were demonstrated in the Plant Smith project: Level 1, Level 11, and Level Ill. These levels represent different ways of using the coal and air to provide reductions in NO_X emissions. The three levels differ from each other as follows:

- Level I involves CCOFA but does not include SOFA. CCOFA is integrated directly into the existing windbox by exchanging the locations of the top coal and air nozzles. LNCFS™ I is the easiest and cheapest to install, because it does not require the addition of the SOFA windbox. It provides the NO_X -reducing advantages of an OFA system without major pressure part modifications to the boiler.
- Level II includes a SOFA system while maintaining the original arrangement of coal and air nozzles. Thus, it includes SOFA but does not include CCOFA. Like Level I, Level II uses secondary or offset air to provide an oxygen-rich environment near the water wall, which prevents slagging and corrosion. Because of the need for the SOFA windbox, the capital cost for Level II is higher than for Level I. Also, for some furnaces, depending on the furnace size and configuration, it may be difficult to install the SOFA windbox.
- Level Ill is a combination of Level I and Level II in that it uses both CCOFA and SOFA to achieve the greatest degree of NO_X reduction. The capital cost for Level Ill is only slightly higher than for Level II.

An advantage is that boiler operation with these in-furnace technologies does not require intensive retraining of the operating staff.

Public Service Company of Colorado's Arapahoe Station, site of a vertically fired boiler project designed to demonstrate LNB+OFA technology for NO_X reduction.

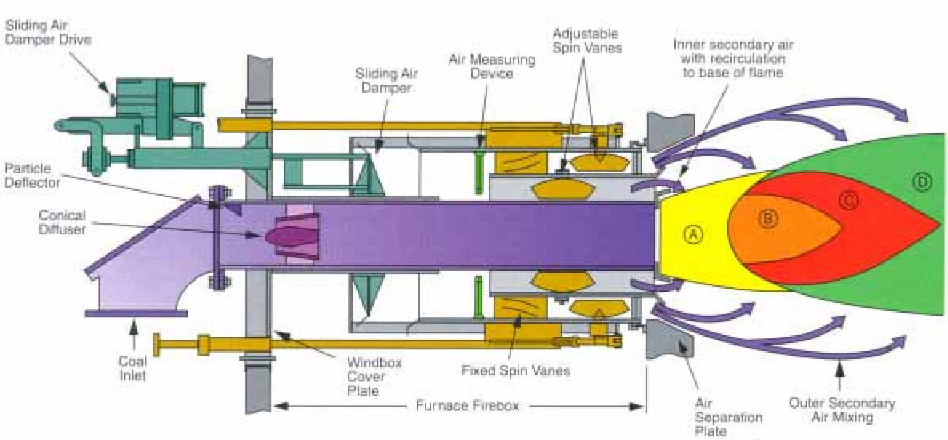


Diagram of B&W DRB-XCL® Low-NO_x Burner showing combustion zones:
Ⓐ high temperature-fuel rich devolatilization zone
Ⓑ production of reducing species zone
Ⓒ NO_x decomposition zone
Ⓓ char oxidizing zone

Source: The Babcock & Wilcox Company

[redacted]

Vertically Fired Boiler Applications

The LNB concept is being evaluated as part of a CCT project entitled Integrated Dry NO_X/SO_2 Emissions Control System, conducted by Public Service Company of Colorado at its Arapahoe Station, Unit No. 4 in Denver. The technologies include: 1) LNB+OFA, 2) in-furnace urea injection for additional NO_X removal, and 3) in-duct injection of dry sorbents for sulfur dioxide removal. For this report, only the LNB+OFA option is discussed.

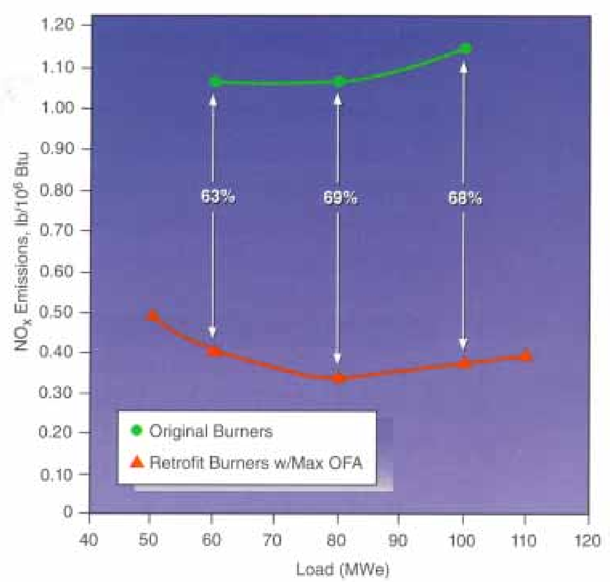
Test Site

Unit 4, the largest of four vertically fired boilers located at the Arapahoe Station, is rated at 100 MWe. The unit was built in the early 1950's and was designed to bum Colorado lignite or natural gas. Currently, the main fuel source for the station is a Colorado low-sulfur bituminous coal having 34% volatile matter, 10% ash, 10% moisture, 0.4% sulfur, and 1.3% nitrogen with a higher heating value of 10,600 Btu/lb on an as-received basis.

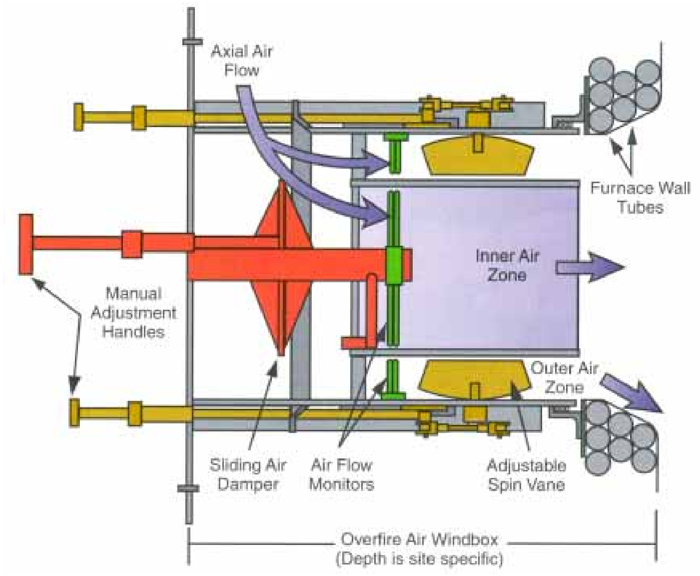
The original furnace configuration was a vertically fired system employing 12 intertube burners located on the roof and arranged in a single row across the width of the furnace. A single division wall separates the furnace into two halves, each with six burners.

This demonstration project uses Babcock & Wilcox (B&W) Dual Register Burner-AXially Controlled Low-NO_X (DRB-XCL®) burners. Most LNBs reduce the formation of NO_X through the use of air staging. The B&W DRB-XCL® burner achieves increased effectiveness by incorporating fuel and air staging.

Combustion air to each burner is measured and regulated to provide balanced fuel /air distribution for optimum NO_X reduction



NO_X emissions results for vertically fired boiler.



B&W Dual Zone NO_X Port.
Source: The Babcock & Wilcox Company

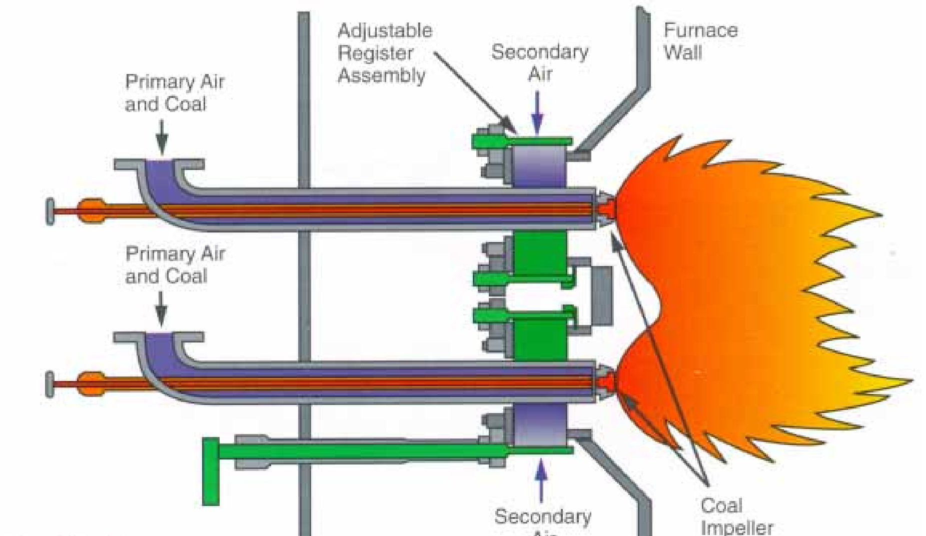
and combustion efficiency. The burner assembly is equipped with two sets of adjustable spin vanes that provide swirl for fuel/air mixing and flame stabilization.

The remaining air for complete combustion is introduced through a set of NO_X ports. Conventional single-jet OFA ports are not capable of providing adequate mixing across the entire furnace. The B&W dual-zone NO_X ports, however, incorporate a central zone that produces an air jet that penetrates across the furnace and a separate outer zone that diverts and disperses the air in the area of the furnace, near the NO_X port. The central zone is provided with a manual air control disk for flow control, and the outer zone incorporates manually adjustable spin vanes for swirl control. Each OFA port contains two separate air flow measurement devices to assist in balancing the two different areas. Because the furnace is a down-flow design, the NO_X ports actually supply underfire air rather than overfire air.

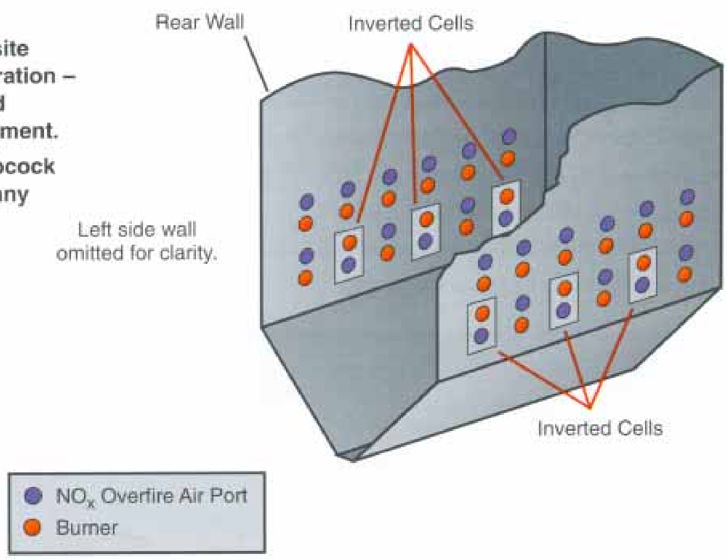
Test Results

NO_X reduction ranged from 63 to 69% over a boiler load range of 60 MWe to 100 MWe. Over the range of OFA flow rates investigated, the majority of the NO_X reduction was obtained with LNBs, with little additional NO_X reduction provided by OFA at equivalent excess air levels.

Dayton Power & Light's J.M. Stuart Station, where B&W conducted a demonstration of Low-NO_X Cell™ Burner (LNCB™) technology.



Two-Nozzle
Standard Cell Burner.



Demonstration site furnace configuration – partially inverted LNCB™ arrangement.
Source: The Babcock & Wilcox Company

However, because port temperature limitations precluded testing at OFA flow rates below 15%, it was not possible to totally separate the effects of LNBs and OFA.

Emissions of carbon monoxide (CO) were not affected by the retrofit, but significant reductions were seen with increasing OFA flow rates. This was contrary to what was expected, and is attributed to increased OFA penetration and mixing at the higher flow rates.

No major operating problems have developed, although the retrofit combustion system has resulted in a decrease in furnace exit gas temperature of approximately 200°F. This has resulted in a small increase in the amount of excess air required to maintain adequate steam temperatures at reduced boiler loads.

Cell Burner Boiler Applications

B&W conducted a demonstration of Low-NO_X Cell™ Burner (LNCB™) technology, with Dayton Power & Light (DP&L) as the host and cosponsor. There are 38 cell burner boilers in the U.S., having a total capacity of about 26,700 MWe. This comprises about 13% of pre-NSPS U.S. coal fired generating capacity.

Test Site

The host site was DP&L's J.M. Stuart Station, Unit 4, located in Aberdeen, Ohio, rated at 605 MWe. The unit is a once-through, positive-pressure cell burner boiler, with two rows of six two-nozzle cell burners in both its front and rear walls, for a total of 48 coal-fired burners in 24 cells.

Fuel for the test program was a midwestern bituminous coal with about 33% volatile matter, 14% ash, 5% moisture, 1.1% sulfur, and 1.3 % nitrogen with a higher heating value of 11,900 Btu/lb on an as-received basis.

Cell Burner Boilers

Most cell burner boilers use two-nozzle cell burners (a few use three-nozzle cell burners), which fire pulverized coal under high-intensity combustion conditions. The resulting high temperatures lead to formation of significant amounts of NO_X.

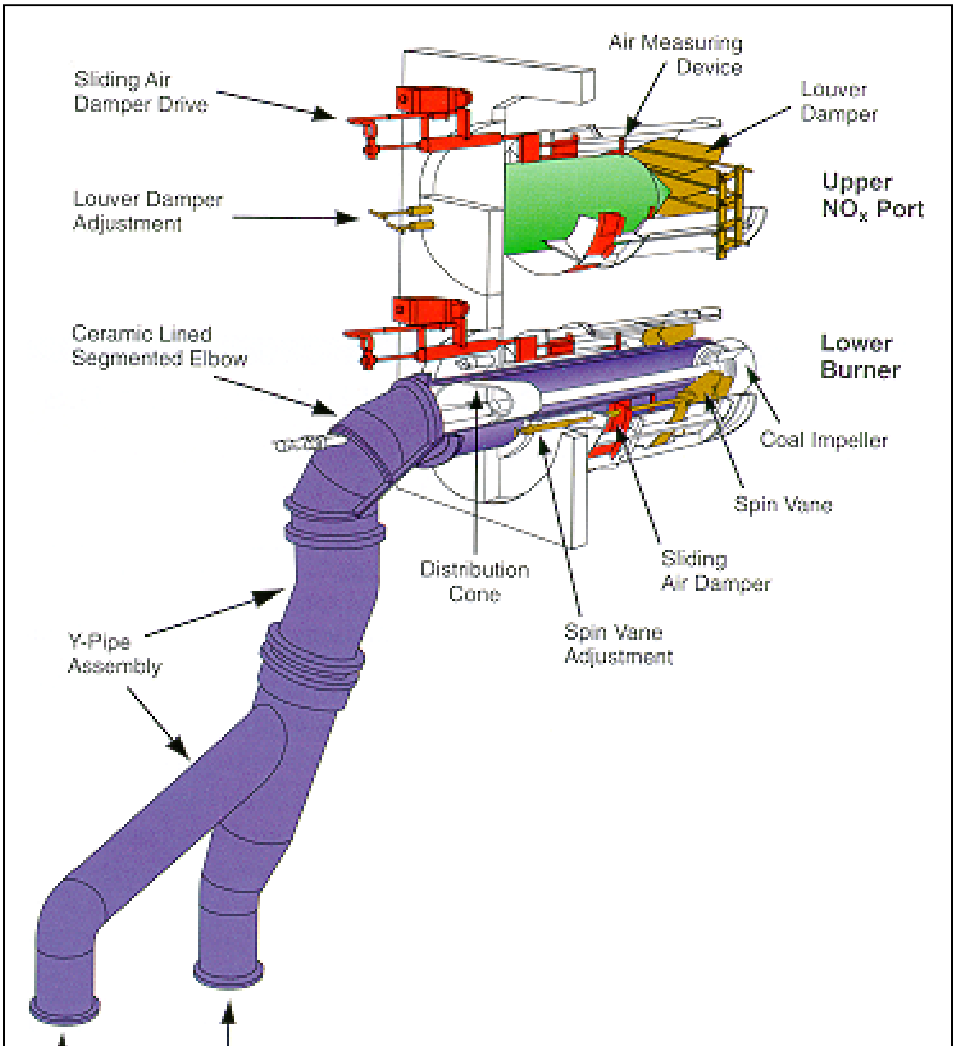
Economic considerations, which dominated boiler design during the 1960's, led to the development of cell burners for achieving high system efficiency in compactly designed utility boilers. Cell burners are designed for rapid mixing of fuel and air to achieve high rates of combustion. The tight burner spacing and rapid fuel/air mixing minimize flame size while maximizing heat release rates and overall unit efficiency.

In a standard two-nozzle cell burner, each cell consists of two circular register burners mounted in close proximity to each other within one vertical assembly. These assemblies are located on opposite walls of the lower furnace. A mixture of coal and primary air enters each burner and is dispersed radially outward into the secondary air stream by means of an impeller located at the furnace end of the nozzle. Secondary air from the windbox passes through an adjustable register into an annular passage around the coal nozzle. The register acts as both a flow control device and a swirl generator.

Retrofitting conventional low-NO_X burners in cell burner boilers requires major boiler pressure part modifications. This is because the cell burner throat openings are too small to permit the low burner air velocities required for delayed combustion. Further, optimum NO_X reduction is achieved by conventional low-NO_X burners when the heat release rate per unit furnace volume is low. This is not readily achievable in a typical cell burner configuration where the burners are closely spaced.

Low-NO_X Cell™ Burner Technology

B&W developed the LNCB™ technology as an alternative approach to conventional LNBs. In this system, a standard two-nozzle cell burner is replaced with an LNCB™, which consists of a single lower coal nozzle and an upper secondary air port. The secondary air port, used for OFA, is designated by B&W as the NO_X port. Approximately 60-70% of the air theoretically required for complete combustion is provided to the lower nozzle, along with the coal. The remainder of the air is introduced through the NO_X port.



Low-NO_x Cell™ Burner (LNCB™). Source: The Babcock & Wilcox Company

In the LNCB™, the lower coal nozzle is a B&W S-type low-NO_X burner, with its burner throat enlarged so that it has the same fuel input capacity as the two burner nozzles it replaces. An impeller mounted at the exit of the lower burner radially disperses the fuel rich coal/air mixture. The impeller angle controls the flame shape and length.

The NOx port is equipped with a sliding disk to regulate air flow and louvers at the outlet to control mixing of the air with the fuel-rich flame. Adjustable spin vanes in the lower burner barrel control the swirl of the secondary air to aid in shaping the flame.

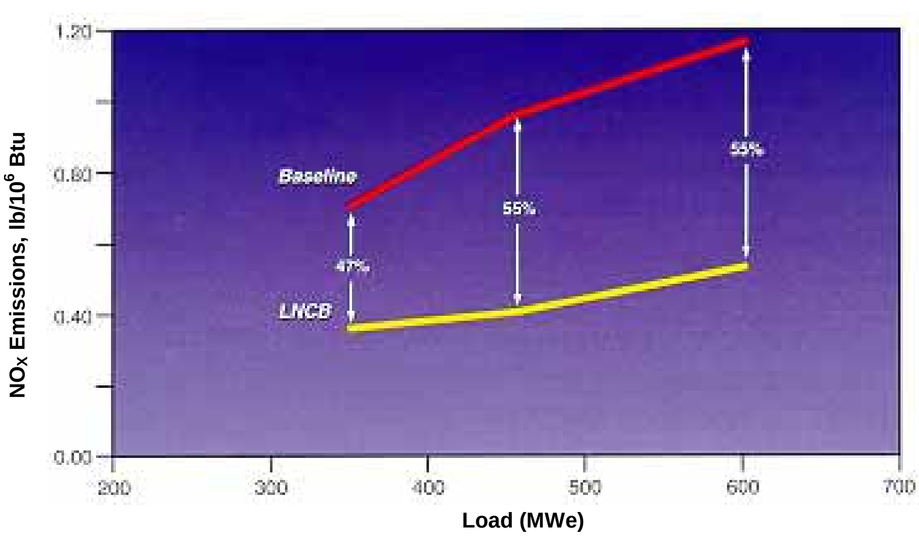
Because the LNCB™ concept was designed specifically to fit standard two-nozzle cell burner openings and spacings, no major modifications to boiler pressure parts are required. These two factors constitute the key attraction of the technology. A laboratory test program conducted by B&W in the early 1980's showed that LNCB™ burners maintain a stable flame throughout the operating range and that the expected reduction in NO_X emissions is about 50%. B&W concluded that LNCB™ retrofit technology could be applied to all of the two-nozzle cell burner boilers in the United States. However, the LNCB™ retrofit technology is not applicable to three-nozzle cell burner boilers. The purpose of the CCT project was to demonstrate LNCB™ technology on a commercial scale.

In initial operation of the full-scale retrofit, excessive concentrations of carbon monoxide and hydrogen sulfide were found in the boiler hopper. Application of B&W's mathematical combustion models led to design of a modified firing configuration that mitigated this problem. The revised configuration involves inverting alternating LNCBs™ in the bottom burner rows on both faces of the furnace. DP&L has accepted the technology and continues to run it on a routine basis.

NO_X Emissions from Coal-Fired Boilers in the U.S.

The following table summarizes NO_X emissions from coal-fired utility plants in the U.S. prior to enactment of the Clean Air Act Amendments of 1990, categorized by boiler type.

Boiler Type	No. of Boilers	Capacity, GWe	% of Total Capacity	NO_X Emissions 1000 Tons/ Year	NO_X Emissions % of Total
Dry Bottom Wall-Fired	411	120.7	36.9	2,147	35.8
Wet Bottom Wall-Fired	39	8.6	2.6	277	4.6
Tangentially Fired	423	138.3	42.3	2,053	34.2
Cyclone Fired	89	27.6	8.5	732	12.2
Vertically Fired	33	4.8	1.5	100	1.7
Cell Burner	36	24.1	7.4	679	11.3
Fluidized Bed	5	0.7	0.2	2	0.1
Other	27	1.9	0.6	6	0.1
Total	**1063**	**326.7**	**100.0**	**5,996**	**100.0**



NO_X emissions results for cell burner boiler.

Test Results

Reaching the emissions target for the test program initially required replacing the 24 burner impellers with impellers having a more shallow angle than used originally. At full load of 605 Mwe, uncontrolled NO_X emissions averaged 1.18 lb/10^6 Btu. With LNCB™ , NO_X emissions decreased to 0.53 lb/106 Btu, representing a reduction of 55%.

At intermediate load (460 MWe) the NO_X reduction averaged 55%, while at low load (350 MWe) it was 47%. This represents an acceptable turndown ratio for boiler operation.

Maximum unit load was not affected, and the impact on furnace exit gas temperature was negligible. In general, boiler efficiency when operating with the LNCB™

retrofit showed very little change from that at baseline conditions. Only minor changes were found in the cleanliness of convective pass heat transfer surfaces. An area of high corrosion was found during the test program, but corrosion rates were not significantly higher than those measured under baseline cell burner operating conditions. Coated tube materials tested in the boiler exhibited excellent corrosion resistance.

A beneficial result of the LNCB™ retrofit was a significant reduction in the buildup of agglomerated "popcorn" ash and associated erosion on horizontal convective pass tubes experienced with the original cell burner firing configuration. Required maintenance for the air heaters, fly ash handling equipment, and bottom ash handling equipment has been reduced as a result of the improved properties of the ash.

Artificial Intelligence for NO_X Control

Experience with several CCT projects involving combustion modification has shown a tendency toward increased UBC values in the fly ash. [This is often expressed in terms of loss-on-ignition (LOI). Because the analytical procedures for determining LOI and UBC are not the same, the terms are not strictly synonymous. However, they are often used interchangeably.]

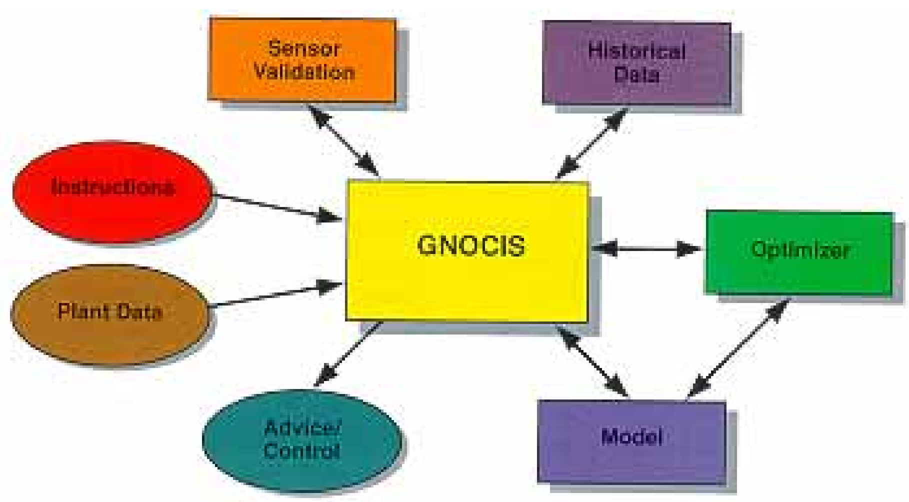
As mentioned previously, increased carbon content of the fly ash adversely affects ESP performance as well as fly ash marketability. Fly ash can be sold for use in cement manufacture and as road construction material, among other things, provided that the UBC content meets specifications. Although UBC can be reduced by operating changes such as increasing coal fineness, a significant UBC problem exists and is receiving considerable attention.

Experience has also indicated that combustion modification leads to difficulties in boiler optimization. This is a result of several factors, including: (1) increased complexity of the combustion system, and (2) increased sensitivity of combustion conditions to process adjustments.

The adverse impacts of applying LNB technology can sometimes be mitigated by burner optimization; however, these measures are typically performed at a few operating conditions and cannot fully account for changes in plant operating conditions and coal characteristics over extended periods. Further, experience has shown that NO_X emissions vary with time by as much as ±20% around the long-term average. A system that reduces the magnitude of these variations and drives NO_X emissions down towards the lower end of this range could help achieve continuous compliance without additional controls. Such an approach could also provide NO_X credits for averaging or trading programs.

GNOCIS

Artificial intelligence has the potential to aid in optimizing boilers with a view to minimizing UBC and maximizing overall efficiency. To demonstrate this concept, the



Major elements of Generic NO_X Control Intelligent System (GNOCIS)

scope of the LNB project being conducted by SCS at Plant Hammond Unit 4 has been expanded to include demonstration of an on-line enhancement tool for the power plant's distributed control system (DCS). This tool, which has been termed Generic NO_X Control Intelligent System (GNOCIS), is designed to provide recommendations that achieve NO_X reduction consistent with economic and operational constraints.

While it is being developed and demonstrated on coal-fired boilers, GNOCIS can operate on units burning gas, oil, or coal and, at least conceptually, is applicable for all combustion firing geometries. GNOCIS is projected to reduce NO_X emissions by 10-35% from the baseline emission level while meeting other site-specific operational constraints, such as UBC and furnace exit gas temperature.

The Evolving World of Artificial Intelligence

Of the three areas that comprise artificial intelligence (neural networks, expert systems, and fuzzy logic), neural networks are considered by many to be best suited as advisors—advanced systems that make recommendations based on various types of data. These recommendations, which change whenever a power plant's operations change, suggest how auxiliary plant equipment or technologies can be optimized.

In the evolution of artificial intelligence systems, neural networks surpass their older cousins, expert systems and fuzzy logic. The least specific type of artificial intelligence software, fuzzy logic is a type of expert system equipped with a set of approximate rules used whenever "close enough is good enough." Elevators and camera autofocusing systems are primary users of fuzzy logic systems. Fuzzy logic stops an elevator at a floor when it is within a certain range, not at a specific, definite point. Expert systems, on the other hand, "learn" by following a set of pre-established rules written in codes or computer language. Expert systems are assumed to understand the relationship between input and output information based on detailed knowledge of a specific process.

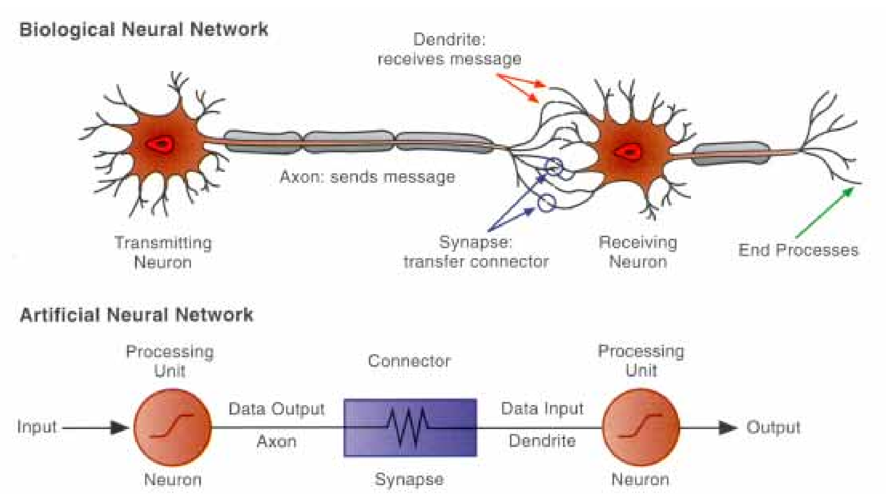


Diagram of the structural relationship shared by biological and artificial neural networks.

Neural networks are the latest type of artificial intelligence to enter the power plant industry. Computational devices that use organized principles of biological nervous systems, neural net-works do not assume relationships. Instead, they determine relationships by analyzing data, learning much the way humans do, by example and repetition. When it assigns an incorrect output with a given input, the network corrects itself by changing the weight matrices. While it can take considerable time to complete this learning curve—depend-ing on the complexity of the problem—neural networks outperform any other current approach to recognizing patterns. Modeled after the human brain, made up of interconnected neurons that contain a limited amount of information, neural networks are constructed of simple data-processing units with limited capabilities. When connected together, they form the highest artificial intelligence system known, capable of estimating the lifespan of mechanical parts, diagnosing malfunctions in automobiles, and recognizing human speech. Most importantly, they provide valuable information that cannot be obtained any other way.

This scope addition complements additional DOE Fossil Energy funding, through the Flue Gas Cleanup Program managed by DOE, and funding provided by a consortium of key industrial players in the United States and the United Kingdom. Under this project, GNOCIS was developed and first demonstrated at a wall-fired site in Alabama and a T-fired site in England. The main GNOCIS contractors are SCS in the United States and PowerGen in the United Kingdom. The work in the United Kingdom is funded by the Department of Trade and Industry, PowerGen, and EPRI. The work in the United States is funded by DOE, Southern Company, and EPRI.

Implementation

GNOCIS utilizes a neural-network model of the combustion characteristics of the boiler that reflects both short-term and longer-term trends.

An optimizing procedure is applied to identify the best set points for the plant. The recommended set points are conveyed to the plant operators via the DCS, i.e., in an advisory or open-loop configuration or, at the plant's discretion, the set points can be implemented automatically without operator intervention, i.e., closed-loop. The package is designed for full-time use.

Prior to demonstrating GNOCIS in the CCT project at Hammond, developmental programs were conducted at PowerGen's 500-MWe tangentially fired Kingsnorth Unit I in the United Kingdom and Alabama Power Company's 250-MWe wall-fired Gaston Unit 4. Hammond is the first full commercial demonstration of the technology.

The Hammond Trial

The objective at Plant Hammond is to evaluate and demonstrate the effectiveness of advanced digital control/optimization methodologies as applied to the NO_X abatement technologies installed during the CCT project (LNB + AOFA). The major tasks for the Hammond project include: (1) design and installation of the DCS, (2) instrumentation upgrades, (3) advanced controls/optimization design and implementation, and (4) characterization of the unit both before and after activation of the advanced strategies.

GNOCIS testing at Hammond Unit 4 commenced during the first quarter of 1996 in both open-loop-advisory and closed-loop-supervisory modes, representing one of the first applications anywhere of artificial intelligence for wide-scale power plant control.

Preliminary results at full load show 0.5% efficiency improvement, with a 1–3% reduction in UBC and a 10–15% reduction in NO_X emissions. This efficiency improvement results in a decrease in CO_2 emissions of about 1.5%.

GNOCIS Commercialization

After proving GNOCIS at Plant Hammond and at other sites, SCS and Radian International intend to commercialize the software in the United States. In its role as commercializer, Radian has been deeply involved in the U.S. demonstrations of GNOCIS. PowerGen and one other as yet unnamed organization will commercialize GNOCIS in Europe. Several U.S. utilities have already committed to follow-on demonstration projects and commercial installations.

Low-NO_X Burner Retrofit Performance and Costs

Boiler Type	Wall-Fired	T-Fired	Cell Burner
Technology	LNB	LNCFS I	LNCB
Size, MWe	500	200	600
NO_X Reduction, %	48	37	55
Capital Cost, $/kW	6	7	9

Performance and Economic Comparison

The several types of LNBs tested in these demonstration projects are being used successfully in commercial retrofits for NO_X reduction.

Based on the results of the demonstration projects, economics have been estimated for full-scale commercial operation. These economics, developed by the project participants, assume a baseloaded power plant with a 65% capacity factor and a 15-year project life. For a wall-fired unit having a capacity of 500 MWe, the capital cost of a typical LNB retrofit is projected to be $3.0 million (1996 U.S. dollars), which is equivalent to about $6/kW. The levelized cost on a current dollar basis is about $100/ton of NO_X removed. Addition of OFA increases the capital by $7/kW, bringing the total to $13/kW.

For a T-fired boiler having a capacity of 200 MWe, retrofitting LNCFS™ Level I requires a capital expenditure of $1.4 million, or about $7/kW, and the levelized cost is $103/ton.

For a 600-MWe cell burner boiler, the capital required for retrofitting LNCB™ technology is $5.4 million, or $9/kW. The levelized cost is $125/ton.

The capital cost of retrofitting a 300 MWe vertically fired boiler with LNB+OFA is $11.7 million, or $39/kW, and the levelized cost is $350/ton. These costs are significantly higher than for other types of boilers discussed in this report owing to the fact that major boiler modifications are required.

In summary, for wall-fired, T-fired, and cell burner boilers, retrofit LNB can be installed at a capital cost of less than $10/kW and a levelized cost of about $100-$125/ton. While these costs are based on the results of the CCT projects, they are consistent with information obtained independently from several commercial installations of LNB, thereby lending credence to the figures.

Bibliography

Federal Register, Vol. 61, No. 13, January 19, 1996, pp. 1442-1480.

J.N. Sorge and S.M. Wilson, "500 MW Demonstration of Advanced Wall-Fired Combustion Techniques for the Reduction of Nitrogen Oxide Emissions from Coal-Fired Boilers," Third Annual Clean Coal Technology Conference. Chicago, Illinois, September 1994.

J.N. Sorge, W. Menzies, S.M. Smouse, and JW. Stallings, "500 MW Demonstration of Advanced Wall-Fired Combustion Techniques for the Reduction of Nitrogen Oxide Emissions from Coal-Fired Boilers," Fourth Annual Clean Coal Technology Conference, Denver, Colorado, September 1995.

R.R. Hardman, L.L. Smith, and S. Tavoulareas, "Results from the ICCT T-Fired Demonstration Project including the Effects of Coal Fineness on NO_X Emissions and Unburned Carbon Levels," EPRI/EPA Joint Symposium on Stationary Combustion NO_X Controls, May 1993.

R.R. Hardman and G.G. Elia, "180 MW Tangentially Fired Low NO_X Demonstration," First Annual Clean Coal Technology Conference, Cleveland, Ohio, November 1992.

R.A. Smith, L.J. Muzio, and T. Hunt, "Integrated Dry NO_X/SO_2 Emissions Control System: Low-NO_X Combustion System Retrofit Test Report," April 1994.

T. Hunt et al., "Current Progress with the Integrated Dry NO_X/SO_2 Emissions Control System," Third Annual Clean Coal Technology Conference, Chicago, Illinois, September 1994.

A.S. Yagiela et al., "Results of Babcock & Wilcox's Clean Coal Technology Combustion Modification Projects: Coal Reburning for Cyclone Boiler NO_X Control and Low NO_X Cell™ Burner Demonstrations," Second Annual Clean Coal Technology Conference, Atlanta, Georgia, September 1993.

A.S. Yagiela et al., "Status of Babcock & Wilcox's Clean Coal Technology Combustion Modification Projects: Coal Reburning for Cyclone Boiler NO_X Control and Low NO_X Cell™ Burner Demonstrations," Third Annual Clean Coal Technology Conference, Chicago, Illinois, September 1994.

A.L. Baldwin, D.N. Smith, A.N. Mann, H.G. McIlvried, and S.N. Rao, "Is Selective Catalytic Reduction (SCR) an Attractive Option for NO_X Control in Coal-Fired Power Plants?," Air & Waste Management Association's Conference on Acid Rain & Electric Utilities, Tempe, Arizona, January 1995.

A-K. Hjalmarsson, "NO_X Control Technologies for Coal Combustion," IEA Coal Research, IEACR/24, June 1990.

To Receive Additional Information

To be placed on the Department of Energy's distribution list for future information on the Clean Coal Technology Program, the demonstration projects it is financing, or other Fossil Energy Programs, please contact:

C. Lowell Miller
Associate Deputy
Assistant Secretary
U.S. Department of Energy
FE-22/27OCC
Germantown, MD 20874-1290

(301) 903-9451
(301) 903-2238 fax

Patrice A. Leister
U.S. Department of Energy
Pittsburgh Energy
Technology Center
P.O. Box 10940-0940
Pittsburgh, PA 15236

(412) 892-6126
(412) 892-6127 fax

List of Acronyms and Abbreviations

ABB/CE .... Asea Brown Boveri/Combustion Engineering Services, Inc.
AOFA .... Advanced overfire air
B&W .... Babcock & Wilcox
Btu .... British thermal unit
CAAA .... Clean Air Act Amendments of 1990
CCOFA .... Close coupled overfire air
CCT .... Clean Coal Technology
DCS .... Distributed control system
DOE .... U.S. Department of Energy
DP&L .... Dayton Power & Light Company
DRB-XCL® .... Dual Register Burner-AXially Controlled Low NO_X burners
EPA .... U.S. Environmental Protection Agency
EPRI .... Electric Power Research Institute
ESP .... Electrostatic precipitator
FWEC .... Foster Wheeler Energy Corporation
GNOCIS .... Generic NO_X Control Intelligent System
kW .... kilowatt
LNB .... Low NO_X burners
LNCB™ .... Low-NO_X Cell Burner
LNCFS™ .... Low-NO_X Concentric Firing System
LOI .... Loss-on-ignition
MWe .... Megawatts of electric power
NO_X .... Nitrogen oxides
NSPS .... New Source Performance Standards
OFA .... Overfire air
PETC .... Pittsburgh Energy Technology Center
psig .... Pounds per square inch gauge
PSCO .... Public Service of Colorado
RACT .... Reasonably Available Control Technology
SCR .... Selective catalytic reduction
SCS .... Southern Company Services
NCR .... Selective noncatalytic reduction
SOFA .... Separated overfire air
T-fired .... Tangentially fired boiler
UBC .... Unburned carbon

Contacts for CCT Projects and U.S. DOE CCT Program

Team Members

Wall-Fired Boiler Project at Plant Hammond

Participant
Southern Company Services, Inc.

Contact
John N. Sorge
Project Manager
14N-8195
P.O. Box 2625
Birmingham AL 35202-2625
205-257-7426
205-257-5367 fax
john.sorge@scsnet.com

Additional Team Members
Georgia Power Company
Electric Power Research Institute
Foster Wheeler Energy Corporation

Tangentially Fired Boiler Project at Plant Smith

Participant
Southern Company Services, Inc.

Contact
Robert R. Hardman
Project Manager
14N-8195
P.O. Box 2625
Birmingham AL 35202-2625
205-257-7772
205-257-5367 fax
robert.r.hardman@scsnet.com

Additional Team Members
Gulf Power Company
Electric Power Research Institute
ABB/C-E Services, Inc

Vertically Fired Boiler Project at Arapahoe Station

Participant
Public Service Company of Colorado

Contact
Terry Hunt
Project Manager
5900 East 39th Avenue
Denver CO 80207-1294
303-571-7113
303-571-7868 fax
thunt@msp.psco.com

Additional Team Members
Electric Power Research Institute
Stone and Webster Engineering Corp.
The Babcock & Wilcox Company
Fossil Energy Research Corporation
Western Research Institute
Colorado School of Mines
Noell, Inc.

Cell Burner Boiler Project at J.M. Stuart Station

Participant
The Babcock & Wilcox Company

Contact
Tony Yagiela
Senior Marketing Specialist
1562 Beeson Street
Alliance OH 44601-2196
330-829-7403
330-829-7801 fax
anthony.s.yagiela@rdd.mcdermoff.com

Additional Team Members
The Dayton Power and Light Company
Electric Power Research Institute
Ohio Coal Development Office
Tennessee Valley Authority
New England Power Company
Duke Power Company
Allegheny Power System
Centerior Energy Corporation

U.S. Department of Energy

Contacts
C. Lowell Miller
Associate Deputy Assistant Secretary
Office of Clean Coal Technology
FE-22/27OCC
Germantown MD 20874-1290
301-903-9451
301-903-2238 fax
lowell.miller@hq.doe.gov

Joseph P. Strakey
Associate Director
Office of Clean Coal Technology
Pittsburgh Energy Technology Center
P.O. Box 10940
Pittsburgh PA 15236-0940
412-892-6124
412-892-4775 fax
strakey@petc.doe.gov

Thomas A. Sarkus
Director, Project Implementation Division
Office of Clean Coal Technology
Pittsburgh Energy Technology Center
P.O. Box 10940
Pittsburgh PA 15236-0940
412-892-5981
412-892-4775 fax
sarkus@petc.doe.gov

This report is available on the Internet at
www.lanl.gov/projects/cctc