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ABSTRACT

The feasibility of retrofitting low-NO_X combustion controls on four different utility wall-fired boiler designs has been evaluated. This evaluation included an engineering analysis of all equipment modifications, and a cost estimate for each retrofit option. Consideration was given to boiler physical limitations and operating constraints, as well as achieving NO_X reduction. NO_X emission predictions were based on correlations developed from both field installations and large pilot-scale combustion tests. The following low-NO_X combustion processes were evaluated:

- Low-NO_X burners
- Conventional air staging (Overfire air)
- Advanced air staging (Overfire air)
- Reburning

Costs are presented in terms of \$/kW, mills/kWh, and \$/ton of NO_X removed. The cost of retrofit NO_X controls were found to vary with unit size and retrofit complexity. Depending on the level of boiler modifications required, the capital cost of retrofit combustion controls can vary from less than \$3/kW to more than \$20/kW.

INTRODUCTION

Retrofit combustion controls have become especially important with the increasing implementation of advanced NO_X control techniques in both Japan and West Germany. Because of the limited retrofit NO_X control experience within the United States, little is known about the cost of such controls for all but a few boiler configurations. Consequently, the Electric Power Research Institute has sponsored a number of programs to develop NO_X control options tailored to individual boiler designs. This paper summarizes the results of one such program to evaluate the performance and cost of low-NO_X retrofit combustion controls for wall-fired utility boilers.

Post combustion flue gas treatment processes, such as selective catalytic reduction (SCR), have been installed on over 30 oil and coal-fired Japanese utility boilers. Up to 80% NO_X reduction has been demonstrated on low-sulfur coal using SCR. The capital cost of SCR for new coal-fired boilers has been estimated at \$50-\$100/kW[1]. Operating costs, which are highly dependent on catalyst life, can range from 8-14 mills/kWh. One of the basic premises of this evaluation was that combustion controls, which can achieve a substantial degree of NO_X control, are more cost effective than post combustion controls.

Combustion NO_X controls have, with a few exceptions, been applied only to new utility boilers. In order to obtain performance and operating criteria on various control techniques, pilot scale combustion tests were performed on several advanced combustion systems in a 100×10^6 Btu/hr test furnace. Tests were conducted on a single Riley Controlled Combustion Venturi (1) (CCV) low NO_X burner in combination with other combustion modification approaches such as overfire air and reburning[2]. The integration of low NO_X burners with advanced techniques was considered for those situations where low NO_X burners alone do not provide the desired level of control. A summary of pilot test results comparing the performance of various combustion controls on four coals is shown in Figure 1. Average pilot scale test results correlated well with limited full-scale burner data[3]. The tests confirmed that up to 50% NO_X reduction can be achieved with single stage low NO_X burners. Up to 75% NO_X reductions were achieved when a low NO_X burner was used in combination with overfire air or reburning.

Combustion modifications by their nature, must be carefully integrated with the design and operation of the boiler. This paper focuses on the feasibility of retrofitting these combustion control techniques to full-scale utility wall-fired boilers.

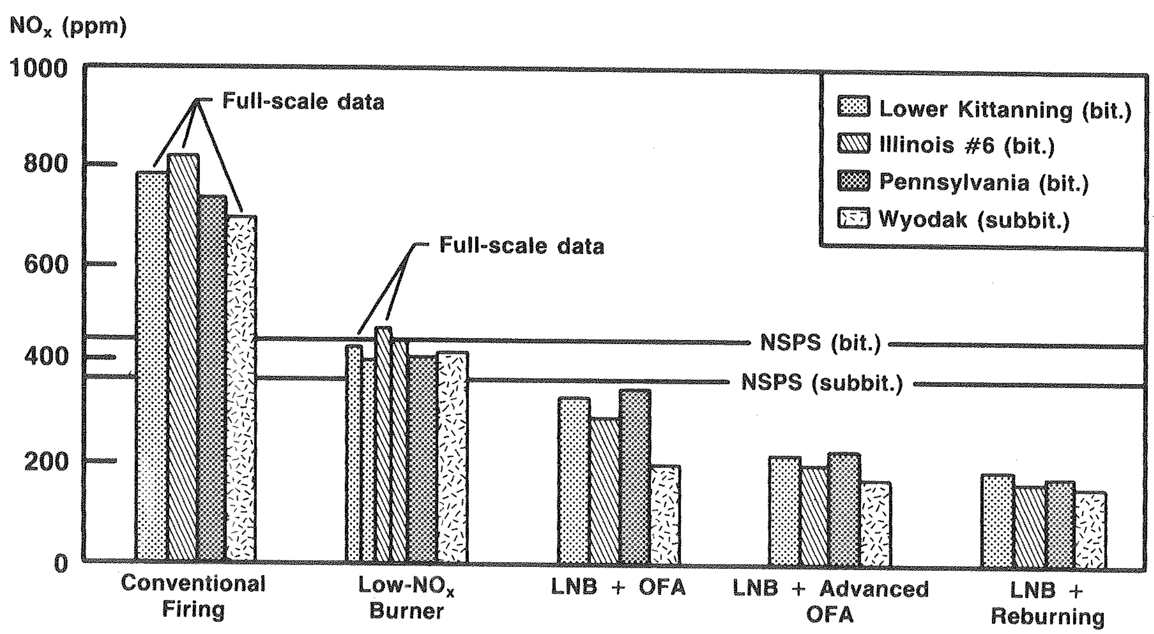


Figure 1 Summary of Pilot Tests Comparing NO_X Reductions of Various Combustion Modifications

(1) Protected by U.S. Patent No. 4,479,442

APPROACH

The overall objective of the feasibility study was to identify and quantify technical and economic issues associated with retrofit NO_X combustion controls. It involved estimating the relative cost of each retrofit option, and determining the effect of boiler size and configuration on both performance and cost. The impact of combustion modifications on boiler operation requires careful consideration of a number of technical issues including: NO_X emission scale-up, design of OFA and reburn fuel injection equipment, combustion efficiency, flame stability/scannability, combustion and steam-side control, fireside corrosion, fouling and slagging, and safety code compliance. Because of their complexity, not all of these issues could be fully resolved in the pilot scale tests.

Control options, which provide different levels of NO_X reduction and require different amounts of boiler modifications, were selected for evaluation. These options included low-NO_X burners; and low-NO_X burners combined with other control methods such as conventional overfire air, advanced overfire air, and reburning. Low-NO_X burners are based on the controlled mixing of fuel and air to influence the fate of fuel-bound nitrogen released from coal during the early stages of combustion. The CCV burner accomplishes this through a patented venturi coal nozzle/spreader design. Low-NO_X burners combined with overfire air provides the next level of control. Overfire air (OFA) is one method of achieving two staged combustion. Conventional overfire air, or air staging involves the diversion of up to 30 percent of the boiler's total air requirement to injection ports located above the top row of burners. Advanced OFA is applied in a manner similar to conventional OFA but with up to 50% of the total combustion air directed to the upper furnace. Reburning involves the injection of both fuel and air to the upper furnace creating a secondary combustion zone. The reducing environment formed by the secondary fuel rich combustion zone serves to destroy NO_X formed in the lower furnace. Reburning was the most complex retrofit option considered. It has the advantage of being able to operate with a fuel lean primary combustion zone thus minimizing the potential for slagging and fireside corrosion in the lower furnace.

Engineering and economic analyses were performed for each of these control options on selected pulverized coal wall-fired boiler retrofit case studies. Design factors such as steam capacity, age of the unit, firing system (front versus opposed), burner location, furnace geometry and distance from the top burner row to the furnace exit were considered. Based on these criteria four wall-fired boiler cases were selected for analysis:

Case A—140 MW, front-fired, four burner rows, no OFA ports
Case B—400 MW, front-fired, four burner rows, no OFA ports
Case C—360 MW, opposed-fired, two burner rows, no OFA ports
Case D—360 MW, opposed-fired, three burner rows, with existing OFA ports

Each of these cases offers a different level of retrofit adaptability. Simplified drawings of each of boiler design case are shown in Figures 2 and 3. For purpose of analysis each of these boilers was assumed to be equipped with pre-NSPS Riley Flare burners firing a high volatile bituminous coal.

ENGINEERING FEASIBILITY

For each case study an engineering analysis was performed on the entire boiler system. Fuel supply and combustion systems, as well as emission characteristics were reviewed to determine the applicability of each retrofit option. The impact on furnace design, convection surface, auxiliaries, and boiler performance were also evaluated. The general arrangement of the boiler was reviewed for clearances and structural supports. In addition, general guidelines and equipment requirements were developed for each retrofit option. These requirements are summarized in Figure 4. It was not the purpose of this study to fully evaluate all of the consequences of combustion retrofit controls on boiler operation. However, based on the pilot scale tests and limited field experience, concerns such as flame stability, corrosion, fouling and slagging, and steam temperature control appear to be manageable.

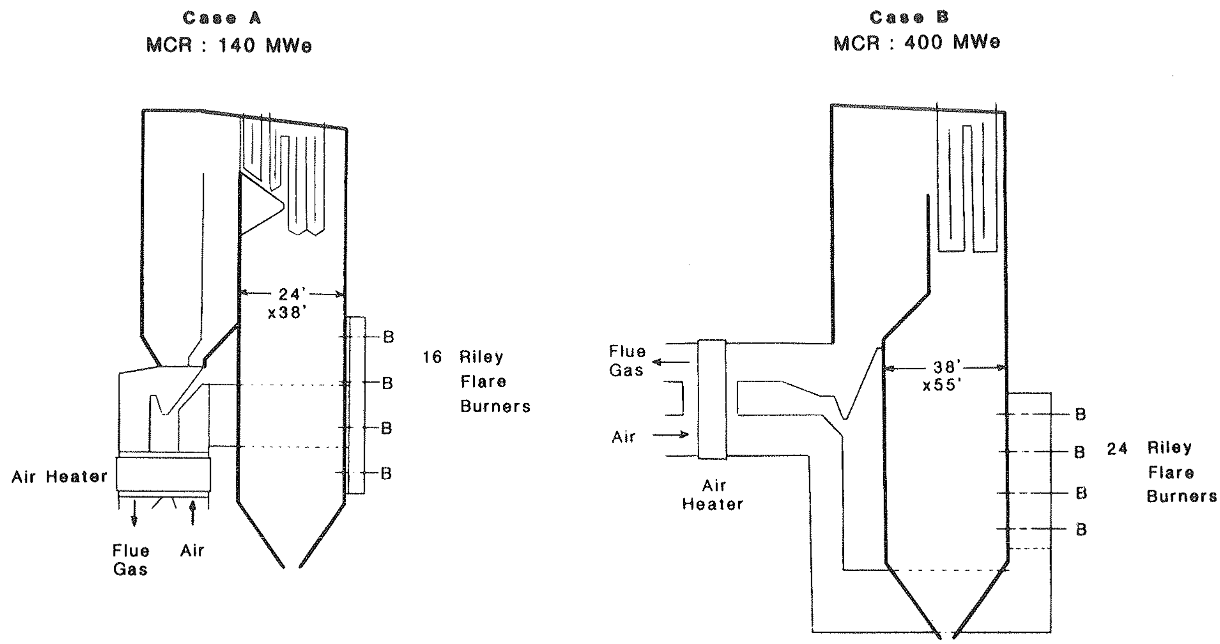


Figure 2 Front Wall-Fired Case Study Units

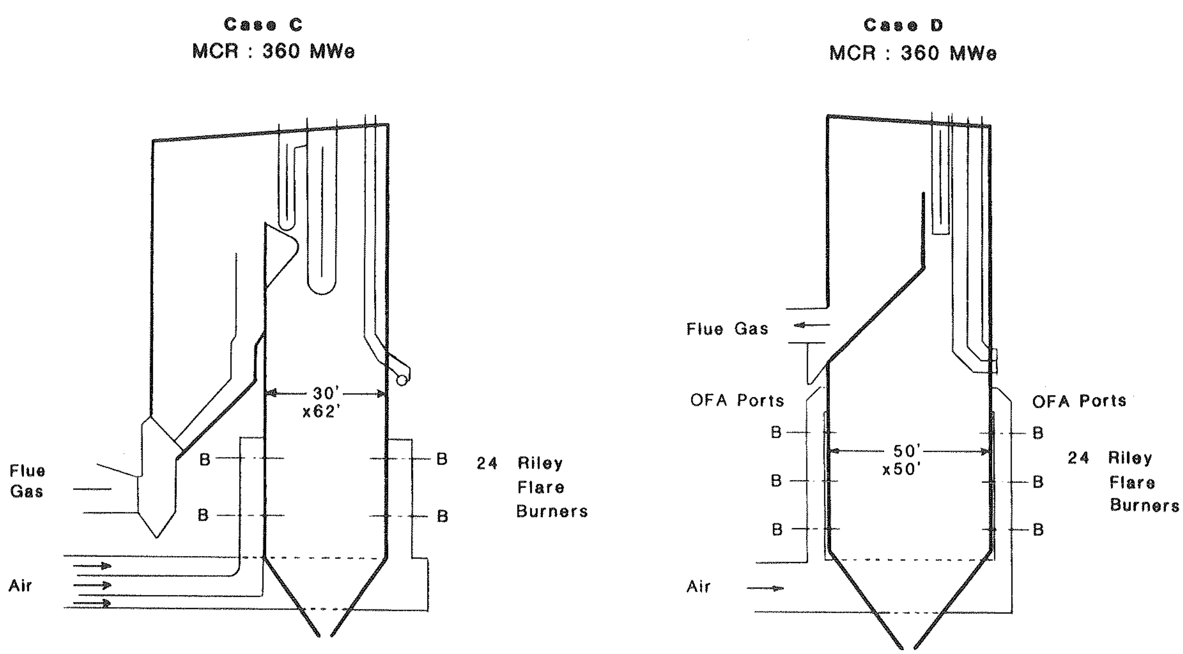
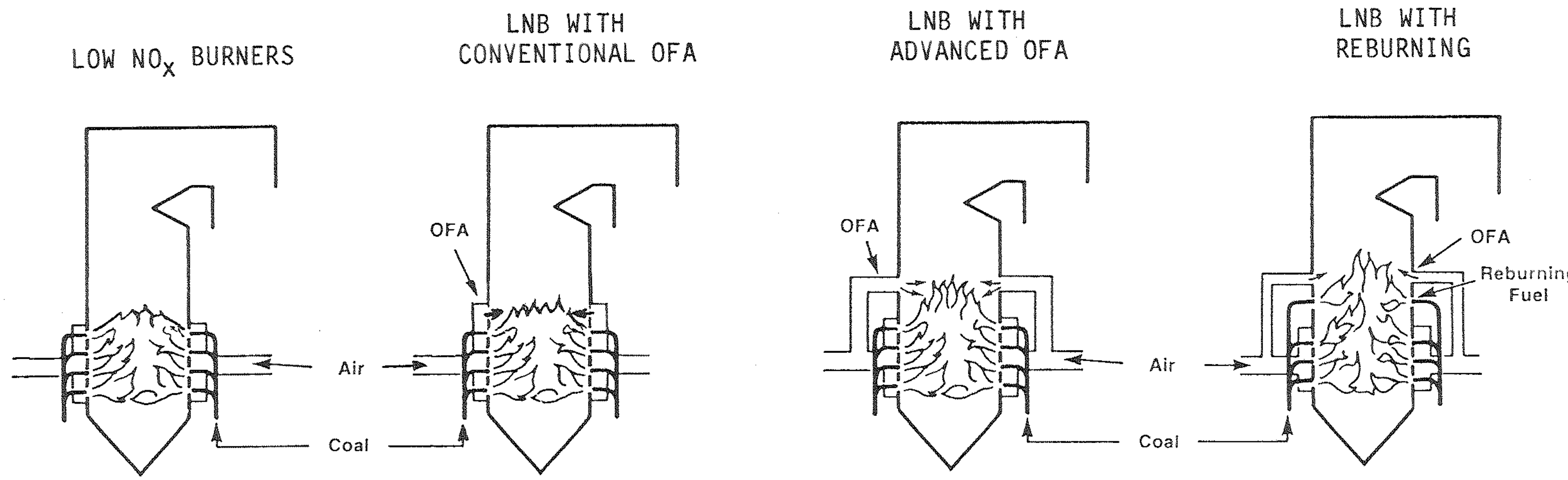


Figure 3 Opposed Wall-Fired Case Study Units



LOW NO_x BURNERS

- Fuel Nozzle
- Coal Spreaders
- Modify Burner Throats (if Necessary)
- Register Replacement (Optional)
- Underfire Air Ports
- Tertiary Air Ports (multistaged burner)

LNB WITH CONVENTIONAL OFA

- Low NO_x Burners
- OFA Ports
- OFA Dampers
- Windbox Extension

LNB WITH ADVANCED OFA

- Low NO_x Burners
- OFA Ports
- OFA Dampers
- OFA Ductwork
- OFA Windbox
- Flow Measurement
- Control Dampers
- Burner Management

LNB WITH REBURNING

- Low NO_x Burners
- OFA Ports
- OFA Dampers
- OFA Ductwork
- OFA Windbox
- Flow Measurement
- Control Dampers
- Fuel Ports
- Rework Coal Piping
- Burner Management
- Additional Coal Handling Equipment (if necessary)

Figure 4 Low NO_x Combustion Techniques Which Were Evaluated for Technical and Economic Feasibility

Low-NO_X burners were the central element in all combustion control options considered. In general, low-NO_X burners require only a minimum amount of boiler modifications. Such burners can be designed to fit within existing burner openings and windboxes. The relative ease of retrofitting more advanced control options, however, is strongly influenced by boiler physical interferences such as buckstays, headers and downcomers. These interferences can limit available locations for overfire and reburn fuel injection ports. While it may be possible to relocate such equipment, the associated cost and potential impact on the structural integrity of the boiler can be prohibitive. Consequently, we attempted to limit the amount of pressure part changes to the boiler.

Low-NO_X Burners

Low-NO_X burners represent the most developed combustion control option evaluated. Actual field experience with the Riley CCV burner was used to identify important retrofit issues. The following burner design questions were addressed during the engineering evaluation:

1. Are the existing burner openings large enough to allow for changes in coal nozzle, air register or burner throat design without requiring pressure part changes?
2. Is the furnace firing depth sufficient to contain potentially longer, low-NO_X flames? Furnace wall flame impingement can result in furnace slagging, fireside corrosion and poor combustion efficiency.

The CCV burner was designed to be retrofit into existing burner openings with a minimum of changes. Only the coal head, nozzle and spreader must be replaced, along with any modification to the burner refractory throat. Another consideration was the complexity of the burner retrofit. Depending on the age of the unit and the condition of the firing equipment it may be desirable, or necessary to replace the entire burner. For this reason both a simple retrofit (coal head, nozzle and spreader) and a total burner replacement were evaluated. In either case small underfire air ports and side air ports were provided to assure an oxidizing atmosphere in the furnace hopper and along sidewalls, as well as to lower the increased windbox pressure caused by the change in burner settings.

Overfire Air

Studies have shown that overfire alone can reduce NO_X from 15 to 30 percent[4]. Our own pilot scale tests (Figure 1) showed that additional NO_X reductions can be achieved when overfire air is used in combination with low-NO_X burners.

We initially assumed, based on work by Johnson et al.[5], that the optimum location for the OFA, to maximize NO_X reduction, was 0.8 seconds above the top burner row. In addition, a minimum of 0.5 seconds residence time was required above the OFA ports to achieve carbon burnout. In practice, most OFA ports are confined in location by the furnace configuration and the presence of major structural members such as buckstays. Generally, OFA ports are located approximately one burner spacing above the top row of burners, between two buckstays. All air staging ports were equipped with pneumatically actuated on/off dampers with a remote/manual station in the control room. Alterations to the combustion control and flame safety systems may be required to insure that the use of overfire air does not interfere with burner stability and performance. For cases requiring conventional amounts of overfire air (less than 30%), the existing burner windbox was extended upward to supply air to the air staging ports.

Overfire air systems design concerns such as, furnace residence time, carbon burnout, and port location become even more critical for advanced staging systems. The major design difference is the requirement for a separate overfire air supply system. Since such a large portion of the combustion air (up to 50%) will be diverted to the OFA ports, it is necessary to exercise precise control over the amount of staging air. To achieve this a separate air supply system, including ductwork, flow control dampers and windbox, are required. Flow measuring devices in the new and existing ductwork would monitor air flow and determine the percentage of air diverted to the OFA ports. New control dampers in both the OFA system and existing ducts would be used to control these flows. Again, the combustion control system must be modified, and in this case the changes could be extensive.

Overfire air port design is a major consideration, for both conventional and advanced air staging systems. The effectiveness of overfire air is strongly dependent on achieving good mixing with primary combustion products. Key design parameters include OFA injection velocity, OFA port size, number, shape and location; and degree of staging. System pressure drop is also another important consideration in retrofit situations. In order to avoid the need for additional fans to boost system pressure, OFA port pressure drop was limited to 3 to 6 inches of water. Preliminary design guidelines developed in another EPRI study were used as the basis for the design analysis[6]. In all of the four case studies the OFA ports were uniformly spaced and located only on the burner firing walls.

The addition of overfire air ports can potentially affect the structural integrity of the firing wall. In these cases provisions were made to transfer structural loads from the firing wall(s) to the side walls. A more detailed review of individual port design, as well as consideration of rectangular or eliptical ports, may result in a compromise on port design which does not require structural modifications.

Reburning

Our evaluation of reburning technology was limited to the use of coal as the reburn fuel. Many of the design considerations required for overfire air staging also apply to reburning. In addition, a minimum of 0.3 seconds residence time between reburn fuel injection ports and overfire air ports was established for design purposes.

For boilers with three or more burner rows, we assumed that the lower burner rows would be operated at a moderate air/fuel stoichiometry (80-100%), with a reburning zone stoichiometry of 60 to 70% of theoretical air. The advantage of operating under these conditions is that burner ignition stability can probably be maintained at lower burner loads, thus providing more turndown of the unit without removing burners from service. The top row can then be modified to operate as coal injectors, with the coal being transported from the pulverizer by primary air.

In the case of boilers with less than three levels of burners, fuel injection ports would have to be installed. Interstage air can be added over the first stage to help protect the waterwalls from possible corrosion and to aid in the reburning process[7]. Overfire air is then injected above the fuel ports to complete combustion. As was the case with the overfire air, actual port locations were governed by physical constraints. Burner and pulverizer designs were reviewed to determine whether the top burner row could be used as reburning ports, providing 20-25% of the total fuel input. In some cases this may require overfiring lower burners, while derating the pulverizers serving the top burner row (reburn ports). The existence of dedicated pulverizers for each burner row is, therefore, highly desirable.

The most difficult, and expensive reburning case, which we evaluated, was Case C with only two burner rows. As a worst case scenario, we also assumed that new fuel storage and pulverizing equipment would be necessary on Unit, C along with the installation of both reburn and overfire air ports.

RETROFIT CASE STUDIES

Detailed engineering studies were performed for each of the retrofit options, on all four case study units. In each case proposal type drawings were prepared, as well as any design layout required to verify the feasibility of a retrofit. Material requirements, such as the amount of plate steel and tubing, and the amount of field work required, were also identified.

Unit A - 140 MWe Front-Wall Fired

Unit A is a 140 MWe natural circulation, superheat/reheat, balanced draft utility boiler, producing 950,000 lb/hr of primary steam. The retrofit of Low-NO_X burners is a relatively simple procedure. The existing 16 burners can be replaced with Riley CCV burners without making any changes to the burner tube bends. To meet burner velocity requirements, it was necessary to reduce the throat diameter by adding refractory. The windbox must be extended downward to accommodate the underfire air ports. Side air ports would also be provided to protect the side walls from any corrosion due to the Low-NO_X burners.

For both conventional and advanced staging, the overfire air ports must be added above the top burner row. In order to provide 0.8 second residence time between the top row of burners and the overfire air ports, the OFA ports should be 14 feet above the burners. Due to the presence of a buckstay, the ports must be located at 10 feet above the burners. This reduces the residence time to 0.6 seconds. In order to cover the entire cross-section of the furnace, nine overfire air ports were evenly spaced across the front wall of the furnace.

Under advanced air staging, overfire air would be supplied from a dedicated duct system. This system would take air from the existing burner air duct immediately after the air heater, and bring it to a separate windbox above the existing burner windbox. Total air flow control is provided by air dampers in both the new overfire air duct and the existing burner air duct. A flow meter would be installed to measure overfire air flow, while air to the burners would be measured by the existing venturi.

The application of fuel staging to this boiler would require all the modifications described for advanced air staging, plus the addition of intermediate air ports. For this configuration the top row of burners would be used as fuel injectors. This can be done since each of the four rows of burners operates from different pulverizer systems. Some air would be added through the intermediate air ports before the fuel injectors (about 10% of total combustion air), to improve carbon burnout, and provide additional protection from corrosion.

Unit B - 400 MWe Front-Wall Fired

Unit B represents a 400 MWe natural circulation, superheat/reheat, balanced draft utility boiler, producing 3,000,000 lb/hr of primary steam. It contains 24 pre-NSPS flare burners located in four rows served by three ball tube mill pulverizers. Except for the size of the equipment the retrofit of all four options to Unit B is similar to Unit A. In this case 13 overfire air ports would be provided above the top row of six burners. Again a compromise was required in the placement of overfire air ports, placing them 13 feet rather than the desired 18 feet, above the top burner row. Under reburning conditions the top row of burners would be used as fuel injectors and intermediate air ports would be added to improve carbon burnout and protect against corrosion. Pulverizer system changes would be required to match the pulverizers with three burner levels and one reburn fuel injection level.

Unit C - 360 MWe Opposed-Fired

Unit C is a 360 MWe natural circulation boiler producing 2,600,000 lb/hr of primary steam. A total of 24 burners are located in two rows on both the front and rear walls. The retrofit of Low-NO_X burners and advanced air staging to this unit is similar to units A and B. Limited space above the burners and the existence of only two burner rows makes fuel staging a complicated retrofit option.

For the advanced overfire air retrofit, the overfire air ports should be 19 feet above the burners to have 0.8 seconds residence time. This was not possible due to the superheater header on the front of the boiler, and the economizer hopper on the rear of the furnace. The ports, therefore, would be 12 feet above the burners which corresponds to about 0.5 seconds residence time.

The application of reburning technology to Unit C would require the installation of reburn fuel injection ports approximately 12 feet above the existing top burner row. This would place the installation of burnout ports in the area of the existing superheater header and economizer hopper. Therefore, major pressure part changes involving the superheater, economizer, and economizer hopper would be required. In addition to the required pressure part work, new coal feed and pulverizer systems would be needed to supply the reburn fuel injection ports. This case represents a worst case scenario for the application of reburning to wall-fired boilers.

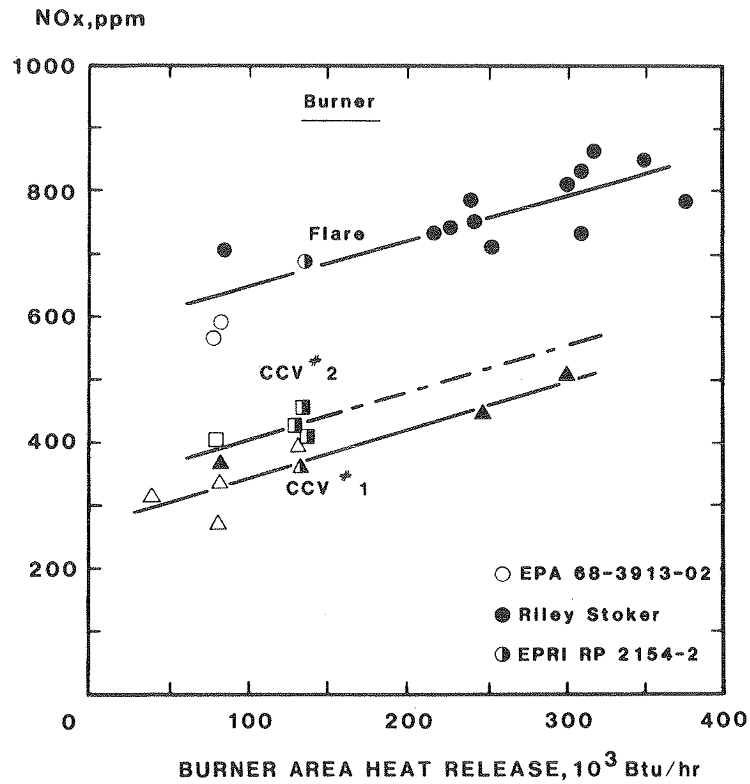


Figure 5 NO_x Prediction Curve for Low NO_x Burners (Base NO_x)

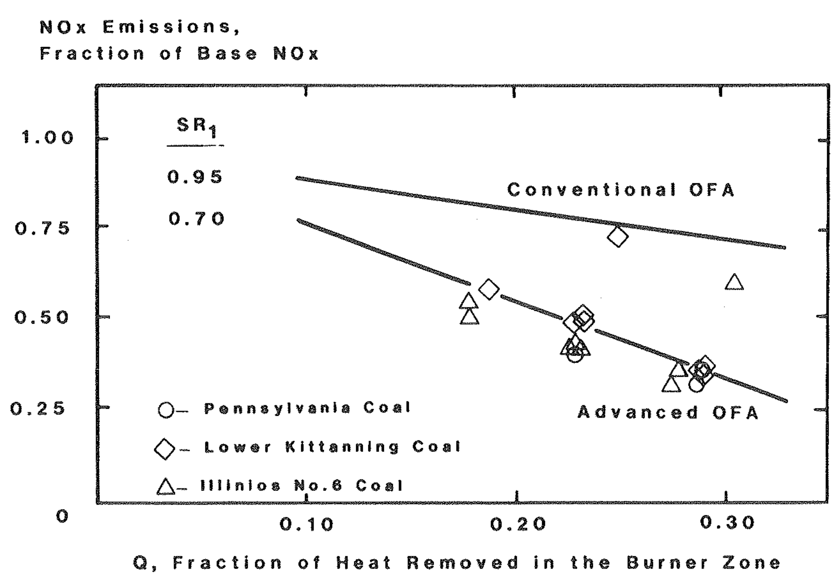


Figure 6 Prediction Curve for LNB with Overfire Air Staging Based on Data from Pilot Scale Combustion Tests

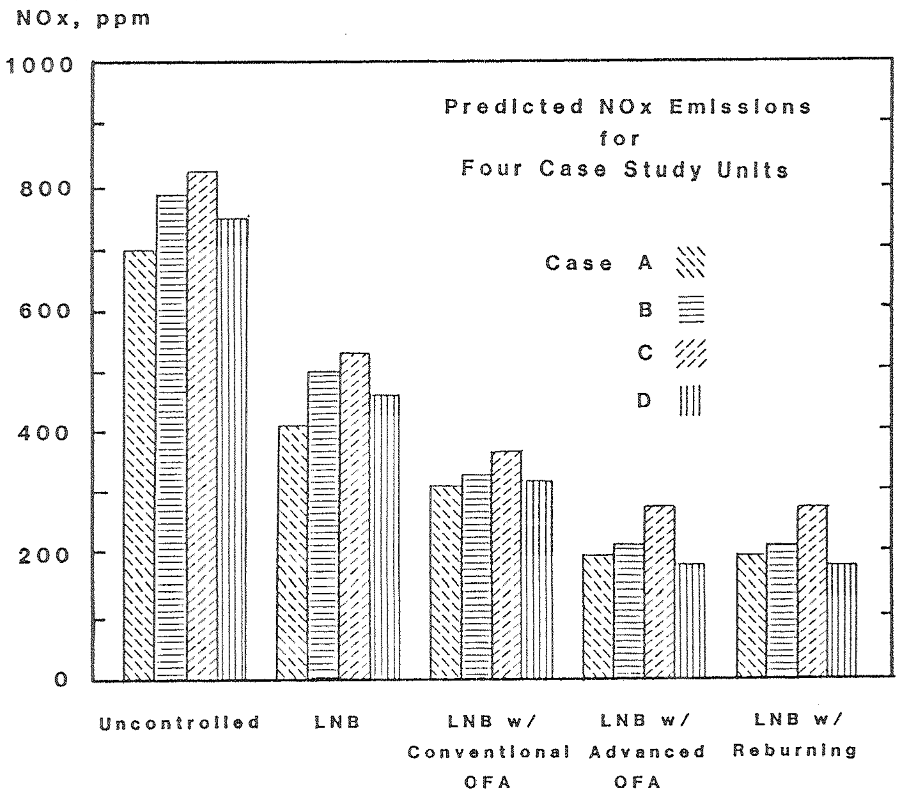


Figure 7 *Predicted NO_x Emissions for Case Studies Compared to Uncontrolled Emissions*

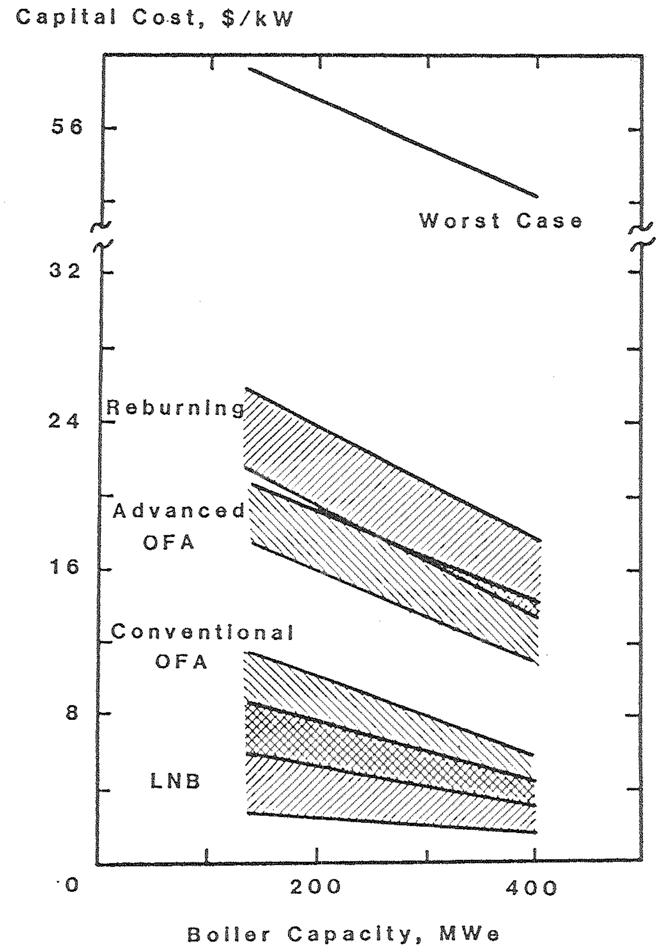


Figure 8 *Projected Capital Costs of Low NO_x Combustion Techniques Showing the Effect of Unit Size*

Unit D - 360 MWe Opposed-Fired

Unit D is a 360 MWe natural circulation, superheat/reheat, balanced draft boiler, producing 2,584,000 lb/hr of primary steam. It has 24 burners, located in three rows on both the front and rear walls. Unit D is already equipped with overfire air. However, the existing system would require modification to improve the effectiveness of overfire air when used in combination with low NO_X burners. The original OFA port design is based on relatively narrow rectangular openings in the furnace wall. These existing ports have insufficient flow area for advanced OFA operation and the shape of the ports must also be changed for better jet penetration and mixing. The existing underfire air and side air ports are sufficient for corrosion protection. Due to the superheater header on the front of the boiler, the overfire air ports are located 11 feet above the burners. This corresponds to 0.6 rather than 0.8 seconds residence time.

Unlike Unit C the top row of burners would be used as reburning fuel injectors. Intermediate air ports would be added to improve carbon burnout and protect against corrosion.

NO_X PERFORMANCE

NO_X emissions were predicted for each of the four retrofit NO_X control options. The predictions are based on the pilot scale combustion tests supported by EPRI as well as U.S EPA and Riley sponsored pilot scale tests[3] and field tests performed by Riley. Uncontrolled NO_X emissions from the four case study units range from 700 to 830 ppm(1).

Full scale low NO_X burner performance was evaluated based on a correlation of emissions with a burner area heat release (BAHR) parameter shown in Figure 5. The BAHR is defined as the gross fuel heat input divided by the cooled surface in the main flame zone. The correlation shown in Figure 5 predicts the performance of a pre-NSPS Flare burner, and two versions of the low NO_X CCV burner. The difference between CCV burners is a result of differences in coal nozzle design. Nozzle Design No. 2 was developed for CCV burners used in two stage combustion systems. Under single stage operation this design results in higher NO_X emissions than design No. 1. For the four case studies evaluated, NO_X reductions on the order of 40% were estimated for low NO_X burners alone.

While the Low NO_X burner emissions can be correlated with a simple heat release parameter, more advanced combustion systems require a more complex analysis. Our pilot scale results revealed that under deeply staged combustion conditions NO_X was a function of first stage heat removal, as well as stoichiometry. This behavior is similar to results observed by Johnson, et al[5]. A furnace heat transfer computer model was used to relate first stage heat removal in both the test furnace and the full scale utility boilers. The model was also used to determine the impact of various combustion modifications on furnace exit gas temperatures.

Figure 6 describes the trend of pilot scale NO_X emissions with first stage heat removal for both conventional and advanced amounts of staging. This curve was used to predict the incremental NO_X reduction when OFA is combined with low NO_X burners. For the four retrofit cases, total NO_X reductions of 56% to 59% were predicted for low NO_X burners with conventional air staging and 67% to 77% for low NO_X burners combined with advanced air staging. Based on our pilot scale test results (Figure 1) we assumed that emissions would be similar for both reburning and advanced air staging.

NO_X emission predictions for all boilers and retrofit options are shown in Figure 7. Emission of less than half the present NSPS standards are predicted for three of the four units with advanced overfire air, and reburning.

(1) All reference NO_X emissions are part per million, dry and at 3% O_2, unless otherwise noted.

ECONOMIC FEASIBILITY

Equipment and modification costs were estimated based on the engineering analysis. Low-NO_X (CCV) burner costs were estimated for two retrofit situations: 1) assuming only the coal nozzle, coal head, and coal spreader need to be replaced; and 2) assuming an entire burner retrofit is required including register, front plate and refractory quarl. Actual retrofit requirements would be site specific. The required level of burner modification would depend on the age of the unit, the condition of the existing burners, and the compatibility of the retrofit burner with the original burner. For example, in one commercial CCV burner application only a coal nozzle/spreader replacement was needed, while in another both coal nozzle and air register modifications were required[8]. Cost estimates for all staged combustion retrofit options assumed a complete burner retrofit.

Equipment costs include material, shop labor, field labor, manufacturer's engineering, sales tax and freight. Estimates were prepared in accordance with normal proposal engineering estimating procedures. Fees, contingencies and operating maintenance costs were estimated according to EPRI "Economic Premises for Electric Power Generating Plants", issued December 15, 1982. The cost estimates are based on a Class II preliminary design. A sliding scale of process and project contingencies were used to reflect the various stages of development for each retrofit option. The calculation of 30 year levelized busbar cost are also according to the EPRI premises. All capital and operating cost estimates are presented in 1983 dollars.

	Case A		Case B		Case C		Case D	
	Capital Cost	Levelized Cost	Capital Cost	Levelized Cost	Capital Cost	Levelized Cost	Capital Cost	Levelized Cost
LNB								
Coal Nozzle Retrofit	2.8	0.10	1.4	0.05	2.1	0.08	1.4	0.05
Total Burner Replacement	8.7	0.32	4.6	0.17	5.4	0.19	4.8	0.17
LNB plus Conventional OFA	11.6	0.42	6.3	0.23	7.1	0.26	6.0	0.22
LNB plus Advanced OFA	17.8	0.80	11.3	0.51	13.8	0.62	14.9	0.67
LNB plus Reburning	21.5	0.97	13.5	0.57	53.2	2.40	18.3	0.82

Capital Cost - \$/kW
Levelized Cost - mills/kW-hr(30-yr average)

Table I Summary of Economic Evaluation

Table I summarizes total capital costs and levelized power costs for the four retrofit options on each case study unit. Capital costs are plotted in Figure 8, versus unit size. For all cases there is an inverse relation of capital costs, expressed in \$/kW, with unit capacity. Units C and D (both 360 MWe) were very close in costs for all options except reburning. In terms of ease of retrofit the Unit C reburning case reflects a worst case scenario. The additional cost of reworking the superheater header and economizer, and the addition of coal handling equipment increases the cost of reburning by almost a factor of three (18.3 \$/kW vs. 53.2 \$/kW). However, even with the high capital cost, the levelized power cost is only 2.4 mills/kW-hr for this worst case.

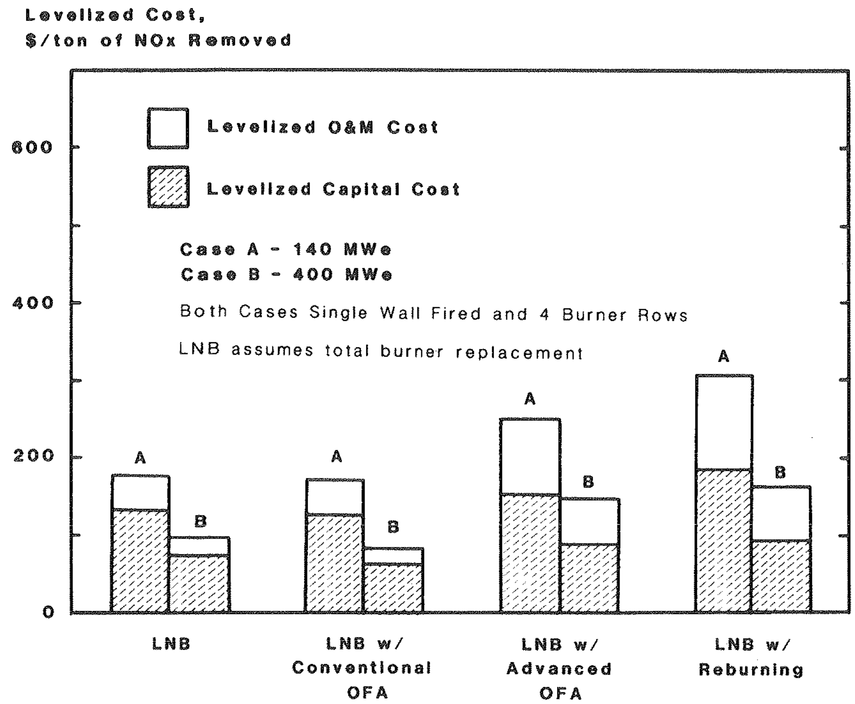


Figure 9 Comparison of Levelized Costs for Single Wall-Fired Boiler Cases. Both Cases Have Four Burner Rows.

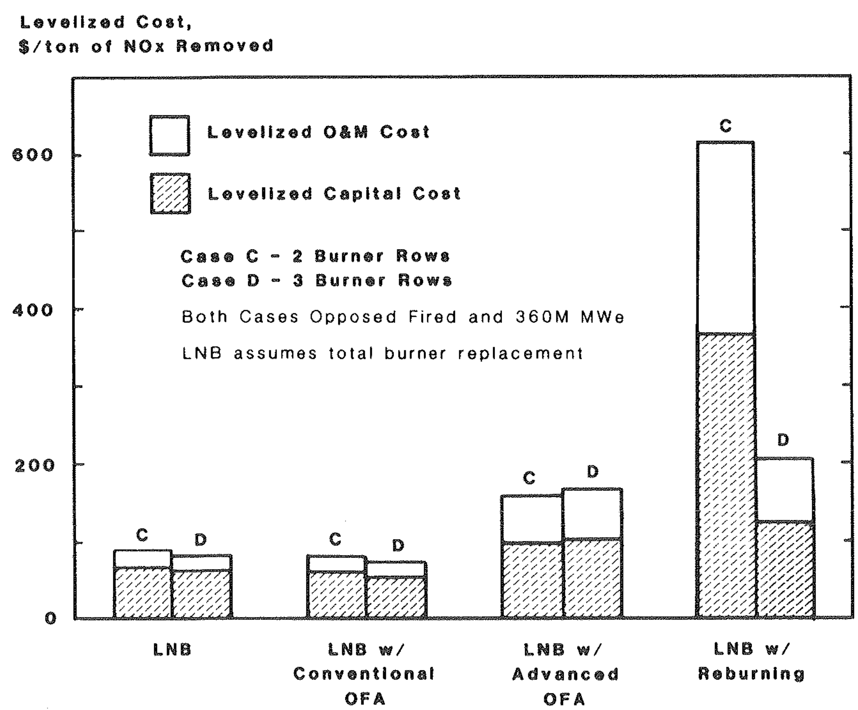


Figure 10 Comparison of Levelized Costs for Opposed Wall-Fired Boiler Cases. Both Cases Are Rated at 360 MWe.

The sensitivity of these costs to changes in the economic assumptions was also considered. The change having the largest affect on capital costs is outage time for construction. We assumed in our analysis that some site work could be performed with the unit on line, and that all construction could be completed with a scheduled four to six week outage. If construction were to require an extended unscheduled outage, the cost of replacement power could increase capital costs as much as 100 \$/kW based on replacement power costs of 45 mills/kWh.

A change in furnace exit gas temperature large enough to require derating of the unit could also increase levelized cost significantly. Again, replacement power cost is the largest contributing factor. Changes in boiler heat rate of 5% to 10% could increase levelized power cost 10 to 15 times, due to the increased cost of fuel. Increased maintenance and operation cost could increase levelized costs two to three times, requiring additional maintenance and operating personnel.

Another way to evaluate the cost of retrofit NO_X controls is in terms of their levelized cost in dollars per ton of NO_X removed. Levelized capital and O&M costs are summarized in Figures 9 and 10. It was assumed new technologies, such as advanced OFA and reburning, would require increased maintenance as a percentage (4%) of installed cost. Although the maintenance cost for low-NO_X burners would be considerably less, some increase is expected over conventional burners. Experience has shown that the mechanical condition of the burner equipment is more critical for low-NO_X operation. Annual maintenance costs for low-NO_X burners and conventional overfire air systems were estimated at 2% of installed cost. Sufficient controls were provided in the design and cost of each system so that no additional operating labor is anticipated for any of the four combustion systems evaluated.

These levelized costs in terms of \$/ton of NO_X removed are an order of magnitude less, for even new NO_X combustion control technologies, than selective catalytic reduction.

CONCLUSIONS

The following major conclusions regarding retrofit low-NO_X combustion controls can be drawn from this engineering and economic evaluation:

1. Low-NO_X burners represent the lowest cost, combustion control system.
2. Low-NO_X burners with conventional overfire air is the next increment in control and cost. This control option can be as cost effective as low-NO_X burners alone when evaluated in \$/ton NO_X removed.
3. Although low-NO_X burner with advanced overfire air, or reburning, produce the lowest NO_X emissions, these combustion technologies have the most uncertainty in terms of both performance and cost.
4. There is an economy of scale, based on \$/kW, for all retrofit combustion options.
5. Major pressure part changes, new auxiliary equipment, and structural modifications can cause a threefold increase in retrofit costs.
6. Retrofit costs are most sensitive to construction outage time and unit derating.
7. The capital and levelized power costs of retrofit combustion NO_X controls are significantly less than selective catalytic reduction.

REFERENCES

1. Maulbetsch, J., McElroy, M., Eskinazi, D., Retrofit NO_x Control Options for Coal-Fired Electric Utility Power Plants. Journal of the Air Pollution Control Association. Vol. 36, No. 11, November 1986, p1297.

2. Lisauskas, R., Snodgrass, R., Johnson, S., Eskinazi, D., Experimental Investigation of Retrofit Low-NO_x Combustion Systems. In: Proceedings of the 1985 Symposium on Stationary Combustion NOx Control, Vol. I, 1986, pp12-1 to 12-18.

3. Lisauskas, R., Itse, D., Masser, C., Extrapolation of Burner Performance for Single Burner Tests to Field Operation. In: Proceedings of the 1985 Symposium on Stationary Combustion NO_x Control, Vol. I, 1986.

4. Thompson, R., Eskinazi, D., Afonso, R., Gilbert,G., Yang, R., and McHale, C., Laboratory Flow Model Studies to Improve Overfire Air Mixing. In: Proceedings of the 1985 Symposium on Stationary Combustion NO_x Control, Vol. I, 1986.

5. Johnson, S., Yang, R., and McElroy, M. Heat Transfer Modeling for Two-Stage Pulverized Coal-Fired Combustors. Paper presented at the Joint ASME/AICHE National Heat Transfer Conference, Orlando, Florida, July 27-30, 1980.

6. Lisauskas, R., McHale, C., Afonso, R., and Eskinazi, D., Development of Overfire Air Design Guidelines for Single Wall Fired Boilers. Paper presented at the 1987 Joint Symposium on Stationary Combustion NO_x Control, New Orleans, March 23-26, 1987.

7. Takehashi, Y., et. al., Development of Mitsubishi 'MACT' In-Furnace NO_x Removal Process. Paper presented at the U.S.-Japan NO_x Information Exchange, Tokyo, May 25-30, 1981

8. Penterson, C., Development of an Economical Low-NO_x Firing System for Coal Fired Steam Generators. Paper presented at the Joint Power Generation Conference, Denver, October 1982.