A Review of DOE/NETL's Advanced NOx Control Technology R&D Program for Coal-Fired Power Plants

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INTRODUCTION

The environmental performance of the United States' fleet of coal-fired boilers has steadily improved since passage of the 1990 Clean Air Act Amendments (CAAA). Emissions of sulfur dioxide (SO_2), nitrogen oxide (NOx), particulate matter (PM) have been significantly reduced. However, further restrictions on emissions from power plants have been proposed in response to issues such as mercury, acid rain, ground-level ozone, nitrification of aquatic ecosystems, ambient fine particulate matter, and visibility impairment (regional haze). For example, the EPA's recently proposed Clean Air Interstate Rule (CAIR) is intended to significantly reduce both NOx and SO_2 emissions. In addition, several multi-pollutant bills have been offered in Congress, including the Clear Skies Act (CSA), to further control power plant emissions.

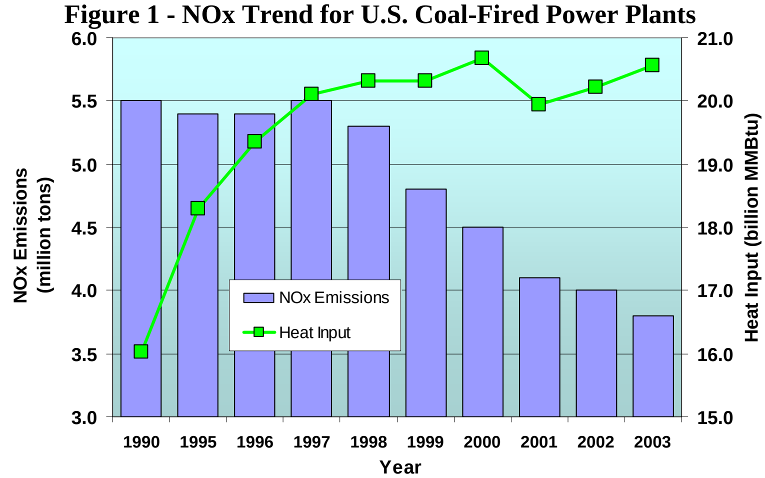
In response to these environmental challenges, the U.S. Department of Energy Office of Fossil Energy's National Energy Technology Laboratory (DOE/NETL) is carrying out a comprehensive, integrated research and development (R&D) effort under its Innovations for Existing Plants (IEP) Program. The overall goal of the IEP Program is to continue to enhance the efficiency and environmental performance of the existing fleet of fossil-fuel-fired power systems that represent more than 320 gigawatts of generating capacity as well as apply these concepts to advanced power systems. An important component of the program is the R&D of advanced NOx control technologies. This effort focuses primarily on in-furnace NOx control systems capable of controlling emissions to a level of 0.15 lb/MMBtu by 2006 and 0.10 lb/MMBtu by 2010, while achieving a levelized cost savings of at least 25% compared to state-of-the-art selective catalytic reduction (SCR) control technology. A long-range goal is to further develop a combination of advanced combustion and SCR control technologies to achieve a NOx emission rate of 0.01 lb/MMBtu by 2020. The research also provides an improved understanding of the impact of these advanced technologies on related issues such as unburned carbon, waterwall wastage, and mercury speciation and capture. The IEP portfolio of NOx control technology R&D projects encompasses laboratory studies, modeling, and pre-commercial demonstration full-scale testing. The success of the projects is intimately tied to key collaborations and partnerships with industry, federal, state, and local agencies, and the academic and research communities. This paper will provide an update on the status of these projects covering Rich Reagent Injection, ultra-low-NOx burners (LNB), selective non-catalytic reduction (SNCR), and enhanced-oxygen combustion.

BACKGROUND

Coal-fired power plants will continue to be subject to progressively more stringent NOx regulations in the near future. The 1990 CAAA contain several provisions that led to significant NOx reductions required by coal-fired power plants over the past ten years (*New Source Performance Standards and New Source Review, Title IV Acid Rain Program, Title I NOx RACT*, *Northeast Ozone Transport Region, and NOx SIP Call Rule*). However, there are other provisions (*Regional Haze Rule* and *Title I Revisions to Ozone and Particulate Matter NAAQS*) and proposed multi-pollutant control initiatives (*Clean Air Interstate Rule, Clear Skies Act, Clean Power Act of 2003, Clean Air Planning Act of 2003, and state-specific emission reduction regulations*) that are likely to require additional NOx emission reductions over the next ten years.

As a result of implementation of the various CAAA regulatory requirements, NOx emissions in 2003 from coal-fired power plants were approximately 3.8 million tons, representing about 18% of the total U.S. NOx emissions. This quantity constitutes a 31% reduction from 1990 NOx emissions despite a 29% increase in total generation as measured by thermal heat input as shown in Figure 1.

Figure 1 - NOx Trend for U.S. Coal-Fired Power Plants



NOx Emissions from Coal-Fired Power Plants

Coal consists of both organic and inorganic matter. In the high-temperature environment during and after combustion, the components of coal and air are physically and chemically transformed into a suite of products. One of the products is NOx, which can be formed by (1) nitrogen and oxygen in the combustion air reacting at high temperature to produce "*thermal NOx*" and (2) fuel-bound nitrogen reacting with the combustion air to produce *"fuel NOx."* The amount of NOx formed depends on numerous factors including flame temperature, nitrogen content of the coal, combustion excess air, residence time, and degree of mixing. For most coal-fired units, thermal NOx typically represents about 20% and fuel NOx about 80% of the total NOx formed. However, for cyclones and other boilers that operate at very high temperatures, thermal NOx can be considerably higher than fuel NOx. In addition, minor amounts of NOx are formed early in the combustion process through complex interactions of molecular nitrogen with hydrocarbon free radicals to form reduced nitrogen species that are later oxidized to NOx, referred to as *"prompt NOx."* The quantity of thermal NOx formed depends primarily on the "three T's" of combustion: temperature, time, and turbulence. Thus flame temperature, the residence time at temperature, and the degree of fuel/air mixing, along with the nitrogen content of the coal and the quantity of excess air used for combustion, determine NOx levels in the flue gas.

Balance-of-Plant Impacts

Unfortunately, the implementation of current NOx control technologies at a coal-fired power plant can have adverse operational and maintenance balance-of-plant impacts that can decrease plant efficiency and/or availability. The impacts are a result of changed combustion conditions in the furnace, changed products of combustion, and the addition of chemical reagents. These impacts can include incomplete coal combustion, boiler tube corrosion, air heater pluggage, deterioration in electrostatic precipitator performance, fly ash contamination, and excessive NH_3 and sulfur trioxide (SO_3) emissions. The magnitude and severity of these balance-of-plant impacts at a particular plant is dependent on boiler design and coal properties, as well as the specific design and operating conditions of the NOx control technology.

DOE/NETL INNOVATIONS FOR EXISTING PLANTS PROGRAM

A comprehensive, integrated environmental R&D program is being carried out under the DOE Office of Fossil Energy's IEP program. The program, which is managed by DOE/NETL, encompasses both in-house and contracted research on advanced, low-cost environmental control systems and ancillary science and technologies that can help the existing fleet of coal-based power plants meet current and future environmental requirements. The program also provides high-quality scientific information on present and emerging environmental issues for use in regulatory and policy decision making. The research directly supports the Administration's CSA and the May 2001 National Energy Policy recommendations concerning the environmental performance of coal-based power systems.

The IEP portfolio includes bench-scale through field-scale R&D related to the control of mercury, NOx, particulate matter, and acid gas emissions from power plants, as well as research in the area of ambient air quality, atmospheric chemistry, and solid by-products. Furthermore, the program recognizes the importance of emerging water-related issues and their relationship with reliable and efficient power plant operations. Partnership and collaboration with industry, Federal and state agencies, research organizations, academia, and non-government organizations are key to the success of the program. Additional information on DOE/NETL's IEP program can be found at: http://www.netl.doe.gov/coal/E&WR/index.html.

ADVANCED NOx CONTROL TECHNOLOGY R&D ACTIVITIES

DOE/NETL has been at the forefront of conducting advanced NOx control technology R&D for coal-fired power plants. The success of achieving the required Title IV acid rain program NOx reductions can be attributed largely to the adoption of LNB technology by the utility industry. The LNBs that are currently installed in 75% of the nation's coal-fired power plants are a direct result of the DOE/NETL Clean Coal Technology Program's government–industry partnerships.

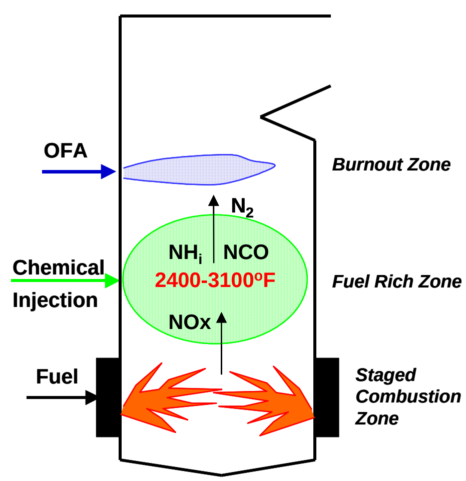
The continuing ratcheting down of NOx emissions by new regulations will require some power plant emission rates to be reduced well beyond 0.15 lb/MMBtu. To meet these requirements, power producers will need to retrofit existing boilers with additional NOx control technologies, some of which will adversely impact plant efficiency and performance. The new NOx control requirements demand an increase in R&D, capital, and operating expenditures from power plants to implement and come at an inopportune time for an industry that has been adversely impacted financially by deregulation and the associated capital market pressures, aging facilities, homeland security, in addition to other ever-expanding environmental control requirements.

In response to this challenge, DOE/NETL is partnering with industry and academia through the IEP Program to conduct advanced NOx control technology R&D. The specific performance target is to develop combustion control technologies for existing plants with a NOx emission rate of 0.15 lb/MMBtu by 2006 and 0.10 lb/MMBtu by 2010, while achieving a levelized cost savings of at least 25% compared to state-of-the-art SCR control technology. A long-range goal is to further develop a combination of advanced combustion and SCR control technologies to achieve a NOx emission rate of 0.01 lb/MMBtu by 2020. However, in a cap-and-trade allowance-based regulatory program, it is realized that low cost NOx control technologies that do not achieve the target emission rates can still have a prominent role as a compliance strategy. Further, the technologies under development are: (1) to have negligible impact on balance-of-plant issues, (2) applicable to a wide range of boiler types and configurations, and (3) capable of maintaining performance over a wide range of feed coals and operating conditions. The research portfolio includes advanced combustion controls, advanced flue gas treatment, and integrated control systems. Additional information on DOE/NETL's advanced NOx emissions control activities can be found at: http://www.netl.doe.gov/coal/E&WR/nox/index.html. The following sections include brief summaries of several current DOE/NETL advanced NOx control technology R&D projects.

Rich Reagent Injection for Cyclone Burners

Reaction Engineering International (REI) has conducted optimization studies of EPRI's Rich Reagent Injection (RRI) process for NOx reduction on cyclone burners. Cyclone burners create an intense flame that melts the ash to form slag. The high temperature generated by this burner results in relatively high uncontrolled NOx emissions, typically exceeding 1.2 lb/MMBtu. RRI uses a nitrogen-containing additive, such as urea, to non-catalytically reduce NOx in the lower furnace. A schematic of the RRI process is shown in Figure 2. Full-scale field-testing of RRI has been successfully completed at Conectiv's 138 MW B.L. England Unit 1 and AmerenUE's 500 MW Sioux Unit 1.

Figure 2 - Rich Reagent Injection Process



At Conectiv's B.L. England Unit 1, prior installation of OFA and SNCR had reduced uncontrolled NOx emissions from 1.2 to 0.35 lb/MMBtu. REI's *GLACIER* computational fluid dynamics (CFD) combustion simulation software was used to design the RRI system. A summary of the RRI test results are shown in Figure 3. Field-testing confirmed modeling predictions and demonstrated that RRI could achieve 25-30% NOx reduction beyond OFA levels with less than 1 ppm ammonia slip and that the inclusion of SNCR could achieve an additional 35% NOx reduction to 0.25 lb/MMBtu with less than 5 ppm NH_3 slip.

Figure 3 - RRI Test Results at B.L. England Unit 1

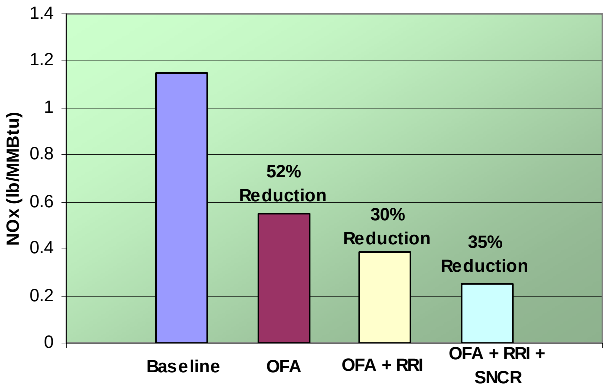
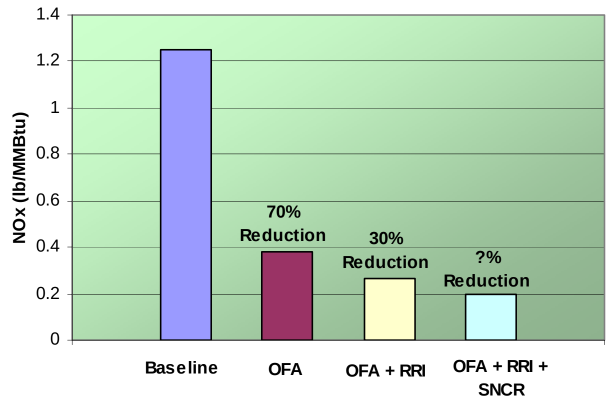


Figure 4 - RRI Test Results at Sioux Unit 1



The objective of the testing at AmerenUE's Sioux Unit 1 was to determine whether similar performance could be obtained with RRI in a significantly larger unit. As detailed in Figure 4, the results were found to be consistent with the CFD model predictions. Both showed that NOx reductions of 30% from full load baseline emissions of 0.38 lb/MMBtu with OFA to 0.27 lb/MMBtu were achievable with RRI. These reductions were achieved with no predicted or measurable ammonia slip. Modeling of this unit also suggests that NOx reductions could be improved through modification of flue gas recirculation (FGR) operation, reduction of lower furnace stoichiometry, or utilization of SNCR. Although the target emissions of 0.15 lb/MMBtu were ambitious for this style of burner, these results are substantial when compared to the Title IV NOx limit of 0.86 lb/MMBtu for cyclone-fired boilers. These units, which account for 8% of the US generating capacity, emit nearly 12% of the coal-fired NOx emissions.

Low NOx Firing System for Tangential Boilers

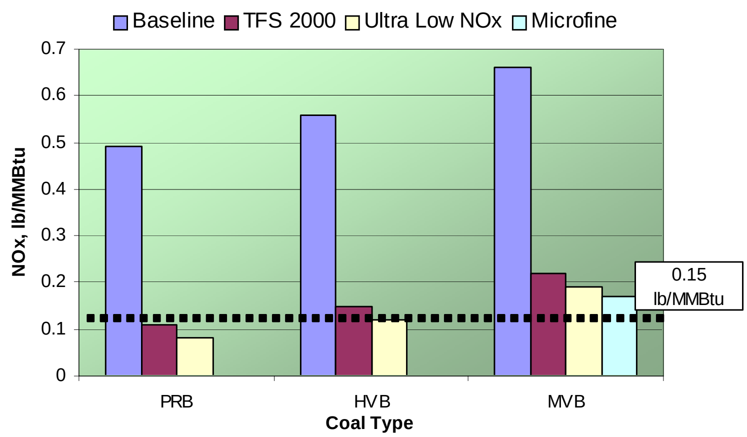
ALSTOM Power Inc. completed a comprehensive pilot-scale study to develop retrofit NOx control technology for tangential boilers to achieve less than 0.15 lb/MMBtu NOx firing bituminous coal and 0.10 lb/MMBtu NOx firing subbituminous coal at a cost that is at least 25% less than SCR technology. ALSTOM's TFS 2000^{TM} low NOx firing system served as a basis for comparison to other low NOx systems evaluated and was the foundation upon which refinements were made to further improve NOx emissions and related combustion performance.

Three coals, ranging from a very reactive subbituminous Powder River Basin coal (PRB) to a moderately reactive Midwestern high volatile bituminous coal (HVB) to a less reactive Eastern medium volatile bituminous coal (MVB), were evaluated using a large, 50-60 MMBtu/hr, pilot-scale boiler. Among the technologies evaluated were finer coal grinding, oxidative pyrolysis burners, windbox auxiliary air optimization, and various burner zone firing arrangements in concert with overfire air. Other technologies, such as an advanced boiler control system, coal and airflow balancing, and a Carbon Burn Out combustor, were also evaluated.

Pilot-scale testing of the three test coals showed that both NOx and combustion performance are a strong function of coal properties. As shown in Figure 5, the most reactive coal, PRB, showed the lowest NOx emission rate, followed by the moderately reactive HVB, and least reactive

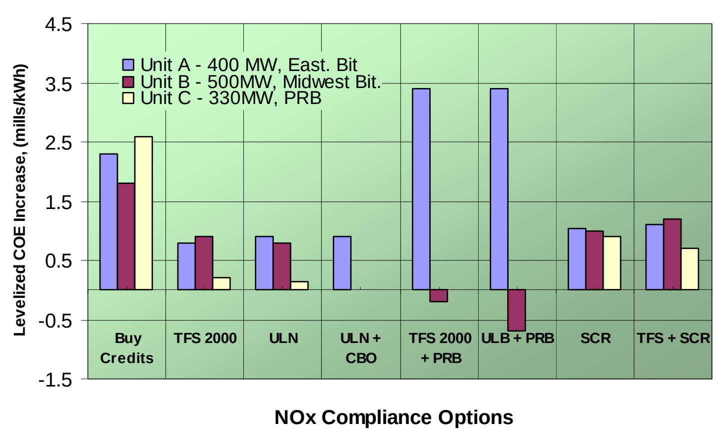
MVB coals. The combination of firing system modifications resulting in the lowest NOx emissions is referred to as the Ultra Low NOx (ULN) integrated system. In general, firing system modifications that reduce NOx emissions can also result in higher levels of unburned carbon in the fly ash and increased levels of carbon monoxide (CO). The PRB coal showed the lowest combustibles in the flue gas, followed by the HVB and MVB coals. When both NOx emission rate and combustion efficiency performance were evaluated, the standard TFS 2000 system gave the best results for the HVB and MVB coals and the ULN system gave the best results on the PRB coal. Many of the firing system components developed in this project have been applied to the TFS 2000 firing system, resulting in improved NOx emissions without significantly affecting the unburned carbon levels. To date, 19 commercial boilers firing PRB coal that utilize aspects of the technologies demonstrated in this project are achieving NOx emissions at or below 0.15 lb/MMBtu.

Figure 5 - ALSTOM Pilot-Scale Test Results



An engineering systems and economic analysis was performed to evaluate various NOx reduction options including the commercially-available TFS 2000 system, the ULN system developed in this project, and SCR. The various NOx reduction alternatives were evaluated as retrofit options for three tangential boilers. These include: (1) a 400 MW boiler on the East coast firing an eastern bituminous compliance coal, (2) a 500 MW boiler in the Midwest firing a midwestern bituminous coal, and (3) a 330 MW boiler in the West firing a PRB subbituminous coal. The objective was to evaluate the economics of various NOx reduction options to gain insight into the optimum NOx reduction strategy for different pulverized coal (PC) fired units.

Figure 6 - ALSTOM Cost Analysis

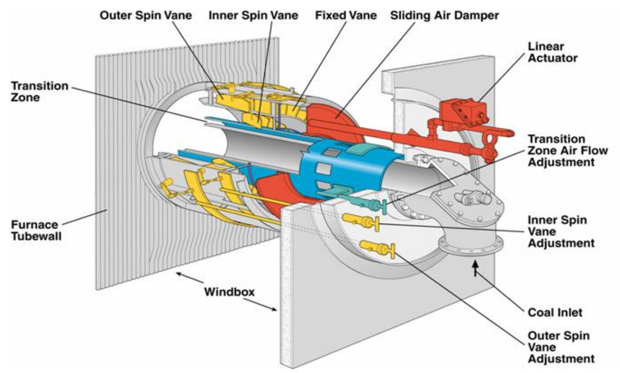


Results from this economic analysis are shown in Figure 6. Switching to a PRB coal, in concert with installation of either a TFS 2000 or ULN system, was the most cost effective option (75-80% less than the cost of an SCR) if the cost of shipping the PRB coal to a particular site was not prohibitive. However, it was recognized that the optimum NOx reduction strategy is unit, site, and system specific.

Integrated Low NOx Burners and SNCR for Wall-Fired Boilers

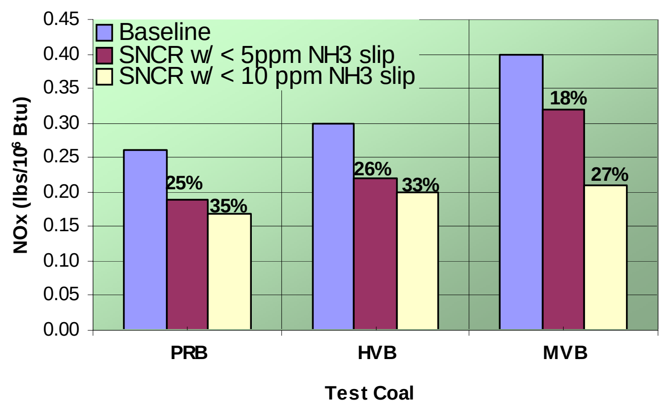
McDermott Technology, Inc. (MTI), the Babcock & Wilcox Company (B&W), and Fuel Tech teamed together to investigate an integrated solution for NOx control. The system was comprised of B&W's DRB-4Z™ LNB technology (Figure 7) and Fuel Tech's NOxOUT®, a urea-based SNCR technology. Large-scale testing was conducted using a 100-MMBtu/hr pilot-scale combustor that simulates the conditions of large coal-fired boilers. The test facility is equipped with one near full-scale burner and is constructed with water walls and refractory to simulate the thermal conditions of the middle row burner in a full-scale boiler.

Figure 7 – B&W's DRB-4Z Low NOx Burner



A wide range of coals were tested including: Spring Creek, a PRB western subbituminous coal; Pittsburgh #8, a high volatile bituminous coal; and Middle Kittanning, a medium volatile bituminous coal. As shown in Figure 8, the DRB-4Z™ burner alone without air staging achieved NOx emissions of 0.26 lb/MMBtu for the PRB coal, 0.30 lb/MMBtu for the Pittsburgh #8, and 0.40 lb/MMBtu for the Middle Kittanning coal. The NOx variations with fuel can be explained with the fuel's fixed carbon over volatile matter ratio (FC/VM) and fuel nitrogen content. Fuel FC/VM ratios for Spring Creek, Pittsburgh #8, and Middle Kittanning were 1.26, 1.19, and 2.38 respectively. In addition, the lower fuel nitrogen and higher moisture content of the Spring Creek coal reduced the overall NOx emissions.

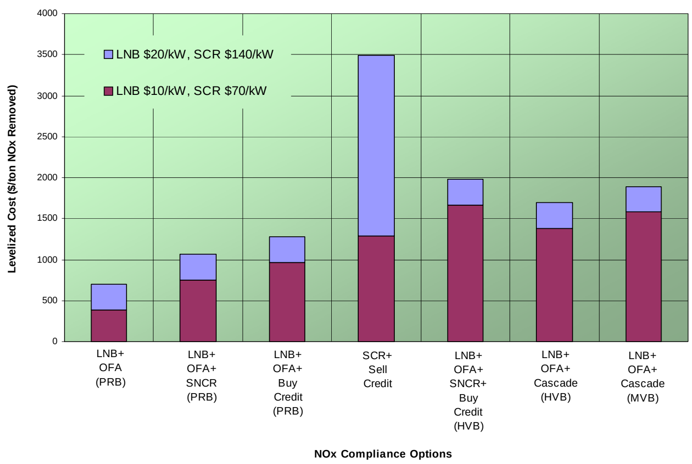
Figure 8 - B&W DRB-4Z and SNCR Test Results



The baseline DRB-4Z™ NOx levels at full load were reduced by the SNCR system (configured with wall injectors only) to 0.19 lb/MMBtu (25% reduction) for Spring Creek, 0.22 lb/MMBtu (26% reduction) for Pittsburgh No. 8, and 0.32 lb/MMBtu (18% reduction) for Middle Kittanning coal. These data indicate that a nominal 25% additional NOx reduction is feasible using SNCR while firing PRB and eastern high volatile coals with a baseline NOx of 0.2 to 0.3 lb/MMBtu when the NH_3 slip is limited to less than 5 ppm. Higher NOx reductions were possible when the ammonia slip was between 5 to 10 ppm. For units firing coals with lower volatile content such as Middle Kittanning, the higher boiler gas temperatures could limit the SNCR NOx reduction to 15-20%.

To further investigate more favorable conditions of the layered technology, additional testing was conducted using the Spring Creek coal in a boiler configuration which included the use of staged combustion with OFA and a multiple nozzle lance in front of the superheater tubes of the convective pass for more conducive temperatures for urea injection. At the optimum conditions, the baseline NOx emission rate of 0.094 lb/MMBtu was reduced to 0.071 lb/MMBtu. This SNCR reduction of 25% was achieved with an ammonia slip of 6 ppm.

Figure 9 – B&W NOx Control Cost Estimates



The cost effectiveness of various NOx control options for a reference 500 MWe wall-fired boiler are shown in Figure 9. Three integrated NOx control options were considered in this evaluation with the goal of reducing the baseline emissions from 0.5 to 0.15 lb/MMBtu. The SCR-only scenario represents the base case for comparing with the costs of other cases.

The LNB in combination with OFA was considered a potential technology for boilers using PRB coal. The LNB/OFA plus NOxOUT® was considered when burner NOx level reached 0.2 lb/MMBtu. Also, Fuel Tech investigated the NOxOUT Cascade® for cases with high reagent injection rates (burner NOx @ 0.3 lb/MMBtu) where ammonia slip can be reduced with a catalyst. In some of the pilot-scale tests, the SNCR system was forced to slip 10-20 ppm ammonia. There was no catalyst available in the pilot-scale combustor to promote reaction between ammonia and NOx, which is the basis for the NOxOUT Cascade® technology. For the purpose of this economic analysis, the NOxOUT Cascade® NOx reduction was estimated based on Fuel Tech's experience. The economic analysis normalized the costs to an emission rate of 0.15 lb/MMBtu based on the buying and selling of NOx allowances at a value of $4,000 per ton.

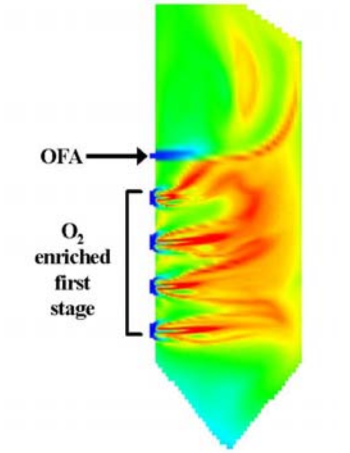
The analysis shows that the DRB-4Z™ LNB in combination with OFA has the lowest levelized cost, 70% to 80% less than SCR. Since LNB are more cost-effective on a $/ton of NOx basis than SNCR or SCR technologies in general, there is a great incentive for using them in combination with post-combustion NOx control methods. LNB/OFA plus the NOxOUT® combination cost is $752 to $1066 per ton of NOx removed when the baseline burner emissions are 0.20 lb/MMBtu, which is 40% to 70% lower than the SCR cost of $1,287 to $3,489 per ton of NOx. The NOxOUT Cascade® levelized cost is close to the lower range of SCR due its lower capital cost. It has been assumed that the catalyst can be placed in-duct and a separate reactor is not necessary. It should be mentioned that these costs are site specific and the results may vary from unit to unit.

Oxygen-Enhanced Combustion

Praxair, Inc. and its partners have developed a novel oxygen-based technology that can reduce NOx emissions from PC-fired boilers, while improving combustion characteristics such as loss-on-ignition (LOI). This novel technology replaces a small fraction of the combustion air with oxygen as shown in Figure 10. In order to support this concept, Praxair is also developing an oxygen transport membrane (OTM) process that uses pressurized ceramic membranes for separation of oxygen from air.

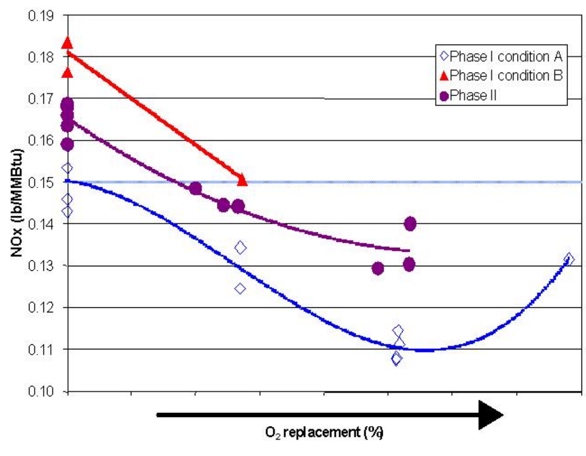
Testing was conducted using ALSTOM Power's pilot-scale combustion facility. The experiments were designed to demonstrate that the concept of oxygen-enhanced low NOx combustion could meet the emissions target of 0.15 lb/MMBtu with minimal impact on CO emissions and furnace performance. The pilot-scale test facility is a water-cooled tunnel furnace designed to test burners up to 50 MMBtu/hr firing rate with time-temperature histories similar to full-scale PC-fired boilers. The test facility has two locations for separated over-fire air (SOFA) injection. An ALSTOM commercially-available wall-fired LNB was used in these experiments. The burner was designed for a firing rate of 26 MMBtu/hr and was typically fired at 24 MMBtu/hr for these tests.

Figure 10 - Praxair Oxygen-Enhanced Combustion



Illinois No. 6 bituminous coal was used during the initial Phase I-A tests. These tests were performed to shake down the furnace and to obtain baseline NOx data for this facility, burner, and coal combination. A series of experiments were then performed to evaluate the effect of oxygen addition on NOx emissions.

Figure 11 - Praxair Oxygen-Enhanced Combustion Test Results



An eastern bituminous coal, Mingo Logan, was then used in Phase I-B to evaluate both the effect of a lower volatile coal and the effect of oxygen addition method. During Phase II, selected experiments were repeated with the Illinois No. 6 coal. As shown in Figure 11, data from the Illinois No. 6 experiments show that even when the baseline (air only) emissions are very low, oxygen addition can drive the NOx emissions even lower. The overall data further show that the reductions are relatively independent of the initial NOx concentration. Data from the Mingo Logan experiments show that the concept works even with the lower volatile coal, and that the technique in injecting the oxygen has a large impact on NOx reduction.

In addition to the reduction in NOx, benefits can be achieved in the areas of reduced LOI and opacity, increased boiler efficiency, and reduced fan limits. Subsequent testing at two utility boilers, City Utilities' James River Unit 3 and Northeast Utilities' Mt. Tom Generating Station, has demonstrated these benefits of the technology while decreasing NOx emissions. Preliminary economic analysis indicates that cost savings of 40-50% can be realized when compared to SCR.

New DOE/NETL IEP NOx R&D Projects

As the NOx control technologies currently under development move toward demonstration and commercialization, the NOx program targets are reevaluated and redefined. In light of the proposed EPA CAIR rule and Congressional multi-pollutant legislation, DOE/NETL issued a solicitation in early 2004 to target even lower NOx emissions for existing boilers. As a result, five new NOx R&D projects were announced in November 2004 and will be completed over the next three years. The challenge will be to develop cost-effective NOx control technologies for the smaller, older, less efficient facilities that are not easy candidates for the current state-of-the-art SCR controls because of space constraints and the reluctance of owners to invest large capital expenditures in the aging plants. These facilities, with a generating capacity of 300 MW or less, comprise 66% of the boilers in the U.S. and have an average age of 38 years as compared to the remainder of the fleet with an average age of 24 years. The benefits of this program will be realized by both the existing fleet and new capacity as the targeted NOx control technologies are adopted. The following is a brief description of the new projects:

Enhanced Combustion Low NOx Pulverized Coal Burner - ALSTOM will develop an enhanced combustion, low NOx pulverized coal burner. The objective is to optimize combustion via control of near-burner time, temperature, turbulence, and stoichiometry. Candidate low NOx burner components for testing include up to four (4) enhanced ignition coal nozzle tips and internal and external air and fuel separators. These components will be integrated into ALSTOM's latest generation of the TFS 2000 firing system that includes enhancements developed in the recently completed "Low NOx Firing System for Tangential Boilers" project discussed previously. The enhanced low NOx burner is designed to achieve an emission rate of less than 0.15 lb/MMBtu and have minimal balance-of-plant impacts while burning a high-volatile bituminous coal. The project includes CFD modeling and large pilot-scale testing to provide the information to design a full-scale version of the enhanced low-NOx burner.

Advanced In-Furnace NOx Control for Wall- and Cyclone-Fired Boilers - Babcock & Wilcox will develop and demonstrate an advanced NOx control technology capable of achieving an emission rate of 0.10 lb/MMBtu while burning high-volatile bituminous coal. The NOx control technology is based on a "layered" strategy that combines deep air staging, continuous corrosion monitoring, advanced combustion-control enhancements, and a proprietary combustion technique using oxygen injection. Wall- and cyclone-fired pilot-scale testing will be used to evaluate the oxygen injection process. Results from the pilot-scale testing will be used to design and prepare a cost estimate for a full-scale version of the technology.

In Situ Device for Real-Time Catalyst Deactivation Measurements in Full-Scale SCR Systems - Fossil Energy Research Corporation (FERCo) will demonstrate the use of an in situ catalyst deactivation measurement device to reduce SCR operating costs through optimized catalyst management. FERCo will develop an *in situ* device to collect real-time SCR performance data by continuously measuring catalyst activity. As the data is collected, it will be analyzed by an existing catalyst management software program. The results of this analysis will provide information on boiler operating conditions that negatively impacts catalyst activity and a means to optimize the catalyst replacement schedule. Testing will be conducted at a Southern Company coal-fired power plant equipped with a SCR.

Cyclone Boiler Field Testing of Advanced Layered NOx Control Technology - Reaction Engineering International (REI) will conduct CFD modeling and full-scale field testing to evaluate a technology known as Advanced Layered Technology Application (ALTA) to achieve a NOx emission rate of near 0.10 lb/MMBtu in a cyclone boiler. ALTA combines deep staging from overfire air, Rich Reagent Injection (RRI), and a novel SNCR approach. Testing will also evaluate potential balance-of-plant impacts such as the amount of unburned carbon in the ash, slag tapping, waterwall corrosion, ammonia slip, and heat distribution. Testing will be conducted at AmerenUE's 500 MW Sioux Station. This project is a follow-up to the recently completed "Rich Reagent Injection for Cyclone Burners" project discussed previously. For this new project, the cyclone burner barrel stoichiometry will be further reduced from 0.95 to 0.85.

Pilot-Scale Demonstration of Advanced Layered NOx Control Technology for Coal-Fired Boilers - REI will develop and verify the performance of the ALTA NOx control technology for wall-fired boiler applications to achieve an emission rate of less than 0.15 lb/MMBtu. The burner will be designed for complete near-burner combustion, rather than traditional staged-combustion. The objective of the burner design is to achieve homogeneity of the combustion products in the boiler. Not only does this create ideal conditions for combustion-related control of NOx, it also results in a stoichiometry and temperature distribution above the burners that is ideal for the chemistry involved in Rich Reagent Injection. REI will conduct CFD modeling and pilot-scale testing to optimize the near-burner combustion system and reagent injection.

Market Potential for Advanced NOx Combustion Control Technologies

As mentioned previously, the specific performance target of the IEP's NOx R&D activity is to develop combustion control technologies for existing plants with a NOx emission rate of 0.15 lb/MMBtu by 2006 and 0.10 lb/MMBtu by 2010, while achieving a levelized cost savings of at least 25% compared to SCR control technology. The technologies currently under development, such as the ultra-low NOx combustion systems, oxygen-enhanced combustion, and rich reagent injection described above, are close to meeting the DOE/NETL R&D goals for 2006 and further development is likely to achieve those goals as well as the R&D goals for 2010.

Coal-fired power plant operators have a number of options available for compliance with market-based allowance cap-and-trade regulatory programs such as the existing NOx SIP call, the proposed Clean Air Interstate Rule, and the proposed Clear Skies Act. Under a cap-and-trade program, power plants have the option to either install additional NOx controls to reduce their emissions to the level of their NOx allowance allocation or not install controls and instead acquire additional NOx allowances from other plants that elect to over comply. Likewise, plants can install additional controls that don't reduce emissions to the level of their NOx allowance allocation and acquire the allowance shortfall from other plants. As a result, low cost NOx control technologies that do not achieve the target emission rates can still have a prominent role as a compliance strategy. For an individual power plant, the decision on whether to install controls or purchase allowances is based primarily on the incremental cost of the available alternative NOx control technologies, measured as cost per ton of NOx reduction, compared to the market price of NOx allowances.

The projected cost and performance for the advanced NOx combustion control technologies were used by DOE/NETL to estimate NOx control costs measured on a levelized cost per ton of NOx removed basis. The NOx control cost for these technologies tends to fall between traditional LNB and SCR. A preliminary evaluation of alternative compliance options to meet the NOx reduction requirements of the proposed Clear Skies Act was conducted for the entire existing 300 GW fleet of U.S. coal-fired power plants. This assessment showed a U.S. market potential for approximately 150 GW of advanced NOx combustion control technologies that could cost-effectively replace 75 GW of new SCR controls resulting in levelized annual cost savings of over $700 million per year.

SUMMARY

While our knowledge of the formation and capture of NOx from coal-fired power plants has greatly advanced over the past decade and a half, many challenges remain. As the Nation moves toward ever-tightening regulation of NOx emissions from the electric power sector, it is critical that research continues to address these challenges. In response, DOE/NETL is continuing to partner with industry and other key stakeholders in carrying out a comprehensive advanced NOx control technology R&D program. This effort is focused on (1) enhancing the NOx capture performance of existing technologies and (2) developing advanced control concepts to achieve high levels of NOx removal at costs considerably lower than current SCR technology. The cost and performance of the advanced NOx combustion control technologies currently being developed under the IEP program are close to meeting the DOE/NETL R&D goals for 2006 and further development is likely to achieve those goals, as well as the R&D goals for 2010. A preliminary DOE/NETL assessment shows a U.S. market potential for approximately 150 GW of advanced NOx combustion control technologies that could cost-effectively replace 75 GW of new SCR controls that would be required for compliance with the proposed Clear Skies Act. DOE/NETL is committed to continue its comprehensive NOx control technology research program to improve performance and reduce costs to enable the existing fleet of coal-fired power plants to reliably and cost effectively comply with future NOx control regulations, while also providing the scientific and technical knowledge needed to help craft sound regulatory policy.

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