DOE/FE-0429

SOUTHERN COMPANY SERVICES, INC.

DEMONSTRATION OF ADVANCED COMBUSTION NO_x CONTROL TECHNIQUES FOR A WALL-FIRED BOILER

PROJECT PERFORMANCE SUMMARY
CLEAN COAL TECHNOLOGY DEMONSTRATION PROGRAM

JANUARY 2001

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ENVIRONMENTAL CONTROL DEVICES

Demonstration of Advanced Combustion NO_x Control Techniques for a Wall-Fired Boiler

Southern Company Services, Inc. demonstration of wall-fired boiler combustion modification technologies and advanced controls for NO_x control:

- **Pioneered introduction of the technology into the United States;**
- **Provided real-time input to regulation development;**
- **Embodied tests necessary to identify key control parameters and understand the effects on the plant as well as environmental and economic performance; and**
- **Resulted in significant market penetration of the demonstrated technologies.**

Overview

The project represents a landmark assessment of the potential of low-NO_x burners, advanced overfire air, and neural-network control systems to reduce NO_x emissions within the bounds of acceptable dry-bottom, wall-fired boiler performance. Such boilers were targeted under the Clean Air Act Amendments of 1990 (CAAA). Testing provided valuable input to the Environmental Protection Agency ruling issued in March 1994, which set NO_x emission limits for "Group 1" wall-fired boilers at 0.5 lb/10^6 Btu to be met by January 1996. The resultant comprehensive database served to assist utilities in effectively implementing CAAA compliance.

The project is part of the U.S. Department of Energy's Clean Coal Technology Demonstration Program established to address energy and environmental concerns related to coal use. Five nationally competed solicitations sought cost-shared partnerships with industry to accelerate commercialization of the most advanced coal-based power generation and pollution control technologies. The Program, valued at over $5 billion, has leveraged federal funding twofold through the resultant partnerships encompassing utilities, technology developers, state governments, and research organizations. This project was one of 16 selected in May 1988 from 55 proposals submitted in response to the Program's second solicitation.

Southern Company Services, Inc. (SCS) conducted a comprehensive evaluation of the effects of Foster Wheeler Energy Corporation's (FWEC) advanced overfire air (AOFA), low-NO_x burners (LNB), and LNB/AOFA on wall-fired boiler NO_x emissions and other combustion parameters. SCS also evaluated the effectiveness of an advanced on-line optimization system, the Generic NO_x Control Intelligent System (GNOCIS).

Over a six-year period, SCS carried out testing at Georgia Power Company's 500-MWe Plant Hammond Unit 4 in Coosa, Georgia. Tests proceeded in a logical sequence using rigorous statistical analyses to establish the incremental performance impacts of each technology evaluated.

Tests showed NO_x reductions for AOFA, LNB, and LNB/AOFA of 24, 48, and 68 percent, respectively. GNOCIS demonstrated an additional 10–15 percent NO_x reduction capability while improving boiler heat rate as well.

This project was extended in 1999 to apply GNOCIS to other pieces of plant equipment, which may increase its commercial potential. Those results will be released under separate documentation. This report is issued now because of the extent of valuable information obtained to date.

THE PROJECT

The original project objectives were to assess in a sequential manner the effects of AOFA, LNB alone, and LNB with AOFA on NO_x emissions, other associated emissions, and impacts on boiler and auxiliary system performance. Chemical emissions testing and carbon-in-ash-monitor evaluation were subsequently added. Moreover, testing of the combustion modification methods led to replacement of the existing pneumatic controls with a digital control system (DCS) and incorporation of a GNOCIS on-line, neural-network optimization system. Both the DCS and GNOCIS underwent evaluation for impacts on NO_x emissions and boiler/auxiliary system performance, with emphasis on GNOCIS.

The unit chosen for testing was Georgia Power Company's Plant Hammond Unit 4, a 500-MWe Foster Wheeler opposed wall-fired boiler. The 1970 vintage unit uses a matrix of twelve burners (4 wide x 3 high) on the front and rear walls with each of six mills supplying coal to the four burners of each elevation. The design steam conditions are 2,400 psig pressure and 1,000 °F superheat and 1,000 °F reheat temperatures. The Unit 4 balanced-draft boiler has a relatively high heat release rate, 425,000 Btu/hr-ft^2 compared to an average 250,000 Btu/hr-ft^2 for this type boiler, and has a relatively short distance of 55 feet between the top burner elevation and furnace outlet.

The coal used is a medium to low volatility eastern bituminous coal having a reactivity similar to Illinois Bituminous B-type coals and a sulfur content of 1.7%.

The overall project test schedule was as follows:

Phase 1-Baseline	11/89–3/90
Phase 2-AOFA	8/90–3/91
Phase 3A-LNB	7/91–1/92
Chemical Emissions	5/93
Phase 3B-LNB/AOFA	5/93–8/93
Phase 4A-DCS	8/94–11/94
Phase 4B-GNOCIS	2/96–5/96

Each phase included: (1) short-term testing to establish emissions trends for key parameter variations (diagnostic tests) and to characterize emissions and air/fuel inputs at expected boiler set positions (performance tests); (2) long-term testing to continuously measure operating parameters, emissions, and boiler performance under unit load dispatch; and (3) short-term verification testing to determine whether significant changes in NO_x emissions had occurred during long-term testing.

Project Sponsor
Southern Company Services, Inc. (SCS)

Additional Team Members
Southern Company—cofunder
Electric Power Research Institute (EPRI)—cofunder
U.K. Department of Trade and Industry—cofunder
PowerGen—cofunder
Georgia Power Company—host
Foster Wheeler Energy Corporation (FWEC)—technology supplier
EnTEC—technology supplier
Radian—technology supplier
Tennessee Technological University—technology supplier

Location
Coosa, Floyd County, GA (Georgia Power Company's Plant Hammond, Unit 4)

Technology
FWEC's low-NO_x burner (LNB) with advanced overfire air (AOFA) and EPRI's Generic NO_x Control Intelligent System (GNOCIS) computer software.

Plant Capacity
500 MWe

Coal
Eastern medium to low volatile bituminous, 1.4% nitrogen, 1.7% sulfur

Demonstration Duration
August 1990–May 1996

Project Funding

Total Project Cost	$15,853,900	100%
DOE	6,553,526	41%
Participant	9,300,374	59%

FWEC LNB installation

THE TECHNOLOGY

West wall of boiler with LNBs and AOFA installed

Hammond Unit 4 uses a partial division wall superheater, which splits the gas flow along two paths (east and west) extending through the economizer and air heater circuits. At the time of testing, it incorporated a cold side ESP with a specific collection area (SCA) of 161 ft^2. The key features of Hammond Unit 4 impacting NO_x reduction and applicability to other wall-fired boilers are: the high heat release rate, the short distance between the top burners and the furnace outlet, and the medium-to-low reactivity of the eastern bituminous coal.

The AOFA system reduces NO_x production by completing combustion away from the high temperature burner flame zone and enabling operation of the burners below the air/fuel ratio theoretically required for complete combustion (stoichiometry of 1.0). Operation of the burners below a stoichiometry of 1.0, or deep staging, maintains a deficiency of oxygen until the bulk of the combustibles fall below 2,800 °F (the peak NO_x producing temperature). The AOFA system enables the delayed combustion and sub-stoichiometric burner operation by introducing 10–20 percent of the secondary air through separate ductwork at high velocity above the burner flame zone and using boundary air ports to protect boiler walls from corroding.

In the Hammond application, the AOFA diverts air from the secondary air ducts and introduces it through four air ports, each on the front and rear furnace walls 9 feet and 2 inches above the top burner. Figure 1 (next page) shows the flow control mechanisms. A greater distance between the top of the burner and AOFA ports is desirable, but not possible with the Hammond boiler configuration.

LNBs stage combustion without additional ductwork and furnace ports. This staging is accomplished by regulating the initial air/fuel mixture and velocity, reducing turbulence to create a fuel-rich core, and sustaining combustion at severely sub-stoichiometric air/fuel ratios. The objective is to introduce excess air after the remaining combustibles drop below 2,800 °F.

The FWEC Controlled Flow/Split Flame (CFSF) burner, shown in Figure 2, divides secondary air between inner and outer flow cylinders and splits the coal/primary air mixture into four concentrated streams. The inner secondary air register apportions the flow between inner and outer paths and controls the degree of additional coal/air mixture swirl. An axially movable inner sleeve tip provides a means for varying primary air velocity while maintaining constant flow. The outer flow cylinder injects air axially into the furnace to provide excess air for complete combustion. The segregation of coal/air mixture into four streams minimizes coal and air mixing, which assists combustion staging.

Combining LNB with AOFA, which was evaluated under this project, enables deeper combustion staging in the boiler than either LNB or AOFA alone.

GNOCIS is a software enhancement package for digital control systems (DCS) targeted at reducing NO_x, mitigating adverse impacts of NO_x controls, and improving boiler efficiency. GNOCIS utilizes a neural-network model of the combustion characteristics of the boiler that reflects both short- and long-term trends in boiler characteristics. A constrained nonlinear optimizing procedure is applied to identify the best set points for the plant. These recommended set points can be implemented automatically without operator intervention (closed-loop), or at the operator's discretion (open-loop). The software is designed for continuous on-line use.

FIGURE 1. FWEC AOFA FLOW CONTROLS

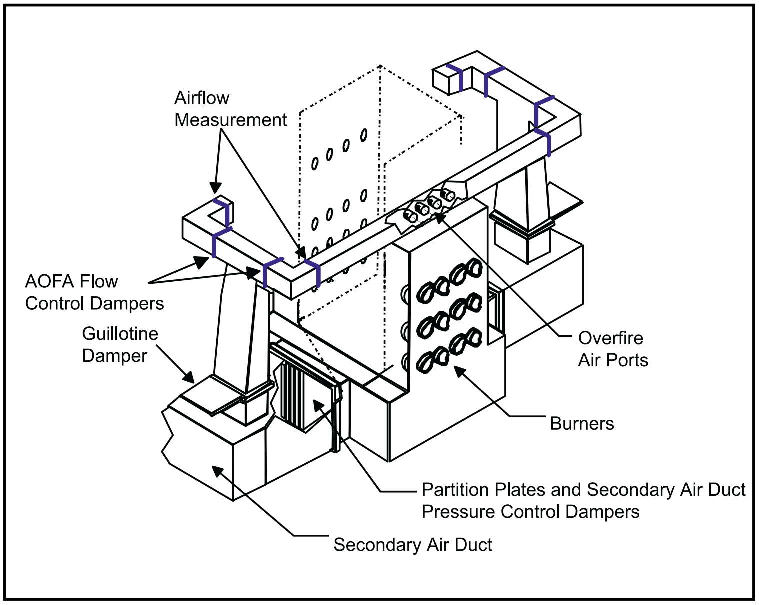
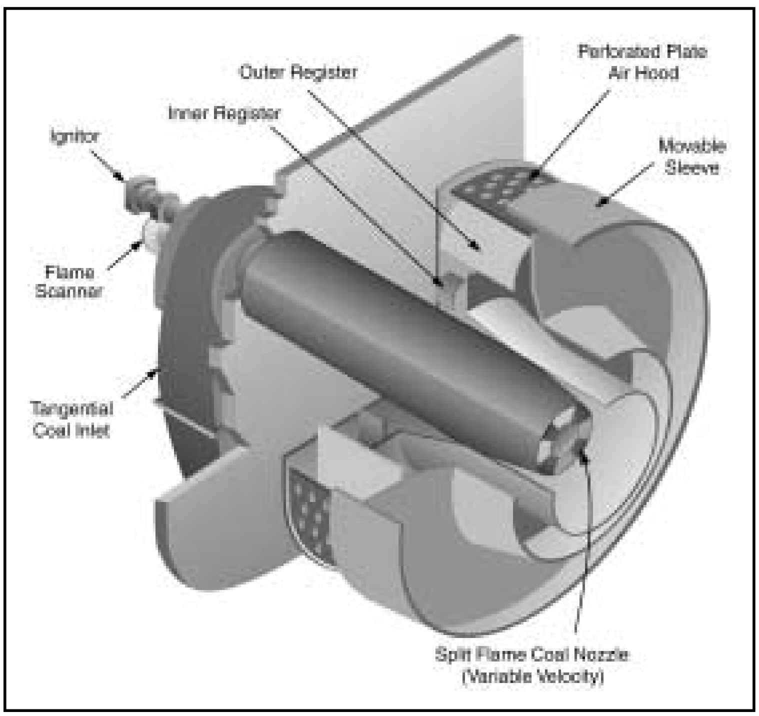


FIGURE 2. FWEC CONTROLLED FLOW/SPLIT FLAME BURNER



DEMONSTRATION RESULTS

SUMMARY

- Long-term NO_x emissions testing at full load showed the following emission rates and reductions from baseline:

Baseline:	1.24 lb/10^6 Btu/na
AOFA:	0.94 lb/10^6 Btu/24%
LNB:	0.65 lb/10^6 Btu/48%
LNB/AOFA:	0.40 lb/10^6 Btu/68%

- AOFA only contributed an estimated incremental NO_x reduction of 17% beyond the LNB emission level, with the balance attributable to operational changes.
- GNOCIS reduced NO_x emissions an additional 10–15% while improving unit heat rate and increasing boiler efficiency nominally 0.5 percentage points.
- Chemical emissions testing showed no evidence of organic compound emissions resulting from the combustion modifications installed for NO_x emission reduction. Trace element control, except for mercury and selenium, proved to be a function of electrostatic precipitator (ESP) performance.
- The low-NO_x combustion technologies increased fly ash loss-on-ignition (LOI) from a baseline of 7% to 8–10% despite reductions in coal particle size—increased coal fineness—as testing progressed.
- LNB and LNB/AOFA substantially reduced boiler slagging, but increased backpass and air heater fouling and significantly increased the dust loading and gas flow rate to the ESP, adversely impacting performance.
- The low-NO_x combustion technologies increased combustion airflow, excess air requirements, and the furnace exit gas temperature, reducing the unit heat rate by more than the heat rate gain from some slight improvement in superheat and reheat steam temperatures.
- The estimated capital cost for a 500-MWe commercial wall-fired installation is $8.80/kW for AOFA alone, $10.00/kW for LNB alone, $18.80/kW for LNB/AOFA, and $0.50/kW for GNOCIS.
- Cost-effectiveness values for AOFA, LNB, LNB/AOFA, and GNOCIS are $134, $54, $79, and -$261 per ton of NO_x removed, respectively (negative number indicates a net saving).

Operational/Environmental Performance

Combustion Modification

Table 1 summarizes the impact of the sequential combustion modification to the boiler on operational/environmental performance at full load.

Each test phase began with short-term testing under steady-state conditions to establish emission trends as a function of key parameters and to characterize air/fuel inputs and emissions at expected boiler set points.

For all phases of testing, average air-to-fuel ratios increased steadily from 2.2–2.5 at full load to 3.5–3.7 at 300 MWe to maintain a coal/air mill outlet temperature of 170 °F and sufficient velocity to prevent settling out of the coal (coal layout).

Resistivity of the particulate matter remained low throughout the test series (low- to mid-1010 ohm-cm) and the mass mean diameter of the particles remained approximately the same, measuring 18 microns during baseline testing and 16.7 during LNB/AOFA testing.

Phase 1–Baseline Testing

Baseline testing proceeded in an "as found" boiler condition, with no tuning of the existing FWEC Intervane burners.

Primary air (PA) represented 25 percent and secondary air (SA) 75 percent of the combustion air over the load range of 480 MWe (full load) to 400 MWe, changing to 30 percent PA and 70 percent SA at 300 MWe. The combustion airflow was 3.3 x 10^6 lb/hr at full load with a 2.6 percent excess oxygen level.

The FWEC planetary roller table type pulverizer mills produced an average coal fineness consistently below the design value of 70 percent through 200 mesh (66 percent). This reduced coal fineness is known to adversely impact combustion, resulting in loss-on-ignition (LOI) and unburned carbon in the fly ash.

Short-term testing measured full load NO_x emissions of 1.44 lb/10^6 Btu with an LOI of 5 percent. But the excess oxygen was deemed unrepresentatively high. NO_x emissions and LOI corrected to an appropriate excess oxygen level at full load were 1.2 lb/10^6 Btu and 7.1 percent, respectively. NO_x emissions increased only slightly over the range of 200 MWe to 480 MWe from around 1.0 lb/10^6 Btu to 1.24 lb/10^6 Btu during long-term testing. Long-term CO emissions were generally below 100 ppm over the load range.

Moderate to high furnace slagging occurred during the baseline tests and the ESP performance was deemed marginal. The economizer exit gas temperature (EEGT) averaged 725 °F at full load versus a design value of 710 °F. The secondary air heater exit gas temperature (AHEGT) averaged 300 °F at full load versus a design value of 282 °F. Superheater and reheat outlet temperatures were consistently below the design value of 1,000 °F, with the reheat temperature particularly low in the 250–420 MWe load range.

Phase 2–AOFA Testing

Following a four-week outage to install the AOFA, short-term testing commenced. Variables included AOFA damper position, load, mill pattern, and excess air. Tests indicated the optimum position for the damper to be 50 percent open. Beyond the AOFA installation modification, the boiler remained in an "as found" condition, with no tuning of the burners.

At the 50 percent AOFA damper position, air distribution was 20–25 percent AOFA, 20–30 percent primary air, and 50 percent secondary air over the load range of 300–480 MWe. The combustion airflow increased 16 percent from baseline to 3.7 x 10^6 lb/hr at full load.

Coal fineness averaged 67 percent through 200 mesh. The solid mass loading at the ESP increased only slightly from baseline, but gas flow measured at the ESP increased significantly. ESP performance remained marginal. LOI at full load and 50 percent open AOFA was 10.1 percent and was the major cause for a drop in combustion efficiency of nearly a percentage point.

Long-term NO_x emissions were not dependent on load, averaging 0.90 lb/10^6 Btu over the load range. The AOFA damper was essentially closed at loads below 300 MWe. Tests at full load established NO_x emissions at 0.94 lb/10^6 Btu, or a 24 percent reduction from baseline. CO remained low during the long-term testing, averaging 15 ppm over the load range.

Furnace slagging was slightly reduced. EEGT remained approximately the same as baseline and AHEGT increased to 305 °F at full load. Superheater outlet steam temperatures improved primarily at lower loads, and reheat outlet steam temperatures improved at upper loads.

TABLE 1. COMBUSTION MODIFICATION FULL LOAD PERFORMANCE IMPACTS

	Baseline	AOFA	LNB	LNB/AOFA
Excess O_2 (avg. %)	2.6	2.6	4.1	3.8
Comb. Airflow (10^6 lb/hr)	3.3	3.7	3.9	4.2
Airflow Distribution (PA/SA/OFA %)	25/75/na	20-30/50/20-25	20-25/75-80/0	21/58/21
NO_x (lb/10^6 Btu/% reduction)	1.24/na	0.94/24	0.65/48	0.40/68
LOI (avg. %/% increase from baseline)	7.1/na	10.1/42	8.2/16	8.4/18
CO (ppm)	~ 100	15	10	~ 100
Coal Fineness (% passing 200 mesh)	66	67	67	74
ESP Mass Loading (gr/dscf)	2.5	2.7	3.3	3.0
ESP Gas Flow (acfm)	1.2	2.2	2.2	2.1
Mean Particle Size (microns)	18	~ 18	~ 18	16.7
EEGT (East/West °F)	725/725	670/740	740/750	750/740
AHEGT (°F)	300	305	300	325
Steam Temperature	Base	Superheat/Reheat Improved	Superheat/Reheat Improved	Superheat/Reheat Improved
Slagging	Moderate to High	Slightly Reduced	Substantially Reduced	Substantially Reduced
Boiler Efficiency (%)	90.0	89.2	89.3	88.7
ESP Performance	Marginal	Marginal	Added NH_3 Injection	Boiler Derated to 450 MWe
Coal Nitrogen (%)/Volatile Matter (%)	1.42/33.50	1.43/33.30	1.39/32.56	1.39/33.66

Phase 3A–LNB Testing

Following a seven-week outage to install the LNBs, optimization testing commenced to tune the burners prior to short-term testing. During the outage, two of the six original pulverizers were replaced with Babcock & Wilcox MPS 75 pulverizer mills. Phase 3A-LNB testing was conducted with the AOFA control dampers open only enough to allow cooling air to the AOFA ports.

Overall air distribution measurements showed 75–80 percent going to the secondary air path over the load range of 300–480 MWe. The combustion airflow increased 21 percent from baseline to 3.9 x 10^6 lb/hr at full load and the excess oxygen requirement increased to 4.1 percent.

Coal fineness averaged 67 percent through 200 mesh. The solid mass loading at the ESP increased significantly and the gas flow remained at the high rate measured at the ESP for the AOFA tests. The increased dust loading severely impacted ESP performance, requiring ammonia injection to re-establish load. LOI at full load was 8.2 percent.

Under long-term LNB testing, NO_x emissions over the load range exhibited a "U" shaped curve, increasing from lows at mid-loads (250–310 MWe) to highs at both full and lowest loads. NO_x emissions at full load averaged 0.65 lb/10^6 Btu, or a 48 percent reduction from baseline.

Furnace slagging was substantially reduced while backpass fouling increased somewhat. EEGT increased significantly, while AHEGT averaged 300 °F. Superheater outlet steam temperatures improved primarily at lower loads, and reheat outlet steam temperatures improved at upper loads.

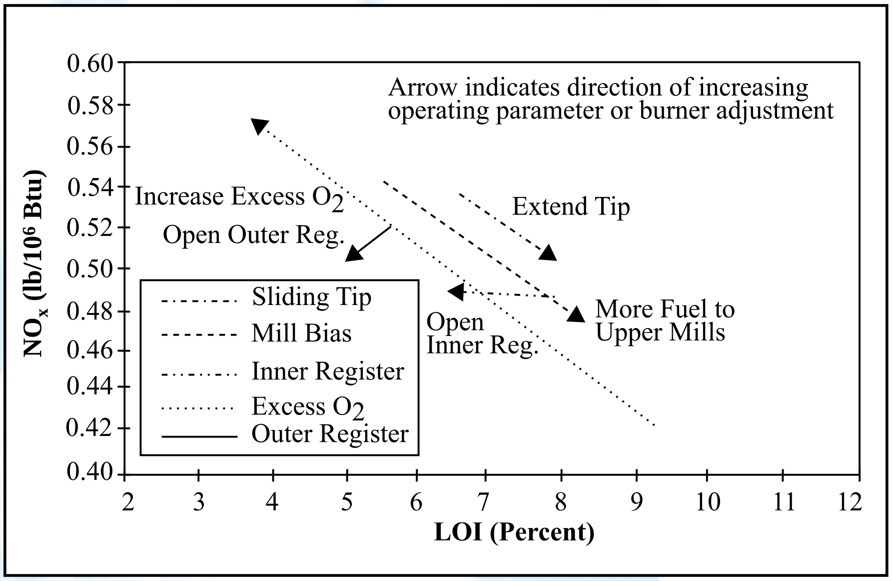
Special LOI Tests

Special LOI tests followed an outage during which two more mills were replaced with Babcock &Wilcox MPS 75 pulverizer mills. The intent of the special investigation was to determine the effects of various burner settings and mill operation on the carbon/LOI content of the fly ash leaving the boiler.

TABLE 2. LNB/NO_x VS. LOI/PARAMETERS TESTED

Parameter	Nominal Value	Range Tested	
		Low	High
Excess Air	4%	2.8%	5.0%
Inner Register	~15%	Nominal	Nominal + 40%
Outer Register	~60%	-20% of nominal	+20% of nominal
Sliding Tip	+4 inches	+2 inches	+4 inches
Mill Bias	No bias	Upper Mills +10%	Upper Mills -10%
		Lower Mills -10%	Lower Mills +10%

FIGURE 3. PARAMETER IMPACTS ON NO_x AND LOI



Prior to the actual LOI testing, the four new mills provided excellent fineness, all better than 70 percent passing 200 mesh with less than 0.23 percent larger than 50 mesh. But coal flow continued to vary significantly from pipe to pipe for all mills. Air-to-fuel ratios ranged from 2.0 to 2.3 for all but one older mill at the 450-MWe test condition.

Table 2 shows the parameters and range of variation evaluated in the LOI testing. The test series was conducted at a nominal load level of 450 MWe, with all mills in service. FWEC established the safe ranges of operation to be tested. AOFA remained in the nominal closed position (50 lb/hr) for all but two tests.

Figure 3 summarizes the results of the parametric tests. Results show that: (1) excess O_2 has a considerable effect on both LOI and NO_x; (2) inner and outer register positions have minimal effect on either LOI or NO_x within the range of adjustments made; (3) mill bias affects LOI substantially and NO_x only moderately; and (4) burner tip position has a slight effect on both LOI and NO_x. Except for the outer register position, all adjustments to reduce NO_x are at the expense of increased LOI, and the outer register effect is deemed an artifact of process noise. Limited testing with AOFA suggested NO_x reduction benefits gained by opening AOFA ports were lost by the increased excess O_2 level needed to maintain acceptable CO levels.

Phase 3B–LNB/AOFA Testing

LNB/AOFA testing began by first tuning the burners for integrated LNB/AOFA operation. For this test phase, an AOFA flow measurement system was installed to enable AOFA air flow to be indexed to load rather than to damper position.

Mill-to-mill coal flows varied considerably and pipe-to-pipe variations in coal mass flow rates measured as high as three to one. Air-to-fuel ratios ranged widely as well. These variations strongly indicated the existence of non-uniform flame stoichiometry. Moreover, the unequal distribution produced a mill bias, with the top mills, middle mills, and bottom mills contributing 38, 33, and 29 percent of the coal flow, respectively. As determined in the previous testing, this mill bias aids NO_x reduction.

Overall air distribution measurements at full load showed 58 percent going to the secondary air path, and 21 percent to both the primary and AOFA paths. AOFA decreased to 10 percent at 300 MWe and was in a closed position below 300 MWe. The combustion airflow increased 30 percent from baseline to 4.2 x 10^6 lb/hr at full load, with an excess oxygen requirement of 3.8 percent

Coal fineness averaged 74 percent through 200 mesh. The solid mass loading at the ESP remained high as did gas flow measured at the ESP. The increased dust loading severely impacted ESP performance, requiring derating of the boiler to 450 MWe even with ammonia injection. LOI at full load was 8.4 percent.

Under long-term LNB testing, NO_x emissions over the load range of 200–480 MWe were essentially constant at 0.40 lb/10^6 Btu, with a slight increase in emissions below 200 MWe. The 0.40 lb/10^6 Btu emission rate represents a 68 percent reduction from baseline. Data suggests that the incremental NO_x reduction due to AOFA was only 17 percent, with additional reductions resulting from other operational changes.

Furnace slagging was substantially reduced while backpass fouling increased somewhat. EEGT remained high and AHEGT jumped to 325 °F. Superheater outlet steam temperatures improved primarily at lower loads and reheat outlet steam temperatures improved at upper loads.

Summary Phases 1–3B

Figure 4 shows the long-term NO_x emissions over the load range for each phase of testing.

Combustion modifications resulted in both beneficial and adverse impacts on unit performance. Benefits included reduced NO_x emission rates, significantly reduced waterwall slagging with LNB and LNB/AOFA, and improved superheat and reheat steam temperatures. Adverse impacts included increased excess oxygen requirements, LOI, backpass fouling and ESP dust loading and gas flow rate.

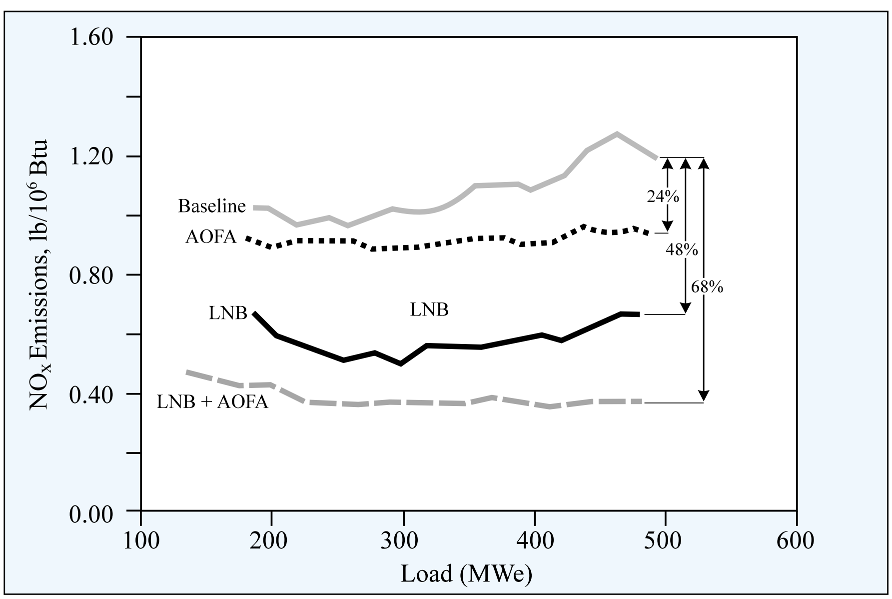
Increased excess oxygen was needed primarily for good LNB flame stability and maintaining CO emissions below 100 ppm. Also, the FWEC CF/SF burners required higher air velocities than the original “Intervane” burners to prevent coal layout, coking, and subsequent overheating. The increased oxygen requirement reduces boiler efficiency and increases the unit heat rate. The excess oxygen operating range is also reduced, which reduces operating flexibility.

Although the LOI increase was moderate, it occurred with substantial improvement in coal fineness.

The benefits of reduced waterwall slagging far outweighed the operation and maintenance downsides of increased sootblowing and more frequent cleaning of backpass components.

While superheater and reheat steam temperatures improved, these improvements failed to balance out factors adversely impacting boiler efficiency and unit heat rate—increased LOI, EEGT, AHEGT, and excess oxygen.

Figure 4. Long-term NO_x Emissions for Phases 1–3B



Chemical Emissions Testing

Chemical emissions testing examined the fate of trace elements in the coal and whether combustion modification increased emissions of organic compounds for both the AOFA and LNB/AOFA operating conditions. Trace elements measured included arsenic, barium, beryllium, cadmium, chlorine (as chloride), chromium, cobalt, copper, fluorine (as fluoride), lead, manganese, mercury, molybdenum, nickel, phosphorus, selenium, and vanadium. Organic compounds included benzene, toluene, formaldehyde, and polycyclic organic matter, which encompasses polynuclear aromatic hydrocarbons (PAH).

Trace element emissions are a direct function of the effectiveness of the particulate matter collection system except for those elements converting to a vapor phase. In both the AOFA and LNB/AOFA operating configurations, the boiler and ESP were effective in capturing most of the solid state trace elements, primarily in the ESP as fly ash with a small portion removed as boiler bottom ash. Only a small portion of the mercury and selenium, which adopt a vapor phase, and none of the vapor phase chlorine (as hydrochloric acid) and fluorine (as hydrofluoric acid) were captured. During the LNB/AOFA tests, ESP performance was superior to that experienced during the AOFA tests. As a result, LNB/AOFA trace element emissions were lower than those measured during the AOFA tests.

FWEC LNB showing split flame channels

For both the AOFA and LNB/AOFA tests, measured concentrations of benzene, toluene, and formaldehyde were so low as to suggest their origin in the use of these compounds in field test blanks. During AOFA testing, no PAHs were detected. Using higher resolution instrumentation, PAHs were detected during LNB/AOFA tests, but at concentrations one to four orders of magnitude lower than the detection limits.

Advanced Control System

Carbon-In-Ash Monitors (CIAM)

The fly ash unburned carbon level is an important consideration for combustion efficiency and fly ash marketing, particularly with the application of low-NO_x burners. CIAMs offer the potential for determining marketability of fly ash and for incorporation in combustion optimization. While offered commercially, there was little U.S. experience with CIAMs. As a result, four commercial CIAMs were evaluated during the demonstration. Detailed information on the particular devices and findings are provided in a separate report listed in the bibliography. In general, it was observed that CIAMs are: (1) useful for determining LOI trends but not absolute LOI levels; (2) useful for on-line combustion optimization if used for inputting trends; (3) less reliable and robust than typical power plant instrumentation; (4) costly from a capital and maintenance standpoint; and (5) lack an adequate parts and service infrastructure.

Phase 4A–Digital Control System (DCS)

SCS installed a Foxboro I/A DCS at Hammond, replacing the pneumatic control system. The installation occurred during a nine-month outage to also replace the marginal ESP and the last two original pulverizer mills (with B&W MPS 75s), and to perform some turbine upgrades.

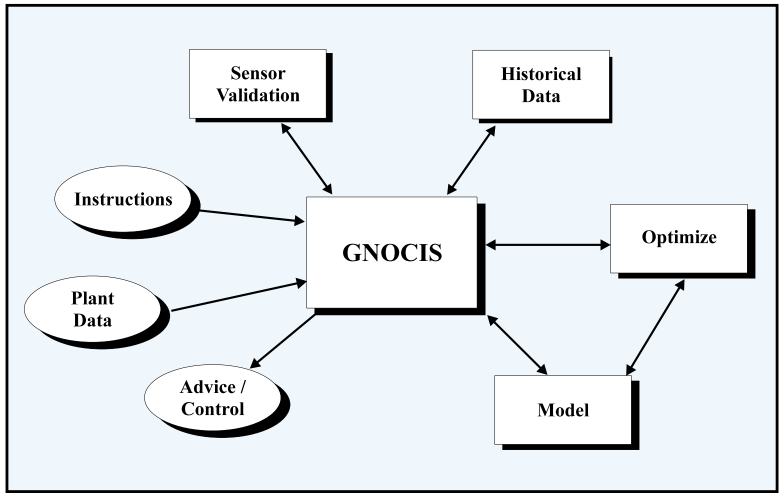
After DCS installation, the boiler performance was re-baselined. The following was observed relative to Phase 3B performance:

- NO_x emissions did not change significantly.
- LOI levels were similar despite the two new mills and coal fineness improvements.
- Excess oxygen levels decreased slightly.
- Pulverizer pipe-to-pipe air and fuel balance improved to industry standards.
- AHEGT dropped slightly.
- Steam temperatures degraded.
- Dispatch speed greatly improved.
- Boiler/unit stability improved significantly.
- Testing and data analysis was greatly enhanced.

Phase 4B–GNOCIS

SCS integrated GNOCIS into the Hammond control system in the first quarter of 1996. The functional interfaces are depicted in Figure 5. The scope of work only allowed for short-term tests. The results validated data obtained from other test sites. GNOCIS reduced NO_x emissions by 10–15 percent beyond those achieved by LNB/AOFA while improving unit heat rate and enhancing boiler efficiency by nominally 0.5 percent, depending upon the operator goals inputted to the GNOCIS system. The system affords utilities the flexibility to dynamically assign goals to a unit such as minimize NO_x (e.g., during summer months), maximize efficiency, or minimize LOI. GNOCIS performs its optimization function rapidly without impacting dispatch in either an open or closed mode and does not cause the unit to wander under steady-state conditions.

Figure 5. Major Elements of Generic NO_x Control Intelligent System (GNOCIS)



Model studies used the short-term data to project potential NO_x/heat rate improvement scenarios for five operating mode/load profile combinations as shown in Tables 3 and 4. Phase 1 uses the actual Phase 1 load profile, and the base load, peaking, cycling, and flat profiles are hypothetical load profiles. Although increased LOI contributes to combustion efficiency loss, minimizing LOI results in a net system efficiency loss (increased heat rate) because the excess air requirement increases.

Table 3. Average Heat Rate Deviation (Btu/kWh) vs. Load Profile and Operating Mode

		Operating Mode		
Load Profile	Baseline	Min. NO_x	Max. Effic.	Min. LOI
Phase 1	–	-47	-78	38
Base Load	–	-56	-88	47
Peaking Load	–	1	-37	-6
Cycling Load	–	-43	-71	18
Flat Load	–	-25	-56	5

Negative number indicates a heat rate improvement.

Table 4. NO_x Reduction Cost Effectiveness ($/ton NO_x removed) vs. Load Profile and Operating Mode

		Operating Mode		
Load Profile	Baseline	Min. NO_x	Max. Effic.	Min. LOI
Phase 1	–	-$261	-$684	n/a
Base Load	–	-$277	-$627	n/a
Peaking Load	–	$43	n/a	n/a
Cycling Load	–	-$293	-$975	n/a
Flat Load	–	-$177	-$2,403	n/a

n/a – There was a net NO_x emission increase for these load/mode combinations.
Negative number indicates a net savings.

Economic Performance

Estimated capital costs for a 500-MWe commercial installation of the NO_x control technologies are shown in Table 5.

Table 5. Capital Costs (1995 $)

	Total (10^6 $)	$/kW
AOFA	4.4	8.8
LNB	5.0	10.0
LNB/AOFA	9.4	18.8
GNOCIS	0.25	0.5

The cost-effectiveness of the technologies was also examined. This economic value measures dollars per ton of NO_x removed and takes into account not only the capital costs and NO_x reduction achieved, but the impacts on operation and maintenance costs (e.g., impacts of net heat rate reductions on fuel cost). Furthermore, the load profile impacts cost effectiveness. Whereas AOFA reduces NO_x to the greatest extent at full load decreasing to zero at 300 MWe, LNBs reduce NO_x on a relatively constant basis over the load range. Table 6 summarizes the cost effectiveness of the NO_x reduction technologies as a function of load profile. The GNOCIS values reflect a minimize NO_x goal. A levelization factor of 0.08 was used.

Table 6. Cost Effectiveness as a Function of Load Profile and Technology (1995 $)

	AOFA	LNB	LNB/AOFA	GNOCIS
Phase 1	$134	$54	$79	-$261
Base Load	$130	$51	$73	-$277
Peaking Load	$270	$59	$119	$43
Cycling Load	$154	$51	$88	-$293
Flat Load	$180	$52	$98	-$177

Negative number indicates a cost savings.

Commercial Applications

The combustion modification technology is applicable to the 411 existing pre-New Source Performance Standard wall-fired boilers in the United States, which burn a variety of coals. The GNOCIS technology is applicable to all fossil fuel-fired boilers, including units fired with natural gas and those cofiring coal and natural gas.

In projecting performance improvements to other sites, consideration must be given to the Hammond boiler's uncharacteristically high heat release rate and short distance between the top burners and the furnace outlet and the medium- to low-reactivity of the eastern bituminous coal used in the demonstration.

The host site has retained the demonstrated technologies for commercial use. As of the date of this report, Foster Wheeler has equipped 86 boilers (51 domestic and 35 international) with low-NO_x burner technology for a total of 1,800 burners representing over 30,000 MWe of capacity valued at $35 million. Twenty-six commercial installations of GNOCIS are underway or planned. This represents over 12,000 MWe of capacity.

Contacts

John N. Sorge, (205) 257-7426
jnsorge@southernco.com
ICCT Project Manager
Southern Company Services, Inc.
P.O. Box 2625
Birmingham, AL 35202-2625
Lawrence Saroff, DOE/HQ, (301) 903-9483
lawrence.saroff@hq.doe.gov

James R. Longanbach, NETL, (304) 285-4659
jlonga@netl.doe.gov

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U.S. Department of Energy

Assistant Secretary for Fossil Energy

Washington, DC 20585