1 of 1

INNOVATIVE CLEAN COAL TECHNOLOGY (ICCT)

500 MW DEMONSTRATION OF ADVANCED
WALL-FIRED COMBUSTION TECHNIQUES
FOR THE REDUCTION OF NITROGEN OXIDE (NO_x)
EMISSIONS FROM COAL-FIRED BOILERS

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EXECUTIVE SUMMARY

This quarterly report discusses the technical progress of an Innovative Clean Coal Technology (ICCT) demonstration of advanced wall-fired combustion techniques for the reduction of nitrogen oxide (NO_x) emissions from coal-fired boilers. The project is being conducted at Georgia Power Company's Plant Hammond Unit 4 located near Rome, Georgia. The primary goal of this project is the characterization of the low NO_x combustion equipment through the collection and analysis of long-term emissions data. A target of achieving fifty percent NO_x reduction using combustion modifications has been established for the project.

The project provides a stepwise retrofit of an advanced overfire air (AOFA) system followed by low NO_x burners (LNB). During each test phase of the project, diagnostic, performance, long-term, and verification testing will be performed. These tests are used to quantify the NO_x reductions of each technology and evaluate the effects of those reductions on other combustion parameters such as particulate characteristics and boiler efficiency.

Baseline, AOFA, and LNB without AOFA test segments have been completed. Analysis of the 94 days of LNB long-term data collected show the full load NO_x emission levels to be approximately 0.65 lb/MBtu. Flyash LOI values for the LNB configuration are approximately 8 percent at full load. Corresponding values for the AOFA configuration are 0.94 lb/MBtu and approximately 10 percent. Abbreviated diagnostic tests for the LNB+AOFA configuration indicate that at 500 MWe, NO_x emissions are approximately 0.55 lb/MBtu with corresponding flyash LOI values of approximately 11 percent. For comparison, the long-term, full load, baseline NO_x emission level was approximately 1.24 lb/MBtu at 5.2 percent LOI. Comprehensive testing of the LNB+AOFA configuration will be performed when the stack particulate emissions issue is resolved.

The NO_x versus LOI testing was performed during this quarter. The primary purpose of this testing was to determine the sensitivity of NO_x emissions and flyash LOI to changes in excess air and burner register settings. Mill characterization was performed the week of October 12, 1992 and NO_x emission characterization began on October 20, 1992 and was completed October 28, 1992. Results from the NO_x vs. LOI tests are included in this quarterly technical progress report.

In order to meet particulate compliance limits, Hammond Unit 4 continues to run at reduced loads until resolution of the particulate emissions issues. Preliminary results from stack particulate emissions testing performed on October 8 indicate that full load (500 MW) emissions levels are above the particulate compliance limits. The unit was tested in the LNB+AOFA configuration with the ammonia flue gas conditioning system in operation.

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TABLE OF ABBREVIATIONS

AOFA	Advanced Overfire Air
ASME	American Society of Mechanical Engineers
C	carbon
CFSF	Controlled Flow/Split Flame
Cl	chlorine
CO	carbon monoxide
DAS	data acquisition system
DOE	United States Department of Energy
ECEM	extractive continuous emissions monitor
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
F	Fahrenheit
FC	fixed carbon
FWEC	Foster Wheeler Energy Corporation
H	hydrogen
HHV	higher heating value
ICCT	Innovative Clean Coal Technology
lb(s)	pound(s)
LNB	low NO _x burner
LOI	loss on ignition
(M)Btu	(million) British thermal unit
MW	megawatt
N	nitrogen
NO _x	nitrogen oxides
O, O ₂	oxygen
psig	pounds per square inch gauge
PTC	Performance Test Codes
RSD	relative standard deviation
S	sulfur
SCS	Southern Company Services
SO ₂	sulfur dioxide
UARG	Utility Air Regulatory Group
VM	volatile matter

1. INTRODUCTION

This document discusses the technical progress of a U. S. Department of Energy (DOE) Innovative Clean Coal Technology (ICCT) Project demonstrating advanced wall-fired combustion techniques for the reduction of nitrogen oxide (NO_x) emissions from coal-fired boilers. The project is being conducted at Georgia Power Company's Plant Hammond Unit 4 (500 MWe) near Rome, Georgia.

The project is being managed by Southern Company Services, Inc. (SCS) on behalf of the project co-funders: The Southern Company, the U. S. Department of Energy (DOE), and the Electric Power Research Institute. In addition to SCS, The Southern Company includes five electric operating companies: Alabama Power, Georgia Power, Gulf Power, Mississippi Power, and Savannah Electric and Power. SCS provides engineering, research, and financial services to The Southern Company.

The Clean Coal Technology Program is a jointly funded effort between government and industry to move the most promising advanced coal-based technologies from the research and development stage to the commercial marketplace. The Clean Coal effort sponsors projects which are different from traditional research and development programs sponsored by the DOE. Traditional projects focus on long range, high risk, high payoff technologies with the DOE providing the majority of the funding. In contrast, the goal of the Clean Coal Program is to demonstrate commercially feasible, advanced coal-based technologies which have already reached the "proof of concept" stage. As a result, the Clean Coal Projects are jointly funded endeavors between the government and the private sector which are conducted as Cooperative Agreements in which the industrial participant contributes at least fifty percent of the total project cost.

The primary objective of the Plant Hammond demonstration is to determine the long-term effects of commercially available wall-fired low NO_x combustion technologies on NO_x emissions and boiler performance. Short-term tests of each technology are also being performed to provide engineering information about emissions and performance trends. A target of achieving fifty percent NO_x reduction using combustion modifications has been established for the project. Specifically, the objectives of the projects are:

1. Demonstrate in a logical stepwise fashion the short-term NO_x reduction capabilities of the following advanced low NO_x combustion technologies:

- a. Advanced overfire air (AOFA)
 - b. Low NO_x burners (LNB)
 - c. LNB with AOFA
2. Determine the dynamic, long-term emissions characteristics of each of these combustion NO_x reduction methods using sophisticated statistical techniques.
3. Evaluate the progressive cost effectiveness (i.e., dollars per ton NO_x removed) of the low NO_x combustion techniques tested.
4. Determine the effects on other combustion parameters (e.g., CO production, carbon carryover, particulate characteristics) of applying the NO_x reduction methods listed above.

2. PROJECT DESCRIPTION

2.1. Test Program Methodology

In order to accomplish the project objectives, a Statement of Work (SOW) was developed which included the Work Breakdown Structure (WBS) found in Table 1. The WBS is designed around a chronological flow of the project. The chronology requires design, construction, and operation activities in each of the first three phases following project award.

The stepwise approach to evaluating the NO_x control technologies requires that three plant outages be used to successively install (1) the test instrumentation, (2) the AOFA system, and (3) the LNBs. These outages were scheduled to coincide with existing plant maintenance outages in the fall of 1989, spring of 1990, and the spring of 1991. The planned retrofit progression has allowed for an evaluation of the AOFA system while operating with the existing pre-retrofit burners. As shown in Figures 1 and 2, the AOFA supply is separately ducted from the existing forced draft secondary air system. Backpressure dampers are provided on the secondary air ducts to allow for the introduction of greater quantities of higher pressure overfire air into the boiler. The burners are designed to be plug-in replacements for the existing circular burners.

The data acquisition system (DAS) for the Hammond Unit 4 ICCT project is a custom designed microcomputer based system used to collect, format, calculate, store, and transmit data derived from power plant mechanical, thermal, and fluid processes. The extensive process data selected for input to the DAS has in common a relationship with either boiler performance or boiler exhaust gas properties. This system includes a continuous emissions monitoring system (NO_x, SO₂, O₂, THC, CO) with a multi-point flue gas sampling and conditioning system, an acoustic pyrometry and thermal mapping system, furnace tube heat flux transducers, and boiler efficiency instrumentation. The instrumentation system is designed to provide data collection flexibility to meet the schedule and needs of the various testing efforts throughout the demonstration program. A summary of the type of data collected is shown in Table 2.

Following each outage, a series of four groups of tests are planned. These are (1) diagnostic, (2) performance, (3) long-term, and (4) verification. The diagnostic, performance, and verification tests consist of short-term data collection during carefully

established operating conditions. The diagnostic tests are designed to map the effects of changes in boiler operation on NO_x emissions. The performance tests evaluate a more comprehensive set of boiler and combustion performance indicators. The results from these tests will include particulate characteristics, boiler efficiency, and boiler outlet emissions. Mill performance and air flow distribution are also tested. The verification tests are performed following the end of the long-term testing period and serve to identify any potential changes in plant operating conditions.

As stated previously, the primary objective of the demonstration is to collect long-term, statistically significant quantities of data under normal operating conditions with and without the various NO_x reduction technologies. Earlier demonstrations of emissions control technologies have relied solely on data from a matrix of carefully established short-term (one to four hour) tests. However, boilers are not typically operated in this manner, considering plant equipment inconsistencies and economic dispatch strategies. Therefore, statistical analysis methods for long-term data are available that can be used to determine the achievable emissions limit or projected emission tonnage of an emissions control technology. These analysis methods have been developed over the past fifteen years by the Control Technology Committee of the Utility Air Regulatory Group (UARG). Because the uncertainty in the analysis methods is reduced with increasing data set size, UARG recommends that acceptable 30 day rolling averages can be achieved with data sets of at least 51 days with each day containing at least 18 valid hourly averages.

2.2. Unit Description

Georgia Power Company's Plant Hammond Unit 4 (Figure 1) is a Foster Wheeler Energy Corporation (FWEC) opposed wall-fired boiler, rated at 500 MW_e gross, with design steam conditions of 2500 psig and 1000/1000°F superheat/reheat temperatures, respectively. The unit was placed into commercial operation on December 14, 1970. Prior to the LNB retrofit, six FWEC Planetary Roller and Table type mills provided pulverized eastern bituminous coal (12,900 Btu/lb, 33% VM, 53% FC, 1.7% S, 1.4% N) to 24 pre-NSPS, Intervane burners. During the LNB outage, the existing burners were replaced with FWEC Control Flow/Split Flame burners. The unit was also retrofit with four Babcock and Wilcox MPS 75 mills during the course of the demonstration (two each during the spring 1991 and spring 1992 outages). The burners are arranged in a matrix of 12 burners (4W x 3H) on opposing walls with each mill supplying coal to 4 burners per elevation. As part of this demonstration project, the unit was retrofit with an Advanced

Overfire Air System, to be described later. The unit is equipped with a coldside ESP and utilizes two regenerative secondary air preheaters and two regenerative primary air heaters. The unit was designed for pressurized furnace operation but was converted to balanced draft operation in 1977.

2.3. Advanced Overfire Air (AOFA) System

Generally, combustion NO_x reduction techniques attempt to stage the introduction of oxygen into the furnace. This staging reduces NO_x production by creating a delay in fuel and air mixing that lowers combustion temperatures. The staging also reduces the quantity of oxygen available to the fuel-bound nitrogen. Typical overfire air (OFA) systems accomplish this staging by diverting 10 to 20 percent of the total combustion air to ports located above the primary combustion zone. AOFA improves this concept by introducing the OFA through separate ductwork with more control and accurate measurement of the AOFA airflow, thereby providing the capability of improved mixing (Figure 2).

Foster Wheeler Energy Corporation (FWEC) was competitively selected to design, fabricate, and install the advanced overfire air system and the opposed-wall, low NO_x burners described below. The FWEC design diverts air from the secondary air ductwork and incorporates four flow control dampers at the corners of the overfire air windbox and four overfire air ports on both the front and rear furnace walls. Due to budgetary and physical constraints, FWEC designed an AOFA system more suitable to the project and unit than that originally proposed. Six air ports per wall were proposed instead of the as-installed configuration of four per wall.

2.4. Low NO_x Burners

Low NO_x burner systems attempt to stage the combustion without the need for the additional ductwork and furnace ports required by OFA and AOFA systems. These commercially-available burner systems introduce the air and coal into the furnace in a well controlled, reduced turbulence manner. To achieve this, the burner must regulate the initial fuel/air mixture, velocities and turbulence to create a fuel-rich core, with sufficient air to sustain combustion at a severely sub-stoichiometric air/fuel ratio. The burner must then control the rate at which additional air, necessary to complete combustion, is mixed with the flame solids and gases to maintain a deficiency of oxygen until the remaining

combustibles fall below the peak NO_x producing temperature (around 2800°F). The final excess air can then be allowed to mix with the unburned products so that the combustion is completed at lower temperatures. Burners have been developed for single wall and opposed wall boilers.

In the FWEC Controlled Flow/Split Flame (CFSF) burner (Figure 3), secondary combustion air is divided between inner and outer flow cylinders. A sliding sleeve damper regulates the total secondary air flow entering the burner and is used to balance the burner air flow distribution. An adjustable outer register assembly divides the burners secondary air into two concentric paths and also imparts some swirl to the air streams. The secondary air which traverses the inner path, flows across an adjustable inner register assembly that, by providing a variable pressure drop, apportions the flow between the inner and outer flow paths. The inner register also controls the degree of additional swirl imparted to the coal/air mixture in the near throat region. The outer air flow enters the furnace axially, providing the remaining air necessary to complete combustion. An axially movable inner sleeve tip provides a means for varying the primary air velocity while maintaining a constant primary flow. The split flame nozzle segregates the coal/air mixture into four concentrated streams, each of which forms an individual flame when entering the furnace. This segregation minimizes mixing between the coal and the primary air, assisting in the staged combustion process. The adjustments to the sleeve dampers, inner registers, outer registers, and tip position are made during the burner optimization process and thereafter remain fixed unless changes in plant operation or equipment condition dictate further adjustments.

Table 1. Work Breakdown Structure			
500 MW Demonstration of Advanced Wall-Fired Combustion Techniques for the Reduction of Nitrogen Oxide (NO _x) Emissions from Coal-Fired Boilers			
Phase	Task	Description	Date
0	1.0	Phase 0 Pre-Award Negotiations	
1	1.1	Phase 1 Baseline Characterization	
	1.1.1	Project Management and Reporting	8/89 - 4/90
	1.1.2	Site Preparation	8/89 - 10/89
	1.1.3	Flow Modeling	9/89 - 6/90
	1.1.4	Instrumentation	9/89 - 10/89
	1.1.5	Baseline Testing	11/89 - 4/90
2	1.2	Phase 2 Advanced Overfire Air Retrofit	
	1.2.1	Project Management and Reporting	4/90 - 3/91
	1.2.2	AOFA Design and Retrofit	4/90 - 5/90
	1.2.3	AOFA Testing	5/90 - 3/91
3	1.3	Phase 3 Low NO _x Burner Retrofit ¹	
	1.3.1	Project Management and Reporting	3/91 - 9/93
	1.3.2	LNB Design and Retrofit	3/91 - 5/91
	1.3.3	LNB Testing with and without AOFA	5/91 - 9/93
4	1.4	Final Reporting and Disposition ¹	
	1.4.1	Project Management and Reporting	9/93 - 12/93
	1.4.2	Disposition of Hardware	9/93 - 12/93

¹Dates of these tasks reflects change from original project schedule.

Table 2. Plant Data Points	
Boiler Drum Pressure	Superheat Outlet Pressure
Cold Reheat Pressure	Hot Reheat Pressure
Barometric Pressure	Superheat Spray Flow
Reheat Spray Flow	Main Steam Flow
Feedwater Flow	Coal Flows
Secondary Air Flows	Primary Air Flows
Main Steam Temperature	Cold Reheat Temperature
Hot Reheat Temperature	Feedwater Temperature
Desuperheater Outlet Temp.	Desuperheater Inlet Temp.
Economizer Outlet Temp.	Air Heater Air Inlet Temp.
Air Heater Air Outlet Temp.	Ambient Temperature
BFP Discharge Temperature	Relative Humidity
Stack NO _x	Stack SO ₂
Stack O ₂	Stack Opacity
Generation	Overfire Air Flows

Figure 1. Plant Hammond Unit 4 Boiler

Figure 2. Advanced Overfire Air System

Figure 3. Low NO_x Burner Installed at Plant Hammond

3. PROJECT STATUS

3.1. Phase 1 - Baseline Characterization

3.1.1. Task 1.5 Baseline Testing Summary

Phase 1 baseline testing ended in April 1990. A summary of the baseline tests results is shown in Table 3 and Figures 4 and 5. During baseline testing, 52 days of long-term data were collected producing an average NO_x emission level of 1.12 lb/MBtu. NO_x emissions generally increased with load and ranged from 0.9 to 1.3 lb/MBtu (Figure 6). The band about the mean represents the range between the 5th and 95th percentiles of the data set and show the variability of NO_x emissions during long-term operation. The long-term data demonstrates a full load, mean NO_x level of 1.24 lb/MBtu at the nominal 2.7 percent excess oxygen (wet measurement, plant O₂ system) operating condition while the short-term test results show a mean level of 1.35 lb/MBtu. The explanation for this disparity most likely is a result of such variables as coal variability, minor unit operating changes (air register settings, etc.) and possibly weather conditions affecting the coal grinding (wet coal) as well as the fact that long-term data includes transients in operating O₂ level which may be greater than the steady load excursions. The important point is that these normal excursions can influence the short-term data taken at one point in time but are essentially averaged out during normal, long-term operation.

The objective of the short-term testing was to establish the NO_x trends for the major parameters that influence emissions on this unit, i.e., excess air, mill pattern, and load. At the high load condition of 480 MW, characterization of the NO_x emissions over the excess O₂ operating range was complicated by unit design constraints which limited the range to ± 0.75 percent about the nominal 2.7 percent O₂ operating point. The full load, design O₂ level for this boiler is approximately 3.3 percent. Full load, short-term NO_x emission levels ranged from approximately 1.2 to 1.5 lb/MBtu. At the boiler design O₂ level, NO_x emissions were approximately 1.4 lb/MBtu.

As an indication of mill performance during this phase, approximately 63 percent of the coal passed 200 mesh while 2.8 percent remained in 50 mesh (Table 4). Coal fineness data is collected during the performance tests.

3.2. Phase 2 - Advanced Overfire Air Retrofit and Characterization

3.2.1. Task 2.2 AOFA Retrofit

The AOFA system was installed during a four week unit outage during spring 1990. For more information on the outage and installation see the *Second Quarter 1990 Technical Progress Report*.

3.2.2. Task 2.3 AOFA Testing Summary

Following optimization by FWEC, AOFA tests at Plant Hammond (with the pre-NSPS Intervane burners still in operation) were completed in March 1991. During the AOFA test phase, the unit was operated according to FWEC instructions provided in the design manuals. A summary of the long-term test results is shown, along with the baseline results, in Table 3. During AOFA testing, 86 days of long-term data were collected for which the average NO_x emission level was 0.92 lb/MBtu. As compared to the baseline characteristic, NO_x emissions were not highly dependent on load during the AOFA test phase (Figure 7). Mill performance during this phase was slightly better than during the baseline phase (Table 4).

3.3. Phase 3 - Low NO_x Burner Retrofit and Characterization

3.3.1. Task 3.2 LNB Retrofit

The LNBs were installed during a seven week unit outage during spring 1991. For more information on the outage and installation see the *Second Quarter 1991 Technical Progress Report*.

3.3.2. Task 3.3 LNB Without AOFA Summary

Following optimization by FWEC, characterization of the low NO_x burner system began in June 1991 and ended in January 1992. Diagnostic testing was performed from July 9 to July 20, 1991 and performance testing began July 16, 1991. During the LNB test phase, the unit was operated according to FWEC instructions provided in the design manuals. This testing indicated that the low NO_x burners were not optimally configured and, therefore, testing was postponed for four days to allow FWEC personnel to make additional adjustments to the new burners and ancillary systems. Testing continued on

July 22 and was completed July 28, 1991.

Long-term testing of the low NO_x burners began on August 7, 1991 and was completed on December 19, 1991. Ninety-four days of long-term data were collected for which the average NO_x emission level was 0.53 lb/MBtu and the full load, mean, NO_x emission level was 0.65 lb/MBtu (Table 3 and Figure 4). As in the baseline long-term test period, NO_x emissions generally increased with load; however, below approximately 275 MW, the converse is true and NO_x emissions rapidly increase with decreasing load. In contrast, NO_x emissions during the AOFA long-term test phase were not highly dependent on load. As can be seen in Figure 8, the long-term variability in NO_x emissions was small, especially at high-loads. This variability is less than in previous tests phases and is probably due to an improvement in burner condition.

3.3.3. Task 3.3 LNB with AOFA Test Summary

Due to load limitations associated with stack particulate emissions (discussed below) comprehensive testing of the LNBs in conjunction with AOFA has not been completed. However, to provide preliminary data, abbreviated testing (short- and long-term) of the LNB+AOFA configuration was performed at Plant Hammond from February to March 1992 and continued following the spring outage. The combined system was optimized by FWEC and operated per their instructions. As shown in Figure 9, long-term NO_x emissions prior to the spring outage were somewhat independent of load above 275 MW. Below 275 MW, NO_x emissions increased rapidly with decreasing load. The decrease in effectiveness of this configuration at low loads is the result of the operating procedures calling for the closure of AOFA dampers below 300 MW. This decrease in NO_x reduction effectiveness is not as prominent in the data collected during the fall of 1992. The cause of the difference in the pre- and post- spring outage mean NO_x emissions is at this time undetermined.

Comprehensive testing of the LNB+AOFA configuration will be performed when full load operation can be resumed. Until full load can be achieved, long-term data will be collected. Appendix A contains a summary of the NO_x emissions and load from October through December 1992.

3.4. Data Comparison

Figure 4 compares the baseline, AOFA, LNB, and LNB+AOFA short- and long-term NO_x emissions data. The AOFA and LNBs provide a long-term, **full load**, NO_x reduction of 24 and 48 percent, respectively. Although the abbreviated long-term testing of the LNB+AOFA configuration performed to date does not provide sufficient data to fully characterize NO_x emissions at full load, the incremental percent NO_x reduction of the combined LNB+AOFA system above LNB alone has averaged approximately 10 percent over the load range. As shown, long-term emission levels can be significantly different than that indicated by short-term tests.

Flyash loss-on-ignition (LOI) values increased significantly for both the AOFA, LNB, and LNB+AOFA test phases (Figure 5). LOI measurements for the baseline, AOFA, and LNB test segments were made during each performance test using EPA's Method 17 at the secondary air heater outlet. High volume sampling was used for the abbreviated LNB+AOFA phase. Mill performance was generally better in the AOFA, LNB, and LNB+AOFA test phases than during baseline (Table 4). Although it was expected to increase following the AOFA and LNB retrofits, CO remained below 20 ppm over the load range following the retrofits.

An important segment of the test program is to determine the impact of the low NO_x combustion technologies on boiler performance. Boiler efficiency testing is performed as part of the performance tests and follows guidelines set forth in ASME PTC 4.1 [1]. Although it can be affected by a number of factors unrelated to the AOFA and LNB retrofits, boiler efficiency has decreased following installation of these technologies on Hammond Unit 4 (Table 5). The major contributors to the loss of efficiency are (1) an increase in combustion air requirements leading to increased dry flue gas losses and (2) higher carbon in ash values.

A side effect of the LNB retrofit has been a decrease in furnace slagging and an increase in flyash production. This change in ash loading has led to post-LNB retrofit rise in primary air heater plugging rates. Also, these increases, coupled with the higher post-LNB retrofit flyash LOI, adversely impacted particulate emissions such that the unit had to be run at reduced loads to meet particulate compliance limits. The impact of the LNBs on

1 ASME Performance Test Codes, PTC 4.1, "Steam Generating Units," New York: American Society of Mechanical Engineers, latest edition.

precipitator performance and stack particulate emissions is highly dependent on a number of factors including the size of the precipitator (Hammond Unit 4 precipitator is sized at approximately 161 SCA) and pre-LNB retrofit slagging characteristics (Hammond Unit 4 was characterized as a heavy slagging unit prior to the LNB retrofit). Ammonia flue gas conditioning was used to improve precipitator collection efficiency, allowing full load operation and the completion of the LNB test phase.

3.5. NO_x vs. LOI Testing

The NO_x versus LOI testing was performed during this quarter. The primary purpose of these tests was to determine the effects of various burner settings and mill operation on NO_x emissions and unburned carbon levels in the flyash. In order to assess the effects of each parameter, the test matrix was designed so that a single parameter was varied each test day to the extent that all other parameters could be held constant. The parameters tested were excess air, mill coal flow bias, burner inner and outer register positions, and burner inner barrel position. Mill characterization was also performed (i.e. primary air and coal through each mill and coal and air distributions and particle size determination in each coal pipe) as part of this test program. Mill characterization was performed the week of October 12, 1992 and NO_x emission characterization began on October 20, 1992 and was completed October 28, 1992. These tests were performed at 450 MW and, except as noted, with minimum AOFA.

Figure 10 shows the composite NO_x and LOI sensitivity to all parameters tested. As shown in this figure, NO_x emissions and LOI levels could be varied from approximately 0.48 lb/MBtu to 0.57 lb/MBtu and 9 percent to 4 percent, respectively. Therefore, there is considerable flexibility in selecting the optimum operating point and making tradeoffs between NO_x emissions and flyash LOI. The values shown in this figure are corrected to 4.1 percent excess O₂. For comparison, the NO_x and LOI for the LNB test phase (based on the performance tests results) were approximately 0.63 lb/MBtu and 7 percent, respectively. The reduced NO_x emissions for the LNB vs. LOI tests are probably the result of improved tuning of the LNBs. Appendix B contains a summary of the results of LNB vs. AOFA test sequence.

3.6. Burner Fires

Three low NO_x burners have been damaged due to excessive heat since the spring 1991 low NO_x burner retrofit. In each instance, portions of the cast burner nozzle assembly melted away, especially in the vicinity of the coal nozzle. The damaged burners were supplied coal from both the new Babcock and Wilcox mills and the FWEC mills and located on front and rear furnace walls and upper and lower burner elevations (Figure 11). Two burners were damaged since resumption of unit operation following the spring 1992 outage. The last and most severe occurred on June 16, 1992, and required a one week outage to repair. Damage in this instance was not limited to the cast burner nozzle and sliding tip assembly, but also included the inner and outer barrel, secondary air register, adjacent burners, and windbox. Following this last failure, an enhanced burner thermocouple monitoring system was installed to provide more comprehensive alarming capabilities. Since the June failure, no other burner failures have occurred.

An analysis of these failures included the collection and review of all available operating data for the time frames in question. Operating data reviewed included information from the project's data acquisition system (unit output, pulverizer flow and primary air temperatures) as well as plant operating records (pulverizer amps, pulverizer differential, pulverizer primary air differential, and burner thermocouple readings). Although there is *insufficient data to conclusively identify the root cause of these burner fires*, the following are observations and hypotheses which resulted from this study:

- All three burner failures occurred with the boiler operating at reduced loads and with the affected pulverizer operating at the lower end of the air/fuel curve (Table 6).
- All three failures appeared to result from layout in the burner and subsequent coking.
- Although calculated primary air velocities entering the burners were at levels which would normally be considered adequate to prevent coal layout, inadequate primary air velocity *could* be considered a possible contributor in all three failures. This appears to be substantiated by the fact that no failures have occurred since a new air/fuel curve was implemented. This new curve requires higher air flows for a given fuel flow at lower pulverizer loads. The new curve was implemented shortly after the failure of the 4CC burner. Minimum air flow is now 108,000 lbm/hr as opposed to the earlier value of 100,000 lbm/hr.

- In regard to plugging and coal layout, the new low NO_x burners appear to be more sensitive to proper air velocities and air/fuel ratios than were the earlier turbulent design burners.

Again, it should be emphasized, that because of instrumentation limitations, the cause of the three burner fires which occurred at Hammond 4 cannot be conclusively identified.

Table 3. Baseline, AOFA, and LNB Long-Term Test Results						
Unit Configuration	Baseline		AOFA		LNB	
	Mean	RSD,%	Mean	RSD,%	Mean	RSD,%
Number of Daily Averaged Values	52	-	86	-	94	-
Average Load (MW)	407	9.4	386	17.9	305	17.7
Average NO _x Emissions (lb/MBtu)	1.12	9.5	0.92	8.6	0.53	13.7
Average O ₂ Level (percent at stack)	5.8	11.7	7.3	12.6	8.4	7.7
NO _x 30 Day Achievable Emission Limit (lb/MBtu)	1.24	-	1.03	-	0.64	-
NO _x Annual Achievable Emission Limit (lb MBtu)	1.13	-	0.93	-	0.55	-

* RSD = Relative Standard Deviation = 100 * Standard Deviation / Mean

Table 4. Mill Performance at Full Load Mill Coal Flow Weighted Averages		
Phase	Left in 50 Mesh	Passing 200 Mesh
	Percent	Percent
Baseline	2.8	63.0
AOFA	2.6	66.5
LNB	1.3	66.5
LNB+AOFA*	1.3	73.6

*Preliminary, data from one test only, 500 MW.

Table 5. Full Load Boiler Performance (Preliminary)									
Phase	Test	Load MW	Total Fuel lb/hr	Total Air lb/hr	Excess O ₂ Percent	Excess Air [^] Percent	Flyash LOI Percent	Efficiency Percent	Change* Percent
Design	N/A	480	3.9E+05	4.2E+06	3.3	18%	4.5%	89.0	-
Baseline	Average	474	3.5E+05	3.7E+06	2.9	10%	5.1%	89.8	-
AOFA	43-1.3	478	3.4E+05	3.8E+06	3.9	14%	9.6%	89.1	0.7
LNB	Average	476	3.3E+05	3.9E+06	3.7	19%	8.0%	88.2	1.6

*Change relative to baseline average.

[^]Calculated using measured total air and fuel.

Table 6: Summary of Burner Fires						
Burner	Date of Fire	Unit Load (MW)	Pulverizer Type	Coal Flow	Air Flow	Air/Fuel
				klbm/hr	klbm/hr	Ratio
4BC	11/22/91	341	FW MB	48.9	N/A	N/A
4FA	5/31/92	211	B&W MPS 75	44.7	102	2.28
4CC	6/17/92	260	B&W MPS 75	42.2	113	2.68

Figure 4. NO_x Emissions Comparison

Figure 5. Flyash Combustibles Loss-on-Ignition

Figure 6. Baseline Long-Term NO_x Trend

Figure 7. AOFA Long-Term NO_x Trend

Figure 8. LNB Long-Term NO_x Trend

Figure 9. LNB+AOFA Long-Term NO_x Trend - Preliminary

Figure 10. Summary of NO_x vs. LOI Tests

Figure 11. Damaged Burner Locations

4. CONCLUSIONS

In conclusion, the results to date at Plant Hammond indicate:

- NOx emissions have been reduced to near 50 percent of baseline values by using low NOx burners alone. These reductions were sustainable over the long-term test period and were consistent over the entire load range. The full load short-term NOx reductions in this configuration were approximately 55 percent. Furnace waterwall slagging has been significantly reduced, leading to a reduction in soot-blowing frequency. Unit operation was approximately the same or slightly better than that experienced during baseline testing.
- Preliminary results show that AOFA used in conjunction with the LNBs provide only marginal, incremental NOx reduction benefits averaging less than 10 percent over the load range. When compared to baseline, the full load long-term and short-term NOx reductions in this configuration were approximately 55 percent and 62 percent, respectively. The long-term, full load NOx reduction using AOFA alone was approximately 24 percent. Operation of the unit was characterized by plant operators as being more difficult when using the AOFA system.
- In the AOFA, LNB, and LNB+AOFA configurations, the unit experienced significant performance impacts including increases in excess air and carbon in flyash.
- The LNBs are susceptible to tip cracking and melting. These problems will impact reliability and may affect performance as it relates to NOx production and LOI. The cause of these failures is at this time undetermined. Future work should address these challenges and the controls necessary to maintain performance and reliability.
- Auxiliary systems can be adversely impacted by the installation of these combustion technologies. Precipitator mass loading and gas flow rates have increased. Excess air requirements and, therefore, fan power requirements have also increased.

5. FUTURE PLANS

The following table is a quarterly outline of the activities scheduled for the remainder of the project:

Table 7. Future Plans	
Quarter	Activity
First Quarter 1993	<ul style="list-style-type: none">• Re-Optimization of LNB+AOFA• Post Retrofit Chemical Emissions Tests• Diagnostic Tests of the LNBs+AOFA
Second Quarter 1993	<ul style="list-style-type: none">• Performance Tests of the LNBs+AOFA• Long-Term LNB+AOFA Tests
Third Quarter 1993	<ul style="list-style-type: none">• Verification Tests of the LNBs+AOFA• Begin Final Reporting• Begin Disposition
Forth Quarter 1993	<ul style="list-style-type: none">• Complete Final Reporting• Complete Disposition• Project Completion

6. ACKNOWLEDGMENTS

The following project participants are recognized for their dedicated efforts toward the success of the wall-fired low NO_x demonstration: Mr. Ernie Padgett, Georgia Power Company, and Mr. Mike Nelson, Southern Company Services, for their coordination of the design and retrofit efforts and Mr. Jose Perez, full-time Instrumentation Specialist from Spectrum Systems, Inc. Also Mr. Jim Witt of Southern Company Services for design, procurement, and installation of the instrumentation systems. The following companies have provided outstanding testing and data analysis efforts: Energy Technology Consultants, Inc., Flame Refractories, Inc., Southern Research Institute, W. S. Pitts Consulting, and Radian Corporation. Finally, the support from Mr. Art Baldwin, DOE ICCT Project Manager, and Mr. David Eskinazi, EPRI Project Manager, is greatly appreciated.

APPENDIX A
Long-Term NOx Emissions - October - December, 1992

APPENDIX B
NO_x vs. LOI Letter Report

July 7, 1992

Mr. John Sorge
SOUTHERN COMPANY SERVICES
800 Shades Creek Parkway
Birmingham, AL 35209

SUBJECT: Results from Special Hammond Unit 4 LOI Testing - Revised

Dear John:

Testing to evaluate the effects of various burner and boiler operating settings on LOI and carbon content of ash particulate emissions from Plant Hammond Unit 4 was conducted between October 15 and 28, 1992. The testing consisted of two separate efforts. The first was performed by Flame Refractories, Inc. (FRI), to characterize the coal and primary air flow rates through each mill, as well as the coal and primary air distributions and particle size range in each individual coal pipe at a nominal load of 450 MWe. The second test effort was conducted jointly by Energy Technology Consultants, Inc. (ETEC - Test Coordinator), Southern Research Institute (SoRI - particulate emissions sampling and analysis) and Spectrum Systems, Inc. (flue gas analysis and data acquisition). This letter presents a summary of the results of the testing. These data and any subsequent analysis will be included in the Final Report for the Hammond DOE CCTII project.

TEST METHODS

The methods used in the conduct of these LOI evaluation tests were identical to the methods used in the Innovative Clean Coal Technology Demonstration Project performance testing for the corresponding test procedures. FRI performed the mill coal and air flow and particle size analyses in the same manner as for the CCTII program. SoRI utilized Method 17 procedures to obtain the ash samples for both LOI (performed on-site) and carbon (performed at the SoRI laboratories) analyses. In order to expedite the collection of ash samples, SoRI collected two separate Method 17 samples simultaneously, traversing the ESP inlet duct in opposite directions, but using the same test ports and probe insertion points. In this manner, duplicate samples could be obtained in about one hour for a single test condition. Spectrum Systems operated the CCTII Gas Analysis System and Data Acquisition System to record gaseous emissions of oxygen, carbon monoxide and nitrogen oxide from various points in the boiler exit gas stream, as well as numerous boiler operating parameters. ETEC established the boiler operating conditions for each test, recorded control room and burner front data and coordinated the efforts of SoRI and Spectrum during the LOI testing. The burner settings employed were previously established by Foster Wheeler Energy Corporation (FWEC).

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TEST RESULTS

Prior to the commencement of LOI testing, ETEC prepared a preliminary test plan as shown in Table 1. Although the initial plan called for 10 days of testing in order to provide for some repetition of test conditions, the testing was concluded after nine days to accommodate the Plant Hammond requirement to bring Unit 4 off-line for installation of electrical control components. All of the test objectives were accomplished in this nine day period and no time was lost due to weather, unit upsets or dispatch requirements.

Mill Characterization Tests

FRI performed tests to evaluate the condition of the coal and primary air supply systems with regard to coal and air flow distributions and coal particle size in each coal pipe. In addition, FRI also measured the Secondary Air flows in each duct (east and west) in an attempt to explain an apparent imbalance in those flows as indicated by plant instrumentation.

The results of the Mill Characterization testing are shown in Table 2. Several important conclusions can be drawn from this data. First, it is apparent that the newer Babcock & Wilcox (B&W) MPS 75 mills (A, C, E, F) provide excellent fineness, both at the small sizes (passing 200 mesh, all greater than 70 percent) and the largest sizes (larger than 50 mesh, all less than 0.23 percent). The older FWEC MB mills (B & D) provided less than 70 percent passing 200 mesh, and approximately 2.0 percent remaining on 50 mesh. Second, there is a large variation in coal flow measured from pipe to pipe for all mills, varying from about ± 8 percent from the mean coal flow for the B mill, to over ± 30 percent for the D mill. Third, the D mill had substantially lower coal flow (and higher A/F ratio) than the other mills. This characteristic is consistent with the results observed during the previous Phase 3A Performance Test series (Test days 66 through 73). For the current mill tests, the D mill feeder coal flow, as indicated by the Stock feeder instrumentation, was approximately the same as the other mill feeders. The apparent conclusion is that either; 1) the D mill Stock feeder calibration is not correct, or 2) the measurement of the D mill coal flow in the burner pipes is incorrect due to some abnormal flow condition such as roping or channeling which prevents the capture of a representative coal sample by the FRI technique. With the exception of the D mill, the A/F ratios were consistently between 2.0 and 2.3.

In addition to the mill testing, FRI also measured the total air flow rates through the East and West secondary air venturi ducts. Although the existing plant air flow instrumentation indicated a significant imbalance between the two venturi flow measurements (1,555,600 lb/hr - West, and 2,214,000 - East), the FRI measurements, made with type S pitot tube traverses across the ducts, indicated that the flows were equal within 0.5 percent (1,651,008 lb/hr - West, and 1,642,427 - East). Due to the apparent error in the East plant instrument reading, the plant instrumentation department has disconnected the East input to the plant air flow totalizer and is using the West venturi input only (doubled) to indicate total air flow for control and monitoring purposes.

LOI Testing

The intent of the current LOI 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. In order to assess the effects of each selected parameter independently, a matrix of test conditions was devised such that a single parameter would be varied during each test day, to the extent that other parameters could be held constant. Table 1 presents the test matrix as it was originally planned and eventually carried out, with only minor exceptions. The main parameters evaluated were, overall boiler excess O₂, mill coal flow bias, burner inner and outer register settings, and coal pipe position (insertion depth).

The burner sleeve dampers, which control the total air flow to each burner, were specifically excluded from the test matrix. Since there are innumerable variations that could be made to the sleeve damper settings, which could affect the furnace combustion balance considerably, it was decided that any adjustment to these dampers should constitute a completely separate test series. As established by FWEC, the sleeve damper positions of the outer burners in each row (the A and D burners) were set at the 7 inch position, and the inner burners (B and C) at the 4 inch position.

Because Hammond Unit 4 has not been able to pass the required particulate emissions test at full load (480 MWe), the present test series was conducted at a nominal load level of 450 MWe, with all mills in service. This was the same condition that the mill coal/air flow and fineness tests were performed as described above.

The "Baseline" condition for all tests was with equal coal flow to each mill and all burner mechanisms set to the "nominal" positions established by FWEC. Prior to the commencement of testing, ETEC obtained a listing of all pertinent burner and Advanced Overfire Air (AOFA) damper settings which constitute the "nominal" condition. FWEC also advised ETEC regarding proper procedures to be used in operating the burner mechanisms and the maximum degree of movement from "nominal" that should be made. This advice was followed in all subsequent testing. The principal cautions expressed by FWEC, were not to close the inner or outer swirl registers excessively and especially not to withdraw the burner inner coal pipe tips more than 2 inches from the current "nominal" setting of 4 inches insertion. The reason for this admonition was to prevent exposure of the burner ignitors to excessive radiant heat. Also, FWEC requested that the AOFA flow control dampers not be closed any more than would permit a minimal air flow of 50 Klb/hr through each of the four dampers, so as to prevent excessive slagging or heating of the OFA ports.

Examination of the burners revealed that there were clear markings indicating the full-open, full-closed and "nominal" positions for the sleeve dampers, inner and outer registers and coal pipe positions on most burners. However, several of the indicated markings, especially for the inner registers, did not agree with the written listings supplied by FWEC. ETEC assumed that all of the burner markings were correct and recorded the

various burner settings throughout the testing program. Since the inner and outer register position indicators were circumferential dials, with only the closed, open and "nominal" settings indicated by FWEC, ETEC estimated the degree of travel from the nominal position. This was done as a percentage of the total travel indicated between the closed and open indications. In all cases the movement indicators responded properly to the operator actuation of the mechanism. Therefore, it is believed that the indicated positions recorded on the data sheets during the testing reflect a reasonably accurate account of the burner positions relative to the "nominal" positions marked on the burner housings.

A total of 40 tests were conducted between October 20 and 28, 1992. Table 3 summarizes the results of those tests. Tests are numbered according to the format XX-Y, where XX represents the sequential test day since the CCTII program began at Plant Hammond, and Y represents the sequential test performed on that day.

On each day of testing, coal samples were taken in accordance with normal plant procedures, a composite sample being obtained from equal samples from each mill feeder. These composite samples were crushed and sealed in three plastic bags identified with the date, time of sample and test number. The standard CCTII sample identification tags were then attached. One portion of each sample was analyzed for chemical composition and heating value at the Alabama Power Company fuel laboratory. One portion was stored in the CCTII sample archive and the third portion was stored separately for random independent analysis.

On day 92, three tests were conducted while the SoRI particulate sampling team was setting up their equipment. These tests were performed primarily to establish that satisfactory operation could be maintained with substantial biasing of the mill coal flows.

On day 93, four tests were performed with the coal flow to all mills approximately equal, and with all burner settings at their "nominal" positions as established by FWEC (see above). The boiler excess O₂ was varied from a "nominal" value of about 4.0 percent (CEM composite economizer outlet average - the plant instrumentation indicated approximately 2.7 percent O₂), to a minimum of 2.8 percent (high CO limiting condition) and a maximum of 4.6 percent (high opacity and ID fan control limitation).

As shown in Figures 1 & 2, the excess O₂ level has a considerable effect on both ash LOI and NO_x emissions. Figures 1 and 2 also include data from subsequent test days which reflect the "Baseline" condition of all "nominal" burner settings, balanced coal flows to each mill and "minimal" air flow to the OFA ports (flow control dampers virtually closed off). The least squares linear curve fit lines shown in Figures 1 and 2 depict curve fits to the "Baseline" data on day 93 only. These curve fits were used to normalize the subsequent parametric data to mitigate the effects of minor variations in excess O₂ on LOI and NO_x emissions when comparing the effects of the other parameters being tested.

Figures 1 and 2 also show the results obtained when the OFA dampers were set to their "nominal" open positions (providing approximately 600 klb/hr of total OFA air flow). It can be seen from Figure 1 that the use of "nominal" OFA produces only a minor effect on LOI (slightly above the extended baseline curve fit line). In addition, Figure 2 illustrates that, while the increased OFA flow (from approximately 200 klb/hr minimum to 600 klb/hr nominal) does reduce Nox below the curve fit line substantially, the increased excess O₂ required to maintain CO emissions at a reasonable level results in little or no actual reduction in total Nox emissions compared to the "baseline" with reduced OFA flow and lower excess oxygen.

On day 94 the inner air registers were opened approximately 20 percent and 40 percent of the full travel from the "nominal" positions indicated on the burners. Most of the "nominal" markings for the inner registers were very close to the indicated "Closed" markings, and therefore no attempt was made to test at a further closed position. Figures 3 and 4 indicate that LOI increased about 2 percent as the inner registers were opened to about 20 percent from "nominal", and returned to the "nominal" level when the registers were further opened to 40 percent from the "nominal" position. This apparent effect may be due solely to random scatter in the effects on LOI or may reflect a real disturbance to the burner flames at that particular burner setting. The effect of inner register adjustments on Nox emissions was negligible, although a minor effect at the 20 percent position may again suggest a real influence on flame conditions.

In all of the figures of LOI and Nox variation with burner settings, the open circles with labels to the right represent the measured data (Nox corrected to 3 percent O₂) and the solid circles with labels to the left represent the data "normalized" to a consistent excess O₂ level by using the slopes of the linear curve fits determined in Figures 1 and 2. Thus, the "normalized" values represent what the LOI or Nox "is presumed to have been" if the excess O₂ level had been maintained absolutely constant during the testing of the parameter of interest. When appropriate, the lines shown in the LOI and Nox figures are least squares fits of the "normalized" data only.

On day 95, variations were made in the Outer register positions of approximately $\pm$ 30 percent from the "nominal" positions ("nominal" varied from about 40 percent to 80 percent of full open, as indicated by the O and C marks made on the register position indicator). Figures 5 and 6 show the results of these variation about the nominal settings. The figures also contain data from test 98-4, which was conducted with the outer registers set to 30 percent below the "nominal" position and all other conditions "nominal". It can be seen that the LOI decreased minimally, but consistently as the outer registers were opened. Surprisingly, this also resulted in a slight decrease in Nox emissions. Both effects, however, are too slight to be of any major significance and are assumed to be within the normal data scatter. It is therefore assumed that the movement of the outer register has no effect on Nox and LOI in the range tested.

On day 96, the coal flow to the mills was biased to provide higher coal flow to the upper burner levels (mills C & F) and lower coal flow to the lower burner levels (mills A & E), with the coal flow to the center burners (mills B & D) in between (Test 96-1). Another test was performed with the coal bias reversed, i.e. lower coal flow to the upper burners and higher to the bottom burners (Test 96-3). Two tests (Tests 96-2 and 96-4) were also conducted with balanced flow to all burners (according to the Stock feeder coal flow indicators). All burner settings were at their normal positions during these bias tests. Figures 7 and 8 show the results of these tests. Clearly, the mill bias affects both LOI and Nox emissions substantially.

On day 97 the positions of the inner coal pipe tips were adjusted (all burners equally) from the "nominal" position established by FWEC. The "nominal" position was 4 inches insertion from the "zero", or fully withdrawn position. In keeping with FWEC's request, the tips were withdrawn only to the 2 inch insertion position so as to prevent excessive thermal radiation exposure to the ignitors. As shown in Table 3, four tests were performed, two at the "nominal" setting and one each at the 2 inch and 3 inch positions. All other burner settings were at their "nominal" positions and the coal flow was equal to each mill. Figures 9 and 10 show that LOI was slightly decreased and Nox slightly increased as the coal pipes were withdrawn to the 2 inch position. The Figures also include data from test 98-3 which duplicated the conditions of test 97-3.

On day 98 tests were conducted to repeat selected burner settings previously performed in order to confirm the "best" settings likely to produce the lowest LOI emissions. In addition, one test of mill bias to the upper burners was repeated. The data from these tests were included in the previous figures.

On day 99, the "best" burner settings (lowest combination of LOI and Nox emissions) were tested. Following a test in the "Baseline" configuration (i.e. the test 92-1 configuration), the inner registers were left at their "nominal" settings, the outer registers were closed 20 percent from "nominal" and the coal pipes were withdrawn to the 2 inch position. All settings were identical on each burner. No mill bias was employed during these tests. The overall boiler excess O₂ was varied from minimum (high CO limit) to maximum (high ID fan control and high opacity limitation), as well as the "nominal" 4 percent level.

Figures 11 and 12 show the effects of excess O₂ on LOI and NOx emissions, respectively, for the assumed "optimum" configuration. The figures show several significant characteristics. The level of LOI at 4 percent excess O₂ with the "optimized" combined burner adjustments is approximately 1% less than that found with the nominal burner settings (day 93). However, the LOI in the baseline configuration on test day 99 shows only an insignificant difference from that of the "optimized" configuration. From Figure 11 it can be concluded that the LOI is the same at the nominal O₂ setting. Interestingly, the slope of the curve fit for test day 99 is lower (-1.713) than the slope of the "Baseline" curve

fit on day 93 (-2.370), indicating that the "optimized" burner adjustments tend to make the LOI emissions marginally less dependent on excess O₂ level. This apparent effect, however, may just be an artifact of measurement inaccuracies and combustion variations.

Figure 12 shows a comparison of the "baseline" NOx from test day 93 (Figures 2) and the "optimized" configuration for test day 99 which illustrates the effects of the "optimized" burner settings on NOx emissions. The "optimized" settings appear to be about 10 percent higher than the "Baseline" settings at an excess O₂ level of 4.0 percent, although part of this apparent difference may be due to normal data scatter. The lower "Baseline" NOx shown for test 99-1 in Figure 12 tends to support the generally higher NOx emissions with the "optimized" burner settings. Finally, the slope of the curve fit lines indicate that the "optimized" settings tend to make NOx emissions more dependent on excess O₂ than the "Baseline" settings (0.0972 slope vs 0.0686).

On day 100, tests were conducted to reconfirm the effect of excess O₂ on LOI and NOx emissions for the "Baseline" conditions. A single test was conducted with the OFA dampers set to their normal positions for a load level of 450 MWe, as recommended by FWEC. The results are shown in Figures 13 and 14. As in the initial "Baseline" tests (day 93), the normal OFA condition shows negligible LOI difference from the nearly closed OFA condition, and only about a 15 percent decrease in NOx from the closed OFA condition at the same excess O₂ level. At a nominal excess O₂ level of 4.0 percent with minimal OFA flow, the NOx level is about equal to the nominal excess O₂ level of 5.0 percent with normal OFA flow. For comparison, the curve fit line from Figures 1 and 2 are included in Figures 13 and 14. It can be seen that the "Baseline" LOI was significantly lower on day 100 than on the previous days, while the NOx level was essentially the same as all other "Baseline" tests. The reason for the reduced LOI on day 100 is not known.

This small amount of data may indicate that the LOI repeatability from day-to-day may be in the range of ± 1 percentage point, however, the variation in LOI and NOx at identical conditions within a single day should be much more repeatable. The day-to-day variation in results is probably dependent upon slightly varying coal properties, variations in mill grinding performance, slight differences in the boiler operation and burner settings and other factors that may not be readily apparent. Despite the day-to-day variations in absolute values, especially for LOI, the slope of LOI and NOx vs the various operating parameters does remain relatively constant, as would be expected.

For all tests, SoRI analyzed the LOI of the ash samples the day following the sample acquisition, using their mobile test laboratory. The carbon, hydrogen and nitrogen (CHN) content of each sample were determined in their chemical laboratory in Birmingham immediately following the conclusion of the test series. The results of both the LOI and Carbon analyses are summarized in Table 4. These results are plotted graphically in Figure 15. The plot shows that the results are very consistent (with the exception of test 96 - 5), and that the LOI was approximately 25 percent higher than the measured carbon content.

This difference is probably due to the presence of volatile sulfates contained in the ash which are driven off in the LOI determination, but are not measured as carbon in the CHN analysis. In test 96 - 5, it is possible that the sulfate content was abnormally high, resulting in the abnormally high LOI content relative to the carbon content.

During the Hammond LOI testing, the unit was configured in many different modes and the excess oxygen was varied over a relatively wide range. To ascertain if a general relationship exists between NOx emissions and LOI, all of the data for the different modes and different excess oxygen levels were plotted and a linear curve fit was determined for the data set. Figure 16 illustrates the result of this correlation. The data show a definite trend of decreased LOI with increased NOx emissions. This leads to the premise that if LOI were an important parameter with regard to achieving performance goals, NOx could be sacrificed to achieve the LOI goal. This would be appropriate if the NOx levels were well below the required NOx limitation. The curve fit for the Hammond data indicate that LOI decreases by 0.5 percentage points with each 10 ppm of NOx increase. The data also indicate that LOI could be varied by as much as 5 percentage points through configuration changes and increases in excess oxygen level over the useful range of the variables investigated. By far, the greatest influence on both LOI and NOx emissions is the level of excess oxygen supplied to the combustion process.

PRELIMINARY CONCLUSIONS

Based on the initial analysis of the test results, the following preliminary conclusions are drawn:

- 1) Excess oxygen is the principal variable influencing both LOI/Carbon content in the fly ash and NOx emissions.
- 2) NOx and LOI/Carbon in ash are inversely related; i.e. NOx increases and LOI/Carbon decreases with increasing O₂.
- 3) The "nominal" inner register settings established by FWEC (nearly at the "zero" position) result in the minimum LOI emissions and maximum NOx emissions, all other parameters being equal.
- 4) Variations in outer register settings produced only slight changes in both LOI and NOx; LOI increased as the Outer Registers were closed from the FWEC "nominal" position. NOx was essentially unaffected by Outer Register position.
- 5) Coal pipe position had a significant effect on both LOI and NOx. LOI decreased and NOx increased as the coal pipes were withdrawn from the FWEC "nominal" position.

- 6) Biasing of the coal flow toward the lower burners resulted in a significant decrease in LOI and an increase in NOx emissions.
- 7) LOI is a reliable indicator of carbon content in the fly ash for this coal, being consistently about 1.1 times the carbon level.
- 8) There is considerable scatter in both LOI and NOx emissions for tests conducted under "identical" conditions on different days. Thus, it is important that any trends of LOI and NOx vs variations in operating parameters be conducted on a single day.

These results are presented as the first indications of the impacts of the burner operating variables on LOI and NOx on the Hammond Unit 4. Additional analyses may be performed subsequently and included in the Final Report of the Hammond CCTII project.

If you have any questions concerning this analysis or the test program, please contact Lowell Smith at (714) 753-9126.

Sincerely,

For Larry L. Larsen

CC

Ernie Padgett - GPC

Jeff Stallings - EPRI

Lowell Smith - ETEC

Stratos Tavoulareas - Decision Focus

TABLE 1
HAMMOND UNIT 4
NOx/LOI TRADE-OFF TEST MATRIX

PARAMETER VARIATION							
DAY	EO	IR	OR	MCF	CPP	LOI	COMMENTS
1	NOM NOM NOM	NOM NOM NOM	NOM NOM NOM	NEG NOM POS	NOM NOM NOM	NONE NONE NONE	ESTABLISH RANGE OF TEST CONDITIONS FOR MILL BIASING, SET UP SAMPLING EQUIPMENT
2	NEG NOM POS NOM NEG	NOM NOM NOM NOM NOM	NOM NOM NOM NOM NOM	NOM NOM NOM NOM NOM	NOM NOM NOM NOM NOM	ISO-K ISO-K ISO-K ISO-K ISO-K	ESTABLISH NOx/LOI VS O2, DETERMINE WITHIN DAY REPEATABILITY
3	NOM NOM NOM NOM	NEG NOM POS NOM	NOM NOM NOM NOM	NOM NOM NOM NOM	NOM NOM NOM NOM	ISO-K ISO-K ISO-K ISO-K	ESTABLISH NOx/LOI VS IR SETTING, DETERMINE REPEATABILITY
4	NOM NOM NOM NOM	NOM NOM NOM NOM	NEG NOM POS NOM	NOM NOM NOM NOM	NOM NOM NOM NOM	ISO-K ISO-K ISO-K ISO-K	ESTABLISH NOx/LOI VS OR SETTING, DETERMINE REPEATABILITY
5	NOM NOM NOM NOM	NOM NOM NOM NOM	NOM NOM NOM NOM	NEG NOM POS NOM	NOM NOM NOM NOM	ISO-K ISO-K ISO-K ISO-K	ESTABLISH NOx/LOI VS MCF SETTING, DETERMINE REPEATABILITY
6	NOM NOM NOM	NOM NOM NOM	NOM NOM NOM	NOM NOM NOM	NEG NOM POS	ISO-K ISO-K ISO-K	ESTABLISH NOx/LOI VS CPP SETTING,
7	TBD TBD TBD	TBD TBD TBD	TBD TBD TBD	TBD TBD TBD	TBD TBD TBD	ISO-K ISO-K ISO-K	ESTABLISH IMPACT OF COMBINATIONS
8	NEG NOM POS NOM NEG	BEST BEST BEST BEST BEST	BEST BEST BEST BEST BEST	NOM NOM NOM NOM NOM	BEST BEST BEST BEST BEST	ISO-K ISO-K ISO-K ISO-K ISO-K	ESTABLISH BURNER SETTINGS FOR BEST BURNER SETTINGS VS EXCESS OXYGEN, DETERMINE REPEATABILITY
9	NEG NOM POS	BEST BEST BEST	BEST BEST BEST	NOM NOM NOM	BEST BEST BEST	ISO-K ISO-K ISO-K	REPEAT DAY 8
10	TBD	TBD	TBD	TBD	TBD	ISO-K	CONTINGENCY DAY

EO: EXCESS OXYGEN
IR: INNER REGISTER
OR: OUTER REGISTER

MCF: MILL COAL FLOWRATE
CPP: COAL PIPE POSITION

D:\SCSV12R3\HLOISUMM\HLOITSTM.WK3

TABLE 2

SUMMARY OF MILL PERFORMANCE TESTS
HAMMOND UNIT 4 SPECIAL LOI TESTS

OCTOBER 15 – 16, 1992

PARAMETER	TEST FRI-01, 10/15/92						TEST FRI-02, 10/16/92					
	A	B	C	D	E	F	A	B	C	D	E	F
MEASURED COAL FLOW, KLB/HR	65.1	65.8	71.6	43.0	72.1	65.3	57.6	62.8	72.5	38.5	71.5	66.1
MEASURED PA FLOW, KLB/HR	132.9	145.6	147.5	155.3	151.0	136.9	127.9	146.1	145.1	152.8	149.1	136.8
A/F RATIO	2.04	2.21	2.06	3.61	2.09	2.10	2.22	2.33	2.00	3.97	2.09	2.07
AVG. BURNER PIPE VELOCITY, FPM	5,288	7,276	5,836	7,814	5,993	5,327	5,093	7,326	5,735	7,680	5,913	5,323
HIGH PIPE COAL FLOW, KLB/HR	20.5	18.9	22.5	14.8	20.3	18.7	15.6	18.1	21.1	14.0	19.5	19.1
LOW PIPE COAL FLOW, KLB/HR	13.1	15.1	14.4	7.3	15.5	12.8	13.3	14.4	15.3	6.5	17.0	13.7
AVG. PASSING 200 MESH, PCT	77.85	65.14	78.89	69.22	78.25	78.82	81.36	66.85	77.56	68.25	70.44	74.77
AVG. PASSING 50 MESH, PCT	99.98	98.01	99.95	97.93	99.93	99.87	99.97	98.28	99.98	97.77	99.88	99.92

TABLE 3
SUMMARY OF LOI TESTING
HAMMOND UNIT 4 SPECIAL LOI TESTS

ALL MILLS IN SERVICE

TEST #	DATE	START TIME	LOAD MW	GR O ₂ %		OFA SETTING	BURNER SETTINGS		MILL BIAS	ECONOMIZER OUTLET EMISSIONS			AVG LOI %	AVG CARBON %	DESCRIPTION
				EAST	WEST		IR %	OR %		O ₂ %	NOx ppm	CO ppm			
92-1	10/20/92	1340	452	4.2	4.1	MINIMUM	NOM	NOM	NONE	5.6	386	0.528	NA	NA	BASLINE
92-2	10/20/92	1535	450	4.4	4.1	MINIMUM	NOM	NOM	BOTTOM	5.6	383	0.524	NA	NA	COAL BIAS TO LOWER 2 MILLS
92-3	10/20/92	1630	450	4.1	4.0	MINIMUM	NOM	NOM	TOP	5.5	365	0.489	NA	NA	COAL BIAS TO UPPER 2 MILLS
93-1	10/21/92	0820	448	2.7	2.9	MINIMUM	NOM	NOM	NONE	4.2	358	0.480	7.9	7.0	MEDIUM O ₂
93-2	10/21/92	1055	447	3.7	3.9	MINIMUM	NOM	NOM	NONE	4.6	430	0.588	4.5	3.4	HIGH O ₂
93-3	10/21/92	1340	442	2.3	2.2	MINIMUM	NOM	NOM	NONE	2.8	319	0.436	10.4	9.5	MIN O ₂ CO POINT
93-4	10/21/92	1600	442	2.8	2.8	MINIMUM	NOM	NOM	NONE	3.5	357	0.489	6.6	6.1	MEDIUM O ₂
94-1	10/22/92	0700	443	3.0	2.4	MINIMUM	NOM	NOM	NONE	3.2	323	0.442	9.3	8.5	BASLINE
94-2	10/22/92	0845	442	2.7	2.3	MINIMUM	NOM	NOM	NONE	3.5	328	0.450	6.9	8.4	INNER REGS + 20%
94-3	10/22/92	1230	441	2.8	2.2	MINIMUM	NOM	NOM	NONE	3.3	331	0.453	8.5	7.5	INNER REGS + 40%
94-4	10/22/92	1425	441	2.8	2.3	MINIMUM	NOM	NOM	NONE	3.4	331	0.453	7.5	6.7	INNER REGS + 40%
94-5	10/22/92	1545	442	2.9	2.2	MINIMUM	NOM	NOM	NONE	3.5	338	0.462	8.6	6.9	BASLINE
95-1	10/23/92	0700	443	3.2	2.6	MINIMUM	NOM	-30%	NONE	4.1	387	0.529	23	4.7	OUTER REGS - 30%
95-2	10/23/92	0910	445	3.1	2.2	MINIMUM	NOM	NOM	NONE	4.0	379	0.518	5.4	5.0	BASLINE
95-3	10/23/92	1200	443	2.9	2.0	MINIMUM	NOM	+30%	NONE	3.3	337	0.461	8.0	6.2	OUTER REGS + 30%
95-4	10/23/92	1415	442	3.4	2.9	MINIMUM	NOM	NOM	NONE	3.9	386	0.545	32	4.1	BASLINE
96-1	10/24/92	0700	445	3.5	2.6	MINIMUM	NOM	NOM	UPPER	4.4	368	0.504	31	6.8	COAL FLOW BIASED TO UPPER BURNERS
96-2	10/24/92	0900	441	3.4	2.2	MINIMUM	NOM	NOM	NONE	4.1	370	0.506	7.9	6.0	BASLINE NO COAL BIAS
96-3	10/24/92	1100	440	3.5	2.2	MINIMUM	NOM	NOM	LOWER	3.9	381	0.534	100	5.5	COAL FLOW BIASED TO LOWER BURNERS
96-4	10/24/92	1315	441	3.7	2.3	MINIMUM	NOM	NOM	NONE	4.2	388	0.531	71	5.3	BASLINE NO COAL BIAS
96-5	10/24/92	1520	440	4.6	3.4	NORMAL	NOM	NOM	NONE	5.5	390	0.534	44	4.2	BASLINE WITH STD OFA
97-1	10/25/92	0845	447	3.6	2.1	MINIMUM	NOM	NOM	NONE	4.0	372	0.509	158	7.2	BASLINE WITH MINIMUM OFA
97-2	10/25/92	1050	442	3.5	2.1	MINIMUM	NOM	NOM	NONE	4.0	384	0.525	113	6.7	COAL PIPES AT 3" INSERTION
97-3	10/25/92	1300	441	3.5	2.3	MINIMUM	NOM	NOM	NONE	4.1	400	0.547	35	5.7	COAL PIPES AT 2" INSERTION
97-4	10/25/92	1510	445	3.7	2.1	MINIMUM	NOM	NOM	NONE	4.2	373	0.510	205	6.2	BASLINE WITH MINIMUM OFA
98-1	10/26/92	0750	447	3.5	2.7	MINIMUM	NOM	NOM	NONE	4.2	360	0.520	14	5.7	BASLINE WITH MINIMUM OFA
98-2	10/26/92	1020	441	3.6	2.6	MINIMUM	NOM	NOM	UPPER	4.4	371	0.507	25	7.1	COAL FLOW BIAS TO UPPER BURNERS
98-3	10/26/92	1245	441	3.7	2.6	MINIMUM	NOM	NOM	NONE	4.3	410	0.561	15	4.9	COAL PIPES AT 2" INSERTION
98-4	10/26/92	1445	440	4.0	2.7	MINIMUM	NOM	-20%	NONE	4.8	418	0.572	15	4.3	OUTER REGISTERS - 20%
98-5	10/26/92	1640	441	3.7	2.2	MINIMUM	NOM	NOM	NONE	4.4	386	0.529	66	6.1	BASLINE WITH MINIMUM OFA
99-1	10/27/92	0720	442	3.4	2.5	MINIMUM	NOM	NOM	NONE	4.2	373	0.510	36	4.9	BASLINE WITH MINIMUM OFA
99-2	10/27/92	1000	445	3.4	2.5	MINIMUM	NOM	-20%	NONE	4.3	407	0.557	18	4.4	COAL PIPES AND OUTER REGS ADJUSTED
99-3	10/27/92	1210	440	2.8	1.7	MINIMUM	NOM	-20%	NONE	3.6	381	0.521	153	5.6	SAME MINIMUM O ₂
99-4	10/27/92	1400	445	4.8	4.0	MINIMUM	NOM	-20%	NONE	5.9	539	0.737	19	1.6	SAME HIGH O ₂
99-5	10/27/92	1630	445	3.5	2.5	MINIMUM	NOM	-20%	NONE	4.2	414	0.566	26	3.6	SAME AS 99-2
100-1	10/28/92	0630	446	3.5	2.4	MINIMUM	NOM	NOM	NONE	4.2	374	0.511	36	3.8	BASLINE WITH MINIMUM OFA & MED O ₂
100-2	10/28/92	0825	442	3.1	1.9	MINIMUM	NOM	NOM	NONE	3.7	353	0.483	99	4.3	BASLINE WITH MINIMUM OFA & LOW O ₂
100-3	10/28/92	1030	443	4.2	3.3	MINIMUM	NOM	NOM	NONE	5.0	428	0.586	17	2.8	BASLINE WITH MINIMUM OFA & HIGH O ₂
100-4	10/28/92	1235	442	3.5	2.4	MINIMUM	NOM	NOM	NONE	3.9	373	0.511	34	4.2	BASLINE WITH MINIMUM OFA & MED O ₂
100-5	10/28/92	1430	443	4.2	3.3	NORMAL	NOM	NOM	NONE	5.0	380	0.519	22	3.0	BASLINE WITH NORMAL OFA, MED O ₂

OVERFIRE
AIR
CONTROL
DAMPERS

INNER REGISTER

OUTER REGISTER

COAL PIPE POSITION

TABLE 4
CARBON / LOI DATA SUMMARY
HAMMOND UNIT 4 SPECIAL LOI TESTS

TEST #	MASS LOADING GR/ACF		GAS FLOW KACFM		TEMPERATURE DEG F		EXCESS O2 PERCENT		LOI OF ASH PERCENT		CARBON IN ASH PERCENT	
	A	B	A	B	A	B	A	B	A	B	A	B
93-1	1.57	1.85	2,011	1,944	287	282	7.2	5.4	8.0	7.8	7.0	7.0
93-2	1.50	1.17	2,112	2,153	294	294	6.7	7.5	4.3	4.6	3.5	3.3
93-3	1.84	1.83	1,877	19	299	296	5.6	6.2	10.8	9.9	10.0	9.0
93-4	1.62	1.53	2,013	2,144	304	294	6.4	7.5	6.6	6.6	6.3	5.9
94-1	1.88	2.00	1,900	1,864	285	279	5.8	6.6	9.2	9.4	8.1	8.9
94-2	.67*	1.73	1,783*	1,919	281	287	6.4	6.5	11.2*	9.6	10.0*	8.4
94-3	.34*	1.81	1,794*	1,953	311	298	6.2	6.2	8.7*	8.5	12.6*	7.5
94-4	1.75	1.44	1,924	1,967	311	301	5.4	6.5	7.0	7.9	6.5	6.9
94-5	1.18	1.76	1,944	1,953	308	301	5.4	6.7	7.2	7.9	6.8	7.0
95-1	1.63	1.82	2,005	1,993	289	281	5.9	7.6	5.1	5.6	4.4	4.9
95-2	1.79	1.81	1,987	1,971	288	287	5.6	7.4	5.7	5.6	5.0	4.9
95-3	1.91	1.81	1,916	1,918	299	293	5.5	7.6	7.0	6.7	6.2	6.1
95-4	1.93	2.06	1,990	1,983	303	298	5.7	6.5	4.5	4.7	3.8	4.3
96-1	1.82	1.81	2,038	1,980	288	281	5.7	6.5	7.4	7.9	6.7	6.9
96-2	1.69	1.96	2,021	1,996	291	286	5.8	6.9	6.5	6.6	5.9	6.0
96-3	1.67	1.97	2,015	1,969	301	294	6.4	6.3	6.2	6.2	5.5	5.5
96-4	1.81	1.64	2,017	2,047	303	300	6.7	6.4	6.2	6.1	5.3	5.2
96-5	1.70	1.76	2,260	2,257	307	304	7.5	7.8	6.2	6.1	4.1	4.2
97-1	1.67	1.87	2,032	2,086	288	296	6.2	6.4	8.3	7.3	7.8	6.5
97-2	1.73	1.72	1,962	2,075	272	299	5.8	7.0	6.9	7.8	6.2	7.1
97-3	1.71	1.72	2,041	2,069	304	302	6.1	6.6	6.1	6.4	5.7	5.6
97-4	1.67	1.47	2,104	2,100	304	303	5.9	6.2	7.1	6.8	6.3	6.0
98-1	1.58	1.88	2,088	2,025	287	284	6.4	7.0	6.5	6.4	5.7	5.6
98-2	1.79	1.71	2,123	2,075	296	295	6.2	6.7	7.6	7.9	6.9	7.2
98-3	1.66	1.80	2,071	2,107	290	301	6.4	6.3	5.7	5.4	5.2	4.6
98-4	1.60	1.71	2,171	2,181	300	304	6.3	6.9	5.0	5.2	4.3	4.3
98-5	1.59	1.61	2,065	2,076	304	300	5.8	6.4	7.0	6.6	6.3	5.9
99-1	1.83	2.12	2,073	2,063	287	285	6.2	6.5	5.3	5.5	4.7	5.1
99-2	1.90	1.96	2,079	2,127	298	294	6.0	6.8	4.7	5.2	4.2	4.6
99-3	1.91	1.78	2,007	2,024	301	298	6.0	6.0	6.1	6.5	5.5	5.7
99-4	1.64	1.71	2,417	2,434	307	307	6.9	8.1	2.1	2.1	1.7	1.4
99-5	1.72	1.77	2,146	2,171	302	298	6.5	7.0	3.8	4.2	3.4	3.7
100-1	2.00	2.00	2,096	2,101	284	288	5.6	6.8	4.2	4.2	3.8	3.7
100-2	1.84	2.14	2,048	2,038	294	292	6.2	6.8	4.9	4.7	4.3	4.3
100-3	1.87	1.77	2,265	2,272	300	296	7.3	7.9	2.8	2.8	2.2	2.1
100-4	1.75	1.80	2,095	2,123	301	297	6.1	5.9	4.2	4.1	3.5	3.5
100-5	1.77	1.88	2,278	2,321	307	300	6.8	7.8	3.5	3.4	3.1	2.8

* SUSPECTED SAMPLE NOZZLE MISALIGNMENT, DATA DISREGARDED

FIGURE 1

LOI/O2 SENSITIVITY

STANDARD BURNER SETTINGS

FIGURE 2

NOx/O2 SENSITIVITY

STANDARD BURNER SETTINGS

FIGURE 3
LOI/INNER REGISTER SENSITIVITY
STANDARD BURNER SETTINGS OTHER THAN IR

FIGURE 4

NO_x/INNER REGISTER SENSITIVITY

STANDARD BURNER SETTINGS OTHER THAN IR

FIGURE 5

LOI/OUTER REGISTER SENSITIVITY

STANDARD BURNER SETTINGS OTHER THAN OR

FIGURE 6

NOx/OUTER REGISTER SENSITIVITY

STANDARD BURNER SETTINGS OTHER THAN OR

FIGURE 7

LOI/MILL BIAS SENSITIVITY

STANDARD BURNER SETTINGS

FIGURE 8

NOx/MILL BIAS SENSITIVITY STANDARD BURNER SETTINGS

FIGURE 9

LOI/COAL PIPE POSITION SENSITIVITY

STANDARD BURNER SETTINGS OTHER THAN CPP

FIGURE 10

NOx/COAL PIPE POSITION SENSITIVITY

STANDARD BURNER SETTINGS OTHER THAN CPP

FIGURE 11
LOI/O2 SENSITIVITY
"OPTIMIZED" BURNER SETTINGS

CEM COMPOSITE EXCESS O₂, PCT

FIGURE 12

NOx/O2 SENSITIVITY

"OPTIMIZED" BURNER SETTINGS

FIGURE 13

LOI/O2 SENSITIVITY VARIABILITY

STANDARD BURNER SETTINGS

FIGURE 14

NOx/O2 SENSITIVITY VARIABILITY

STANDARD BURNER SETTINGS

FIGURE 15

COMPARISON OF LOI AND CARBON RESULTS

HAMMOND UNIT 4 PHASE 3A LOI TEST PROGRAM

FIGURE 16

LOI/NOx SENSITIVITY

ALL BURNER SETTINGS, ALL EXCESS OXYGEN LEVELS

**DATE
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