Project Status Report for: July 2000

Project Title: Ultra Low NOx Integrated System for Coal-Fired Power Plants

Project Number: 91890460 **Project Manager:** John Marion

Customer Name: U.S. DOE / Performance Projects **Project Leader:** Charles Maney

GOALS AND OBJECTIVES:

Develop low cost, retrofit NO_x control technologies to address current and anticipated, near term emissions control legislation for existing coal fired utility boilers. Specific goals include:

- Achieve < 0.15 lb/MMBtu NO_x for eastern bituminous coals
- Achieve < 0.10 lb/MMBtu NO_x for western sub-bituminous or lignitic coals
- Achieve economics at least 25% less than SCR-only technology
- Validate NOx control technology through large (15 MWt) pilot scale demonstration
- Evaluate the engineering feasibility and economics for representative plant cases
- Provide input to develop commercial guidelines for specified equipment
- Provide input to develop a commercialization plan for the resultant technologies

WORK PLANNED FROM PREVIOUS REPORT:

Task 2.3 – Global Mixing Process Improvement

- The remaining parametric runs to evaluate SOFA mixing will be completed in July. Additional post processing of the existing cases will be started to investigate the impact of SOFA mixing on the mass flow and temperature distributions entering the convective pass. Chemical kinetic modeling to investigate / evaluate the high temperature SNCR process will be continued.

Task 2.4 – Advanced Control System Design

- Install and configure AC 460 DCS Upgrade (internally funded, project related work)
- Obtain unit data suitable for NOx-heat rate and carbon in ash neural net modeling from at least one large Tangentially Fired Pulverized Coal Utility Boiler and begin modeling effort.
- Receive the first of the PC flow meters; develop detailed plans for August installation.
- Build on-line extractive sampling CIA sensor system
- Build optical combustion sensing system for use during BSF testing.

Task 3.1 – Test Planning & Facility Preparation

- The following work will be completed in July for Task 3.1:

  Plumbing / Mechanical

  - Finish repairing identified leaks in the BSF water-jacket
  - Install corner SOFA assemblies
  - Service CFS air buckets
  - Install coal and air nozzles in windbox
  - Procure materials for installation of coal mass flow meters
  - Install 18" flexible ducting for combustion air system

- Remove blankoff plate after Maxon (direct fired air preheat / warm-up) burner

Electrical

- Check out BSF in-furnace camera system,
- Upgrade direct-fired air heater burner,
- Begin construction of flame scanning hardware for BSF,
- Design and fabricate extractive system for carbon in ash measurements,
- Install U-tube heat flux water flow meters,
- Complete refurbishment of individual windbox compartment flow devices,
- Pull cable for remote I/O for new DCS,
- Design and order heat exchanger level control system

Task 4 – Carbon Burnout System Evaluation

- Work on the CBO™ system evaluation will be initiated in July, including the transfer of preliminary CBO™ cost and performance data from Progress Materials to U.S. Power Plant Laboratories.

Task 5 – Engineering Systems Analysis & Economics

- Complete the preliminary economic comparison of the selected ultra-low NOx emission systems. Upgrade the economic model program to enable performance calculations the results of which will be used by the existing program to perform economic analysis.

ACCOMPLISHMENTS FOR REPORTING PERIOD:

Task 2.1 – Test Fuels Characterization

- *A sample of the candidate low reactivity bituminous coal will be obtained and characterization work will be initiated in July.*

A five (5) gallon sample of the medium volatile, low reactivity, bituminous coal was obtained and analyzed for ASTM properties in July. As shown in Table 1, the low reactivity coal sample has 27.5% VM on a dry ash free basis, consistent with the program objectives, and the previously selected fuel analysis. However, both the sulfur (1.9% vs. a spec of <1.65%) and ash contents (16.1% vs. a spec of <15%) are higher than expected or desired based on specified fuel properties.

The coal supply house has been notified of this discrepancy and a second 5 gallon sample has been requested with assurances that is will meet the desired test fuel specification. Repeat ASTM analysis will be performed upon receipt to verify compliance followed by performance of planned bench scale test procedures.

Table 1 – Medium Volatile Bituminous Coal Sample Analysis

	Med Vol Bit Selected	Med Vol Bit Actual
Proximate		
VM	24.3%	22.1%
FC	57.9%	58.2%
FC/VM	2.38	2.63
VM, DAF	28.1%	27.5%
Ultimate		
Moisture	-	3.6%
Hydrogen	4.6%	3.8%
Carbon	71.8%	69.8%
Sulfur	1.5%	1.9%
Nitrogen	1.3%	1.2%
Oxygen	7.2%	3.6%
Ash	13.7%	16.1%
Total	100.0%	100.0%
HHV, BTU/lb	12,689	12,292

Task 2.3 – Global Mixing Process Improvement

- *The remaining parametric runs to evaluate SOFA mixing will be completed in July. Additional post processing of the existing cases will be started to investigate the impact of SOFA mixing on the mass flow and temperature distributions entering the convective pass. Chemical kinetic modeling to investigate / evaluate the high temperature SNCR process will be continued.*

A suite of approximately 30 computational fluid dynamic (CFD) runs were made to examine the impact of velocity and location on the degree of separated overfire air (SOFA) mixing. For this work, the SOFA mixing at a given plane is defined as:

$$Mixedness = \sum_{n=1}^{n_{tot}} M_n \frac{(x_n - x_{final})}{x_{final}}$$

where n is the local grid cell, n_{tot} is the total number of cells on a given horizontal plane, M_n is the normalized mass flux through cell n, X_n is the oxygen mole fraction in cell n, and x_{final} is the average oxygen mole fraction at the furnace outlet, which was 0.027 (2.7% O2 by volume) for these simulations.

Figure 1 shows the predicted improvement in SOFA mixing at the horizontal furnace outlet plane (boiler nose) of the BSF for eight variations to injection velocity for a TFS 2000™ equip boiler (re. two elevations of tangentially fired separated overfire air). For the first four cases / first data series, both the upper and lower SOFA elevation velocities were modified as reported in the June Month end. For the second four cases / second data series, only the upper SOFA elevation velocity was modified, while the lower SOFA elevation velocity was maintained at the design condition.

As expected, the degree of SOFA mixing increases with increasing velocity (decreasing nozzle free area) suggesting a significant improvement in mixing can be made through the use of higher injection velocities for current T-fired SOFA des gns. In addition, the data shows that in general increasing the injection velocity of both the upper and lower SOFA results in improved mixing as compared to increasing the velocity of the upper SOFA only.

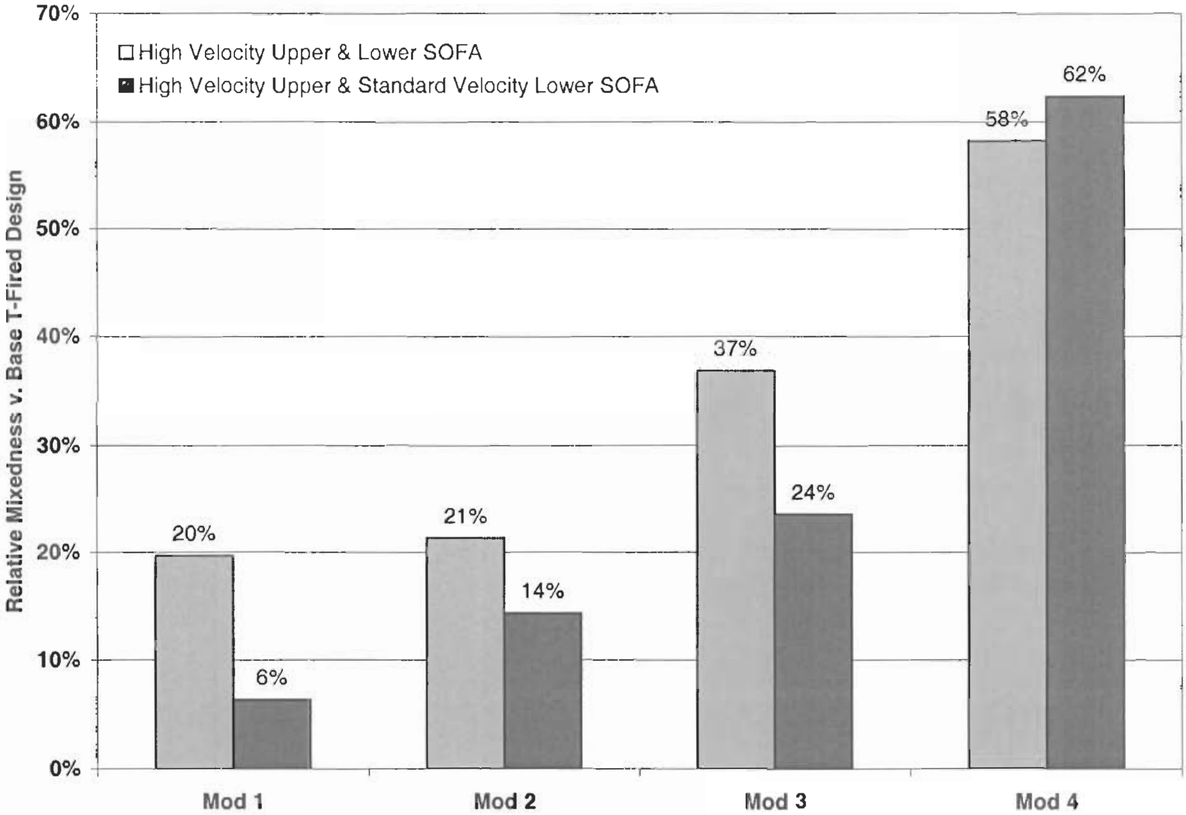

Figure 1 – Relative SOFA Mixedness v. Velocity for T-Fired OFA Systems

The above CFD cases were also examined to investigate the impact of SOFA velocity on the mass flow and temperature distributions entering the boiler's convective pass. In general, as SOFA velocity increases, the tangential velocity or swirl of the bulk furnace gases also increases which may result in an undesirable increase in side-to-side distribution of the flue gas energy in the boiler's convective region.

Figure 2 shows the change in gas side energy peak over the baseline condition for the above considered T-fired SOFA systems. Here, the gas side energy peak is defined as the maximum percent increase in flue gas energy for a vertical slice in the boiler's convective section as compared to the mean energy value across the plane. Thus, an increase in the gas side energy peak is indicative of an increase in localized furnace gas energy in the convective region.

As illustrated in Figure 2, all modeled conditions resulted in 6% or less increase in the gas side energy peak over the baseline, standard SOFA velocity TFS 2000™ configuration suggesting increased SOFA velocity can be used without adverse impact on gas side energy distribution. Note that all of the CFD cases were run with the same, zero degree SOFA nozzle yaw and that yaw adjustment could be potentially used to reduce the change in gas side energy peak as well as improve the overall degree of SOFA mixedness.

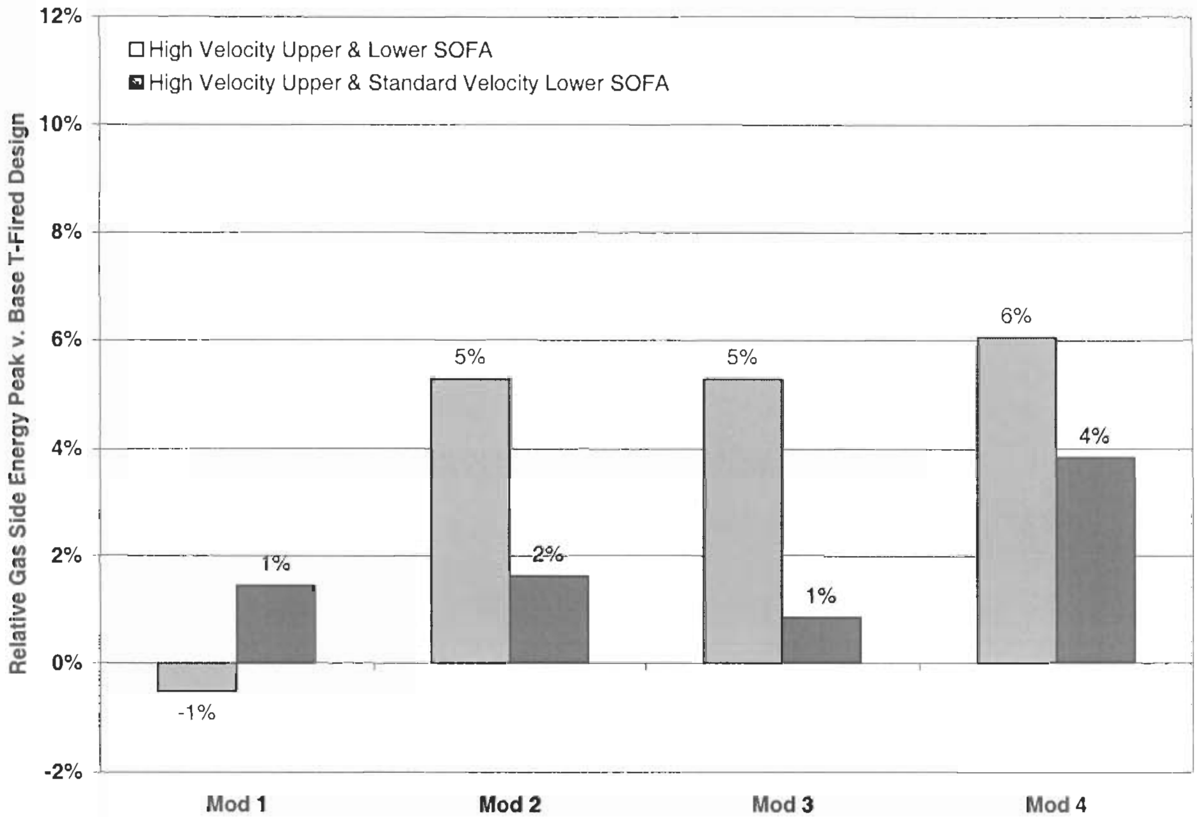

Figure 2 – Relative Gas Side Energy Peak v. Velocity for T-Fired OFA Systems

Chemical Kinetic Modeling

A CHEMKIN software utility, specifically the SENKIN[1] code, was used to parametrically investigate the impact of ammonia on NO reduction in a fuel-rich, post-flame zone. SENKIN is a program that predicts the time-dependent chemical kinetics behavior of a homogeneous gas mixture. It was used in the present study to simulate plug-flow reactor characteristics (without species transport effects) in order to simulate SNCR/NO chemistry in a fuel-rich environment.

For this work, the kinetic mechanism of Glarborg[2] was utilized. The detailed mechanism consists of approximately 66 species and 440 elementary steps and contains both reburn and NO/NH_3 chemistry. Computed fuel-rich equilibrium compositions (at a given stoichiometry) served as the baseline mixture, to which various amounts of NO, NH_3, and O_2 were added parametrically to form the final feed stream composition that was input to the SENKIN code. Each SENKIN case was run at a prescribed, constant temperature and residence time to assess the impact of the NO, NH_3, and O_2 concentrations, as well as temperature, on NO reduction.

Preliminary results indicate that the NH_3 injection does help to reduce the NO levels in a fuel-rich, post-flame environment as shown in Figure 3. Here, the NH3 injection benefit ranged 23% to 500%, depending

[1] "SENKIN User Manual – A Program for Predicting Homogeneous Gas-Phase Chemical Kinetics in a Closed System with Sensitivity Analysis", CHEMKIN Collection Release 3.5, Reaction Design, San Diego, CA, SEN-035-1 (July, 1999).
[2] Glarborg, P., Alzueta, M. U., Dam-Johansen, K., and Miller, J. A., "Kinetic Modeling of Hydrocarbon/Nitric Oxide Interactions in a Flow Reactor," Combustion and Flame, 115, pp. 1-27 (1998).

on the reaction time at condition and the ammonia mole fraction. Expected, typical reductions lie in the 20 to 30% range.

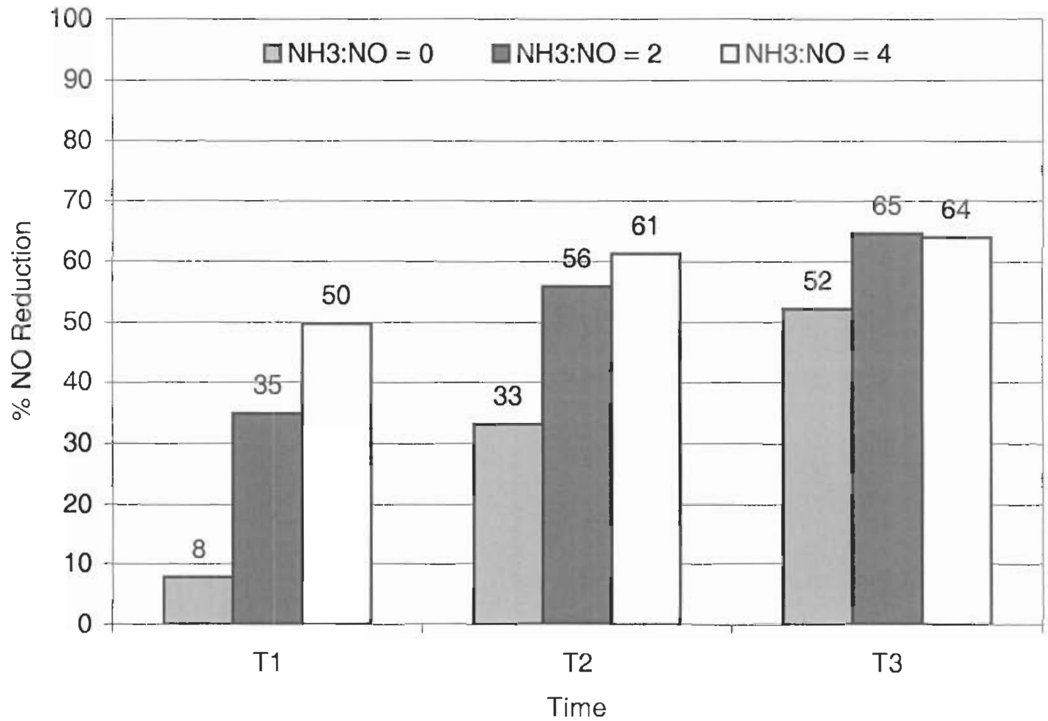

Figure 3 – Predicted NO reduction as a function of residence time and NH_3 concentration.

Task 2.4 – Advanced Control System Design

- *Install and configure AC 460 DCS Upgrade (internally funded, project related work)*
- *Obtain unit data suitable for NOx-heat rate and carbon in ash neural net modeling from at least one large Tangentially Fired Pulverized Coal Utility Boiler and begin modeling effort.*
- *Receive the first of the PC flow meters; develop detailed plans for August installation.*
- *Build on-line extractive sampling CIA sensor system*
- *Build optical combustion sensing system for use during BSF testing.*

The AC 460 DCS upgrade of the large pilot scale combustion test facility was completed in July. Shakedown testing of the new control system will occur in August and September.

Three to four large Tangentially Fired Pulverized Coal Utility Boiler units having suitable data sets have been identified by Pavilion. The process of obtaining utility permission to use a data set has now begun.

The ABB Instrumentation PC Flow meters have not yet arrived, but are in early August. Expediting efforts on this item are underway.

A decision has been made to omit the online carbon in ash (CIA) sensor system construction from this work and instead use the available funding to support iso-kinetic fly ash sampling during the combustion testing followed by post-test laboratory carbon content analysis to obtain the needed CIA data. This decision follows from the difficulty in designing and constructing an accurate carbon in ash device for this work and the corollary implied accuracy of the iso-kinetic technique.

Optical combustion sensing system port locations selected and test hardware defined.

Task 3.1 – Test Planning & Facility Preparation

- *The following work will be completed in July for Task 3.1:*

  Plumbing / Mechanical

  - *Finish repairing identified leaks in the BSF water-jacket*
  - *Install corner SOFA assemblies*
  - *Service CFS air buckets*
  - *Install coal and air nozzles in windbox*
  - *Procure materials for installation of coal mass flow meters*
  - *Install 18" flexible ducting for combustion air system*
  - *Remove blankoff plate after Maxon (direct fired air preheat / warm-up) burner*

  Electrical

  - *Check out BSF in-furnace camera system,*
  - *Upgrade direct-fired air heater burner,*
  - *Begin construction of flame scanning hardware for BSF,*
  - *Design and fabricate extractive system for carbon in ash measurements,*
  - *Install U-tube heat flux water flow meters,*
  - *Complete refurbishment of individual windbox compartment flow devices,*
  - *Pull cable for remote I/O for new DCS,*
  - *Design and order heat exchanger level control system*

On the mechanical side, the majority of the previously identified leaks in the BSF water jacket have been repaired, with work remaining only on completion of the superheater tube assembly installation work. Installation of the corner fired SOFA assemblies has, however been delayed to repair additional, damaged dampers that were overlooked during their initial rework and allow the tilt and yaw control arm linkages to be replaced in order to support updated external tilt / yaw position marking.

All required CFS™ air nozzles have been repaired and set to the desired, test offset angle. In addition, two (2) new CFS™ air nozzles have been designed to provide optical access for testing of alternate flame scanning / flame front control feedback system components. Materials for installation of the coal mass flow meters, including flanged transitional spool pieces, have been designed and / or specified and ordered. Installation of the main windbox coal and air nozzles has been delayed pending minor, welding repair of the internal windbox flange / nozzle seat.

Remaining mechanical work including the installation of the 18" flexible ducting and removal of the blank-off plate after the Maxon direct fired air heater has been completed.

On the electrical side work has begun on the construction of the flame scanning hardware for use in the BSF test campaign. This includes the installation of a NEMA 4X enclosure at the test facility to house the scanner electronics, and the pulling of a communication cable back to the control room for remote monitoring purposes as well as design of the two aforementioned new CFS™ air nozzles.

In addition, required soot blower components were ordered, a quote to repair the direct fired (MAXON) air heater burner was received, and the individual windbox compartment flow measurement devices were repaired. Checkout of the in-furnace camera system, installation of the U-tube heat flux water flow meters, and the design and order of the heat exchanger level control system have, however been delayed.

As for the extractive carbon in ash system, a decision has been reached to omit this from the work scope in favor of iso-kinetic fly ash sampling for post-test, carbon in ash analysis. Iso-kinetic sampling is both more reliable and the industry standard for this type of work and thus is felt to be a better methodology for assuring test data quality than available on-line sampling methods. Funding previously earmarked for the design, purchase and installation of an on-line carbon in ash measurement device will be diverted to support the iso-kinetic samp ing work.

At present, due to the delay in completion of a number of preparatory items, the Facility Preparation task is approximately one month behind schedule, which will lead to a delay in the execution of the combustion test program of approximately equal duration. An internal review of remaining preparatory activities as well as scheduler issues associated with the operation of other test facilities which share ancillary equipment with the BSF has been completed resulting in the selection of a new test window in mid to late October from the original mid-September time frame. Internal commitment of resources to meet this revised date has been obtained. A bimonthly review of program status will be made to ensure this schedule is met.

In addition to the overall facility preparation activity, a draft list of test parameters was generated for the first combustion test period work. This list, shown in Table 2 includes identification of the major parameters presently under consideration for exploration during the first combustion test period. As shown, the plan includes most of the firing system components or operating conditions presently considered for inclusion in an ultra low NOx integrated system. This strategy will ensure that a substantial portion of the expected, final system emissions performance will have been validated at large pilot scale upon completion of the first test period work.

Table 2 – First Combustion Test Period Test Parameters

1	Transport Air & Fuel Flow Balance
2	MBZ Stoichiometry
3	Subcompartmentalization
4	SOFA Velocity
5	SOFA Elevation
6	Transport Air to Fuel Ratio
7	SNCR
8	Staged Residence Time
9	Coal Fineness
10	Excess O2 / Final Stoichiometry
11	Boiler Load

Task 4 – Carbon Burnout System Evaluation

- *Work on the CBO^{TM} system evaluation will be initiated in July, including the transfer of preliminary CBO^{TM} cost and performance data from Progress Materials to U.S. Power Plant Laboratories.*

Initial analyses of the Progress Material's CBO^{TM} device began in July. This work included the transfer of preliminary design (Autocad^{TM} files) and cost / performance information for a CBO^{TM} system capable of being retrofit to a typical 500 MWe utility boiler. This information was used to support the preliminary Engineering Systems Analysis & Economics work reported below.

Task 5 – Engineering Systems Analysis & Economics

- *Complete the preliminary economic comparison of the selected ultra -low NOx emission systems. Upgrade the economic model program to enable performance calculations the results of which will be used by the existing program to perform economic analysis.*

A preliminary economic evaluation of seven low NOx control systems as applied to a hypothetical 500 MWe (Base) plant firing a medium to high volatile Eastern Bituminous coal was performed. Evaluated cases included:

#	Low NOx Control System Description
1	Base uncontrolled tangential firing unit
2	Modified with SCR
3	Modified with TFS2000R
4	Modified with TFS2000 R plus SCR polishing system
5	Modified with TFS2000 R plus advanced control system
6	Modified with TFS2000 R plus advanced control system plus CFI
7	Modified with TFS2000 R plus advanced control system plus CFI plus SNCR
8	Modified with TFS2000 R plus advanced control system plus CFI plus SCR

Financial assumptions and estimated system performance used in performing the analysis are summarized in Table 3. For this work it was assumed that the plant will continue routine operation without the disruption to its generating capacity during equipment installation and the necessary tie in into the existing plant system would be carried out during scheduled maintenance intervals.

Table 3 – Financial Assumptions and Economic Model Input

Case #	1	2	3	4	5	6	7	8
Case ID	Base	SCR	TFS 2000	TFS 2000 + SCR	TFS 2000 +Adv Cntrl	Case 5 + CFI	Case 6 + SNCR	Case 6 + SCR
SYSTEM PERFORMANCE								
NOx Emissions, lb/MMBtu	0.7	0.15	0.25	0.15	0.225	0.165	0.15	0.15
Tons Of NOx Removed/Yr	0	9726	7958	9726	8400	9461	9726	9726
PLANT INFORMATION								
Parasitic Power, %	5.00%	5.37%	5.12%	5.46%	5.12%	5.16%	5.18%	5.37%
Net Electric Power Output, KW	475,000	473,141	474,390	472,697	474,390	474,211	474,112	473,143
Net Plant Heat Rate, Btu/kWh	10,000	10,039	10,013	10,049	10,013	10,017	10,029	10,039
Capacity Factor, %	85%	85%	85%	85%	85%	85%	85%	85%
Remaining Operating Life, Yrs	25	25	25	25	25	25	25	25
Fixed O&M Costs $\kW-yr	$22	$22	$22	$22	$22	$22	$22	$22
FUEL INFORMATION								
HHV, Btu/lb	11,000	11,000	11,000	11,000	11,000	11,000	11,000	11,000
Ash Content, %	10%	10%	10%	10%	10%	10%	10%	10%
VARIABLE OPERATING COST								
NH3 / Urea Use, lb/lb coal	0.00E+00	2.30E-03	0.00E+00	4.00E-04	0.00E+00	0.00E+00	5.33E-04	9.20E-05
NH3 / Urea Cost, $/ton	$0	$345	$0	$596	$0	$0	$333	$1,549
ELECTRIC TARIF RATE $/kWh	$0.035	$0.035	$0.035	$0.035	$0.035	$0.035	$0.035	$0.035
FINANCIAL INFORMATION								
Capital Cost, KUSD	$0	$18,520	$6,500	$18,228	$7,250	$11,250	$15,250	$19,890
Operating Years	25	25	25	25	25	25	25	25
Inflation Rate	3%	3%	3%	3%	3%	3%	3%	3%
Term Of Loan, Yrs	25	25	25	25	25	25	25	25
Depreciation, Yrs	25	25	25	25	25	25	25	25
Tax Rate	38%	38%	38%	38%	38%	38%	38%	38%
Equity	50%	50%	50%	50%	50%	50%	50%	50%
Debt	50%	50%	50%	50%	50%	50%	50%	50%
Cash Discount Rate	7%	7%	7%	7%	7%	7%	7%	7%
Interest on Loan	10%	10%	10%	10%	10%	10%	10%	10%

All economic estimates are based upon calendar year 2000 dollars. Capital costs are on a D&E basis. Operating costs include both fixed and variable costs additions to the Base design. The fixed costs include operating labor, maintenance and administrative costs. Variable costs include ammonia or urea, and catalyst replacement (where applicable). Additional power consumption takes into account the increase in ID fan power, mills and dynamic classifiers, ammonia vaporizers, dilution air blowers, and instrumentation and controls as required.

In estimating plant performance for the Base and Case 2, typical carbon losses were used. An additional 20% increase in carbon loss in fly ash was assumed for all design cases that have a TFS 2000™ R firing system installed (cases 3 through 8).

Results of the analyses are presented in Table 4. The financial results are expressed in terms of Capital Cost, total Net Present Value (NPV) of the 25 year project cost, the cost of electricity, and total project cost per ton of NOx removed. All results are referenced to the Base case.

Table 4 – Preliminary Economic Analysis Summary

Case #	1	2	3	4	5	6	7	8
Case ID	Base	SCR	TFS 2000	TFS 2000 + SCR	TFS 2000 +Adv Cntrl	Case 5 + CFI	Case 6 + SNCR	Case 6 + SCR
Estimated NOx, lb/MMBtu	0.7	0.15	0.25	0.15	0.225	0.165	0.15	0.15
Tons of NOx Removed / yr	0	9,726	7,958	9,726	8,400	9,461	9,726	9,726
Capital Cost, KUSD	$0	$18,520	$6,500	$18,228	$7,250	$11,250	$15,250	$19,890
NPV for 25 yr life, KUSD	NA	$52,244	$11,369	$39,903	$12,372	$18,413	$29,369	$37,643
Increase in $/MWh	$0.0	$0.8	$0.2	$0.6	$0.2	$0.3	$0.4	$0.5
Cost per Ton of NOx	NA	$5.4	$1.4	$4.1	$1.5	$1.9	$3.0	$3.9
Cost vs. SCR								
Capital Cost	NA	0%	*-65%*	-2%	*-61%*	*-39%*	-18%	7%
NPV	NA	0%	*-78%*	-24%	*-76%*	*-65%*	-44%	-28%
Cost Per Ton of NOx	NA	0%	*-73%*	-24%	*-73%*	*-64%*	-44%	-28%

Preliminary economic analyses have shown that the lowest cost per ton of NOx removed is for Cases 3 and 5, TFS 2000™ and TFS 2000™ with Advanced Controls, respectively. However, neither of these cases meets the project NOx target of 0.15 lb/MMBtu NOx. Nevertheless, the results are useful since they lead toward the generation of cost effective solutions.

Case 7 which includes a maximum in-furnace NOx reduction system including TFS 2000™ with Advanced Controls and Coal Fines Injection (CFI) combined with an SNCR polishing system offers, potentially, the most cost effective solution for a single unit installation that requires NOx compliance of 0.15 lb/MMBtu. As shown, total operating cost for this system is 44% less than an SCR only solution (Case 2), which is in excess of the program goal of a 25% cost savings.

The second most cost effective solution is represented by Case 8 which includes the same maximum in-furnace NOx reduction system noted above combined with an SCR rather than an SNCR polishing system. As shown, total operating cost for this system are estimated to be 28% less than an SCR only solution, which also exceeds the program goal of a 25% cost savings.

WORK PLANNED FOR NEXT REPORTING PERIOD:

Task 2.1 – Test Fuels Characterization

- Obtain a second 5 gallon sample of the low reactivity coal and perform ASTM analyses.

- Determine high temperature volatile matter yield from a 200x400-mesh size cut in the DTFS-1 in nitrogen gas at 2650 ºF and ~ 0.5 sec. residence time
- Determine fuel nitrogen evolution from three size cuts -- 200x400-mesh, 270x400-mesh, and -400 mesh -- in the DTFS-1 in argon gas at 2650 ºF and ~ 0.5 sec. residence time.
- Send out a representative coal sample to an independent lab for petrographic analysis.

Task 2.3 – Global Mixing Process Improvement

- Continue post-processing of the CFD cases to examine the impact of SOFA mixing on predicted CO and carbon in ash levels.
- Continue CHEMKIN modeling of high temperature SNCR process.

Task 2.4 – Advanced Control System Design

- Install and check-out Coal Flow sensors
- Obtain field data set and begin NOx-heat rate and carbon in ash neural net modeling.

Task 3.1 – Test Planning & Facility Preparation

Plumbing / Mechanical

- Repair ignitor horns.
- Mark & install SOFA assemblies
- Begin installation of main windbox coal and air nozzles

Electrical

- Calibrate BSF O2 sensor
- Calibrate U-tube heat flux probe flow meters
- Check-out audio and video system
- Loop RTD sent out for calibration
- Install flue gas heat exchanger level control
- Confirm the BSF DCS system operability

Task 4 – Carbon Burnout System Evaluation

- Complete CBO™ feasibility study

Task 8 – Project Management

- Hold internal project status review meeting; make go / no go decision for Combustion Test Period #1 (Note: this activity may be delayed into September to correspond with the postponement of the first combustion test period).