# USDOE/EPRI BIOMASS COFIRING COOPERATIVE AGREEMENT

Quarterly Technical Report

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## ABSTRACT

During the period of April 1, 2000 through June 30, 2000, alternatives for relocating the Seward Generating Station cofiring project were investigated. A test was conducted at Bailly Generating Station of Northern Indiana Public Service Co., firing a blend of Black Thunder (Powder River Basin) coal and Illinois basin coal, in cyclone boiler designed for Illinois basin coal. This test at Bailly was designed to determine the technical feasibility of cofiring at that station using PRB coals.

This report summarizes the activities during the second calendar quarter in 2000 of the USDOE/EPRI Biomass Cofiring Cooperative Agreement. It focuses upon reporting the results of construction and testing activities at these generating stations.

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## EXECUTIVE SUMMARY

The fifteenth Quarter of the USDOE-EPRI contract, April 1, 2000 through June 30, 2000 was characterized by continued activities designed to relocate the pulverized coal separate injection demonstration from Seward Generating Station to a new home. It was also characterized by an assessment—including testing—concerning the feasibility of cofiring wood waste with PRB coal at the Bailly Generating Station.

The warm winter caused Sithe Energies to continue not operating Seward Generating Station Boiler #12. This resulted in the conclusion that the Seward Generating Station cofiring demonstration—with separate injection of sawdust into a pulverized coal (PC) boiler—must be moved in order to be completed. The impacts of electricity generation deregulation in Pennsylvania have been significant for this demonstration. Deregulation was not a factor when the Seward cofiring program was started in 1996. Activities in support of relocating this demonstration included discussions with other utilities, and reallocation of USDOE-EPRI Cooperative Agreement funds to support the relocation and completion of this demonstration.

The use of triburn fuels at Bailly Generating Station led to the logical next step of considering firing the blend of wood waste and petroleum coke with a coal blend based on Powder River Basin (PRB) coals. Since the PRB coals are characterized by higher moisture, lower heat content, and high volatility; there is the belief that they could work together with biomass to further reduce NOx emissions. Certain technical factors, however, make firing PRB coals infeasible in some boilers and some applications. This concern led to the PRB testing prior to attempting firing wood waste and/or petroleum coke with this new fuel blend.

# INTRODUCTION

Cofiring—the firing of two dissimilar fuels at the same time in the same boiler—has been proposed for using biomass in coal-fired utility boilers. In practice, this cofiring introduces a family of technologies rather than a single technology. The family of technologies includes blending the fuels on the coal pile or coal belt, and feeding them simultaneously to any processing (e.g., crushing and/or milling) systems on their way to the boiler; preparing the biofuels separately from the coal and introducing them into the boiler in a manner that does not impact fossil fuel delivery; or converting the solid biofuels to some other fuel form (e.g., producer gas) for firing in a coal-fired or natural gas-fired installation.

The practice of cofiring biofuels with coal, or blending biofuels with other opportunity fuels to be used in coal-fired generating stations, has reached a new stage in its commercialization process. Demonstrations are underway for cofiring with separate wood feeding at a wall-fired boiler—the Seward Generating Station of GPU Genco. Demonstrations also are underway for cofiring biomass with petroleum coke in a cyclone boiler—the Bailly Station #7 boiler of NIPSCO. More utilities are expressing interest in cofiring. Still others are beginning the process of investigating this technology.

Cofiring is often recognized as the least cost form of "green power" available to utilities which have access to a wood products industry, a furniture industry, a home construction industry, and/or the "urban forest" of broken pallets, tree trimmings, and the like. The Wisconsin Renewable Portfolio Standard explicitly recognizes cofiring of residues as an acceptable form of green power and renewable energy. Similarly, New Jersey recognizes the combustion of residues as renewable energy. Cofiring is also considered to be potentially a major contributor to fossil $CO_2$ reductions.

USDOE and EPRI developed a cooperative agreement to support the commercialization of this family of technologies. Some 16 projects have been developed as part of this program, as summarized below. As noted in the Executive Summary, several of these tasks have been completed or cancelled.

1. Combustion Tests at GPU's Seward Plant (30 MWe, PC)

   EPRI and GPU (an EPRI member utility operating the Seward power plant near the Johnstown, Pennsylvania headquarters of GPU's Penelec system) will arrange for other cofunding to augment USDOE's cofunding and will

conduct a test of mid-level cofiring in a wall-fired PC unit using separate feed for the wood (i.e., not fed through the pulverizers along with the coal, as was done in the recent test cosponsored by USDOE, EPRI, GPU and the State of Pennsylvania at Penelec's Shawville plant in November 1995). This program also includes a long-term demonstration of cofiring at the Seward Generating Station, as a logical extension of the parametric performance testing.

This project is being relocated.

2. Fuel Preparation Tests at NYSEG's Greenidge Plant (100 MWe, PC)

EPRI is cosponsoring New York State Electric and Gas Company (NYSEG)—now AES—in a test program that focuses on the preparation of wood fuel for cofiring in a tangentially fired PC unit with separate feed for the prepared wood fuel. Size reduction equipment, such as wood "grinders" or hammermills, and drying equipment will be evaluated, and the suitability of the prepared product tested in full-scale com- bustion in the 100 MWe boiler at NYSEG's Greenidge plant. Mid-level, i.e., about 10% by heat, cofiring is planned.

This project has been terminated, unless significant changes occur in the approach taken by AES.

3. Pre-commercial Test Runs at TVA (~200 MWe)

EPRI is cosponsoring the next testing program at TVA, this one being the long-term "pre-commercial" test runs to cofire wood at levels up to 10% by heat, starting at the cyclone plant (Allen) in Memphis, and continuing at one of TVA's pulverized coal plants. This program includes considering gasification as a basis for cofiring, using the producer gas from biomass as additional fuel injected in the primary furnace.

4. Switchgrass Cofiring with Madison Gas & Electric (50 MWe)

EPRI is cofunding the University of Wisconsin at Madison in a test program being conducted by the University and the local utility (Madison Gas and Electric) at MG&E's Blount Street Station, where an existing retrofit to burn refuse-derived fuel (formerly) and shedded paper waste

(currently) in a wall-fired PC unit is to be used to conduct the first U.S. test of cofiring switchgrass along with coal in a full-size utility boiler.

This task has been completed.

5. High-level Cofiring with Southern Company (50 MWe)

Southern Company Services has discussed with EPRI a potential cosponsored project to do long-term testing of high-level (i.e., up to 40% by heat) cofiring of wood with coal, perhaps with some natural gas overfire, in a tangentially-fired PC boiler in Savannah, Georgia. This project would be a follow-up to an initial set of short test runs there in 1993, which indicated that separate feed of this much wood was possible. This test will provide the opportunity to explore the upper limits of cofiring wood with coal in an existing PC boiler. This project also includes demonstration and testing of the entire fuel cycle for switchgrass as a biofuel. It includes growing and harvesting the switchgrass, milling this biofuel, and then cofiring it with coal in both the Southern Research Institute test combustor and then the 60 $MW_e$ Gadsden Station of Alabama Power.

Support for this program has been provided. Further support is not anticipated at this time.

6. Study and Testing with NIPSCO (~500 MWe, Cyclone)

EPRI is completing a study, cofunded by EPRI and Northern Indiana Public Service Company (NIPSCO), to evaluate the fuel supply and the power plant operations for cofiring wood in a full-size cyclone boiler as one of NIPSCO's voluntary measures to reduce emissions of fossil $CO_2$ under the Climate Challenge program of the federal government. The next phase, assuming the expected favorable findings that cofiring is a low-cost $CO_2$ mitigation measure, is to be a cofunded test at, perhaps, NIPSCO's Michigan City plant, where manufacturing process waste wood is the expected source of relatively dry wood already at small size and with potential for a 5% by heat cofiring operation in an urban area outside of the normal wood products regions of the South, Upper Midwest or Pacific Northwest. This program also includes demonstrating the results of

cofiring testing, over a longer term, at Bailly #7, another NIPSCO cyclone boiler.

7. Switchgrass Test with Nebraska Public Power District

One of EPRI's members, the Nebraska Public Power District (NPPD), has expressed interest in a preliminary evaluation of switchgrass cofiring, an evaluation that can be performed without commitment to a full-size unit test. EPRI has suggested to NPPD an evaluation based on laboratory testing at the Sandia National Laboratory's Combustion Research Facility in Livermore, California. With USDOE cofunding this would test the ability of the well-controlled, well-monitored test facility at Sandia to provide data and analysis capable of predicting the potential for the fouling of superheater tubes by the cofiring of high-alkali biomass, namely switchgrass, with coal. Combined with (1) the Madison test (Item 4, above), in which NPPD will participate, and (2) the series of tests done by Sandia on both biomass fuels and coals for DOE, NREL, USDOE, EPRI and industry during the past three years, and (3) USDOE's in-house testing of switchgrass/coal cofiring at CERF, this new project is expected to reveal the potential and the limits of laboratory testing as a facilitator of decisions on biomass cofiring.

This task has been cancelled.

8. Waste Plastics Cofiring with Duke (50-200 MWe, PC)

EPRI, Duke Power Company (Duke), and the National Plastics Council have cosponsored a laboratory test and engineering analysis of the cofiring of clean plastic manufacturing wastes with coal in a PC boiler. The next step is a unit test at full-size in a PC boiler, perhaps at 50 MWe or perhaps up in the 200 MWe range, approximate size. While actual biomass cofiring, i.e., waste wood cofiring, may or may not be part of the first unit tests, this project is important for the future of biomass cofiring because it involves a major investor-owned, coal-firing utility, located in a region of a major wood-products industry as well as major, and changing, agricultural and meat/poultry industries, as well as textile industries. It is an excellent test of waste cofiring justified on purely business grounds (fuel savings and customer service) but with potential to move toward environmental grounds, if warranted.

This task has been completed.

9. Plastic/Fiber/Pulp Wastes with SCE&G (~100 MWe, PC)

EPRI has discussed possible follow-on testing with South Carolina Electric and Gas Company (SCE&G), tests that would be a follow-on to a test run in 1993 where mixed plastic and wood fiber were fired with coal to determine technical feasibility for disposal of an industrial customer's manufacturing residues. Other residues, consisting primarily, or entirely, of pulp wastes rather than plastic may be tested next. Or, a second test, longer and with more variations, using the same plastic/ fiber residue may be the prime focus. The rationale for this as a biomass cofiring test is similar to that for Duke (a neighboring utility in the same wood industry region), but the scope is more directly on biomass, as well as plastic, as fuel, and the options for boiler retrofit may be different.

This task has been cancelled.

10. Urban Wood-Waste Study and Test in Pittsburgh

USDOE has suggested that EPRI join an evaluation of the urban wood waste resource in the industrial/commercial/residential region of Pittsburgh and environs. Course, low-cost or no-cost wood wastes would be fired with coal in a stoker boiler at the Bellefield Boiler Plant owned by a consortium that includes the University of Pittsburgh. The University would oversee and monitor a long-term test of low-level (about 2% by heat) cofiring of urban wood wastes (including tree trimmings) together with coal. The key elements of the test would be off-site wood processing, assessment of the urban wood supply and cost by means of actual fuel procurement, and, perhaps, assessment of fines separation and separate cofiring of fines in a normal utility boiler (i.e., PC or cyclone).

This task has been completed.

11. Toxic Emissions

Both EPRI and USDOE have measured trace emissions and effluents from the combustion of coal and from ash resulting from coal combustion. In

this new project, EPRI and USDOE will combine their respective data sources, test facilities and expertise in an effort to determine the extent of trace emissions or effluents from the cofiring of wood or other biomass wastes with coal. After an evaluation of data on fuels and control processes, including data on fuel chemistry, ash chemistry, emissions, emission control systems, liquid waste streams and solid waste streams, EPRI and USDOE will plan and conduct a test to measure and/or predict the emissions, if any, of toxic species that may arise from cofiring biomass with coal. This project will explicitly consider a test at the ECTC (Environmental Control Test Center) at the Kintigh power station operated by NYSEG near Buffalo, New York. The best site and fuel combination for a test will be identified and a test will be conducted, if the evaluation indicates that a useful measurement of toxic emissions can be obtained.

This task has been cancelled.

12. Fuel/Powerplant Models, Analysis and Interpretation

In order to interpret results from this entire set of projects and to facilitate the transfer of the results to the industry, EPRI will develop a SOAPP ("State-of-the-Art Power Plant") module for evaluating wood cofiring situations. SOAPP already has modules for combustion turbine power systems, and SOAPP modules for conventional utility PC and cyclone plants, and also FBC and coal gasification systems, are under development. By July 1996, the first SOAPP cofiring module will be completed, for natural gas as the cofired fuel in a reburn or other mode. This new project (No. 12 of the USDOE/EPRI cofiring program) will add wood cofiring to SOAPP, and also will add a fuels database capable of putting the properties of each new cofiring fuel into a context for comparison to some 50 other fuels and for prediction of slagging/fouling/agglomeration potential in comparison to those other fuels. The result will be a model that will make possible the interpretation of test results from all the cofiring experiments in terms of the performance and cost impacts on a state-of-the-art coal-fired powerplant. Currently, but separate from this proposal, EPRI and USDOE are cooperating on the EPRI-developed CQIM computer model by doing tests to obtain data on slagging/fouling for blends of coals. This work will be used and expanded under this USDOE/EPRI biomass cofiring project. EPRI's fuels database for biomass and other alternative fuel properties (including slagging

indices, etc.) will be incorporated into CQIM, SOAPP and other analytical frameworks as appropriate. EPRI's biomass resource assess-ments and tools for developing supply/cost curves will be applied as appropriate to address regional or local biomass resource issues important to USDOE.

This task has been cancelled and the funds have been redirected to the relocation of the Seward Cofiring Demonstration.

13. $CO_2$ Utilization in Algal Systems for Wastewater Treatment

EPRI and USDOE have independently done experiments and studies of systems that can take advantage of the high rates of capture of $CO_2$ by aquatic biological systems such as seaweed (kelp), microalgae (ocean and land-based) and halophyte species (both in water and on dry land). This new project under this USDOE/EPRI cofiring project will assess what appears to be one of the few near-term options for an algae-based system to contribute to reductions of $CO_2$ emissions: the use of $CO_2$ to speed the growth of algae in water treatment facilities. This approach adds a coproduct value, namely the improved performance of the water (i.e., sewage) treatment plant, that may make the system one of the low cost options for near-term $CO_2$ mitigation. Two forms of fossil $CO_2$ reduction are involved: (1) capture of $CO_2$ into a biomass form, i.e., a process similar to carbon sequestration in forest biomass, but in this case coupled directly to use of a $CO_2$-enhanced stream like powerplant fluegas; and (2) replacement of a fossil fuel by a biomass fuel, as the algae grown with the enhanced $CO_2$ stream replace fossil fuel, i.e., a process similar to the $CO_2$ recycling inherent in all uses of biomass fuels replacing fossil fuels.

This task has been completed.

14. Combustion Tests and Combustor Development

EPRI and TVA have sponsored an initial assessment of slagging com-bustion as a way to use high-alkali biomass as fuel in power generation without having to solve the problems associated with gas cleanup to meet the purity required by the gas turbines in biomass gasification combined cycle power systems. USDOE has completed the first in a planned series of bench-scale tests of the cofiring of high-alkali fuels with coal in CERF (Combustion Environment Research Facility) at USDOE. This new

project in the USDOE/EPRI cofiring program will use test systems at USDOE to obtain data to predict performance and guide design for use of high-alkali biomass fuels in mid- to high-level fractions (approximately 20% to even 100% of the heat into a coal-fired power system). The new project will start with follow-up design and fuel/ash studies that apply and interpret relevant work already completed. Tests will be planned and performed as appropriate, in accord with assessments and plans prepared by EPRI and USDOE staff and contractors, and in accord with an implementation plan approved by USDOE.

This task has been cancelled.

15. Ash Sales

An immediate barrier to the cofiring of biomass with coal in existing coal-fired powerplants is the potential that the flyash from the cofired operation of the plant will not be purchased by the cement industry, which is now the best market for flyash from coal-fired utility boilers. This project will develop and communicate an action plan that will enable a cement industry standards board to make as early as possible a finding that cofired ash is acceptable for purchase from utility powerplants.

This task has been cancelled.

16. $CO_2$ Capture and Disposal

This project will conduct a series of feasibility studies of various proposed options for capture and disposal of carbon dioxide from U.S. coal-fired power plants. Consideration will be given to both land and ocean-based disposal options in an effort to determine which options would be most amenable to fossil carbon sequestration for both existing and future U.S. power generation capacity. This effort will build on the results of studies previously performed by the International Energy Agency (IEA) Green-house Gas Research and Development Program with joint DOE and EPRI funding.

This task has been completed.

# TECHNICAL PROGRESS

## Project 1 – Combustion Testing at the Seward Generating Station

Warm weather, and the high cost of operating Boiler #12—a 32 MWe installation at the Seward Generating Station—has caused this unit to be idle during virtually all of the first half of 2000. The unit has had a very low capacity factor for the past 12 months, and it is projected to have a very low capacity factor until it is completely retired. The competitive nature of the Pennsylvania energy market makes consistent operation of Boiler #12 at a high capacity factor uneconomic. A decision was made by Sithe Energies, EPRI, and USDOE-NETL to relocate this project as expeditiously as possible. This relocation is necessary in order to demonstrate the long term viability of cofiring in PC boilers using separate injection.

Presentations were made to Allegheny Energy Supply Co., LLC concerning this demonstration. Allegheny conducted a site visit at Seward as well. Additional utilities also were contacted regarding the prospect of relocating the Seward Demonstration.

## Project 2 – Fuel Preparation Tests at Greenidge Generating Station

This project remains outside the cooperative agreement at this time due to business decisions by AES.

## Project 3 – Precommercial Testing and Gasification Investigation at TVA Fossil Plants

TVA has continued to evaluate its options regarding cofiring, including gasification. TVA completed its investigation into the relocation of the Seward Demonstration to one of its PC plants during this time period, and came to the conclusion that it would not be an appropriate demonstration for that utility.

## Project 4 – Switchgrass Testing at Blount St. Station of Madison Gas & Electric

This project was completed.

## Project 5 – High Percentage Cofiring with Southern Company

No operational activity occurred on this project

## Project 6 – Cofiring Testing at Michigan City Generating Station of NIPSCO, and Demonstration of Cofiring at that Utility

Foster Wheeler Development Corporation (FWDC) supported Northern Indiana Public Service Company (NIPSCO) in testing the use of Powder River Basin (PRB) coal as a means for reducing $NO_x$ emissions. Testing was conducted in boiler #7. The tests were conducted over the general period May 15 through May 24. PRB coal was blended with high sulfur coal at mass percentages ranging from 30 percent to 70 percent. Testing was largely conducted at or near full load. Testing was performed to evaluate the impacts of PRB not only on $NO_x$ emissions but also on $SO_2$ formation, boiler efficiency, boiler capacity, and boiler operations.

The test was conducted to baseline the unit on a blend of PRB and Illinois Basin coal, and to determine the feasibility of firing a blend of wood waste and petroleum coke with the blend of PRB and interior province coal. The focus was to determine the relationships between PRB coals and biomass as fuels used to reduce NOx emissions and achieve other environmental benefits.

The test program was conducted under circumstances that created significant limitations, yet it had to be conducted in May in order to avoid the potential for problems during the heat of the summer months. The test was conducted during the end of the boiler #8 outage. During the test program, the coal grind was not optimal for normal PRB coal firing. During the test program the unit operated at low windbox pressure relative to the needs of the boiler when firing PRB coal (37.2 in $H_2O \pm 0.87$ in $H_2O$ on average).

Despite these conditions, five successful tests were run, and these tests strongly indicated the potential of PRB blends in Bailly #7 boiler. These tests document the fact that PRB coal can accomplish the following:

- PRB coal can reduce $NO_x$ emissions when fired, and the results can be improved by optimizing boiler performance
- PRB coal can reduce formation of $SO_2$ from combustion
- PRB coal can increase the base/acid ratio of the coal ash, thereby reducing the $T_{250}$ temperature

These results document the fact that PRB coal performs much the same function as biomass when fired in a cyclone boiler. They document the fact that the reactivity of the PRB coal has similar benefits to the reactivity of the wood waste.

The tests also indicated that problems can be significant when firing PRB blends, particularly if the unit is not set up to use these fuels. During the testing, the unit did experience high loss on ignition (LOI) and unburned carbon levels. It did exhibit higher than normal air heater exit temperatures, consistent with increased flue gas volumes and consequent decreased gas residence times in the primary furnace, boiler, and economizer sections of the unit. These results led to the conclusion that *it is not prudent to attempt cofiring of wood waste with a coal blend dominated by PRB coal in the Bailly Generating Station #7 boiler.*

Further, the problems of residence time indicated by the high LOI levels, demonstrate that the unit can not fire a blend with > 60 or 70 percent PRB coal. The furnace is sufficiently small in volume that higher blends of PRB are not recommended.

## PRB Test Program Overview

Northern Indiana Public Service Company (NIPSCO) conducted a test of Powder River Basin (PRB) coal at Bailly Generating Station (BGS) in order to determine its impact on boiler #7. This test included a determination regarding whether biomass could be cofired with a blend of coals dominated by PRB in the #7 boiler.

The test evaluated the following parameters:

- The impact of PRB blends on boiler capacity
- The impact of PRB blends on boiler efficiency
- The impact of PRB blends on operations
- The impact of PRB blends on other emissions

Initially, a test including 100 percent PRB firing was targeted. When this became infeasible, one objective was to determine the maximum percentage of PRB that could be successfully burned in BGS boiler #7. From there, projections concerning cofiring with biomass could be made.

The scope of the test program was to characterize the fuels being burned, characterize the combustion process, and characterize the products of combustion including flyash, $NO_x$, $SO_2$, and CO emissions. This involved parametric testing over a 10-day period.

Fuel characterization was performed by Foster Wheeler Development Corporation (FWDC) at its laboratories in Livingston, NJ. Testing included proximate and ultimate analysis, ash elemental analysis, and mercury determination. Flyash was characterized by the FWDC laboratories as well. Combustion conditions were determined by obtaining extensive control room data. Combustion conditions were also determined by video camera observations of the discharges from the reentrant throats of all cyclones to the primary furnace; NIPSCO supplied the camera and its operators.

Emissions were characterized by using portable instrumentation, measuring $NO_x$, $SO_2$, and CO at the entrance to the air heater. FWDC supplied the instrumentation and the operator of that instrumentation.

Once the data were obtained, they were analyzed by constructing heat and material balances about the boiler for each test period. Emissions were then related to each heat and mass balance in order to evaluate outcomes. Further, the data were analyzed statistically to evaluate trends.

## Fuels Data

NIPSCO fired a blend of Black Thunder PRB coal with high sulfur coal from the Illinois Basin. Tables 1 – 3 provide characterizations of these fuels including proximate and ultimate analysis, higher heating value, ash elemental analysis, mercury analysis, and selected performance parameters.

**Table 1. Proximate and Ultimate Analysis of Coals Burned at BGS Boiler #7**

| | PRB Coal | High Sulfur Coal |
|---|---|---|
| | Average | Average |
| **Proximate Analysis (wt %)** | | |
| Fixed Carbon | 35.71% | 43.13% |
| Volatile Matter | 31.03% | 34.14% |
| Ash | 4.77% | 9.98% |
| Moisture | 28.50% | 12.75% |
| Total | 100.00% | 100.00% |
| | | |
| **Ultimate Analysis (wt %)** | | |
| Carbon | 51.21% | 62.90% |
| Hydrogen | 3.58% | 4.21% |
| Oxygen | 10.89% | 5.72% |
| Nitrogen | 0.69% | 1.15% |
| Sulfur | 0.36% | 3.30% |
| Ash | 4.77% | 9.98% |
| Moisture | 28.50% | 12.75% |
| Total | 100.00% | 100.00% |
| | | |
| **HHV (Btu/lb)** | | |
| as-received | 8553 | 10993 |
| dry | 11962 | 12599 |

**Table 2. Ash Analysis of Coals Burned at BGS Boiler #7**

| | PRB Coal | High Sulfur Coal |
|---|---|---|
| **Ash Elemental Analysis (wt %)** | | |
| $SiO_2$ | 36.60% | 52.43% |
| $Al_2O_3$ | 19.13% | 21.73% |
| $TiO_2$ | 1.60% | 1.07% |
| $Fe_2O_3$ | 5.83% | 14.40% |
| CaO | 24.80% | 5.50% |
| MgO | 5.00% | 1.20% |
| $Na_2O$ | 1.33% | 1.20% |
| $K_2O$ | 0.43% | 2.30% |
| $SO_3$ | 5.73% | 0.60% |
| $P_2O_5$ | 1.40% | 0.57% |
| Total | 101.87% | 101.00% |
| | | |
| **Mercury (mg/kg)** | 0.041 | 0.051 |

**Table 3. Performance Parameters of Coal Burned at BGS Boiler #7**

| Performance Determinant | PRB Coal | High Sulfur Coal |
|---|---|---|
| | | |
| Volatile/fixed carbon ratio | 0.87 | 0.79 |
| Lbs fuel/million Btu | 116.92 | 90.97 |
| Lbs S/million Btu | 0.42 | 3.00 |
| Lbs S/million Btu [as $SO_2$] | 0.85 | 6.00 |
| Lbs N/million Btu | 0.81 | 1.04 |
| Lbs ash/million Btu | 5.57 | 9.08 |
| Lbs $H_2O$/million Btu | 33.32 | 11.60 |
| | | |
| Lbs Hg/million Btu | 4.755E-06 | 4.639E-06 |
| | | |
| Base/acid Ratio | 0.65 | 0.33 |
| Si/Al Ratio | 1.91 | 2.41 |

It is important to note that the PRB coal is somewhat more volatile than the high sulfur coal, and has significantly lower sulfur content. It has somewhat lower fuel nitrogen content and much higher moisture content. It does not reduce the mercury content of the

fuel. It does increase the base/acid ratio and thereby decreases the $T_{250}$ temperature of the blended fuel. The volatility, and the impact on base/acid ratio, is similar to that associated with wood waste. However the biofuel is even more volatile than the PRB coal, and the ash content of the biofuel is less than that of the PRB coal.

**Combustion Conditions**

Selected combustion conditions measured during the test program are shown in Table 4. These are average readings taken during the testing on May 16, 17, 18, 19, and 23. Note that these data are averages of the test programs. Data were taken every 10 minutes during the test periods, such that sufficient data sets were developed to accurately depict the conditions fired. These data were not adjusted for discrepancies in the instrumentation. Rather they came directly from the computer reporting information to the operator.

It is useful to note that the PRB percentages employed during these test periods was approximately as follows:

- May 16 – 50% PRB
- May 17 – 50% PRB
- May 18 – 30% PRB
- May 19 – 70% PRB
- May 23 – 60% PRB

Those percentages are on a mass basis. The relationship of mass percentages to heat input percentages is shown in Figure 1.

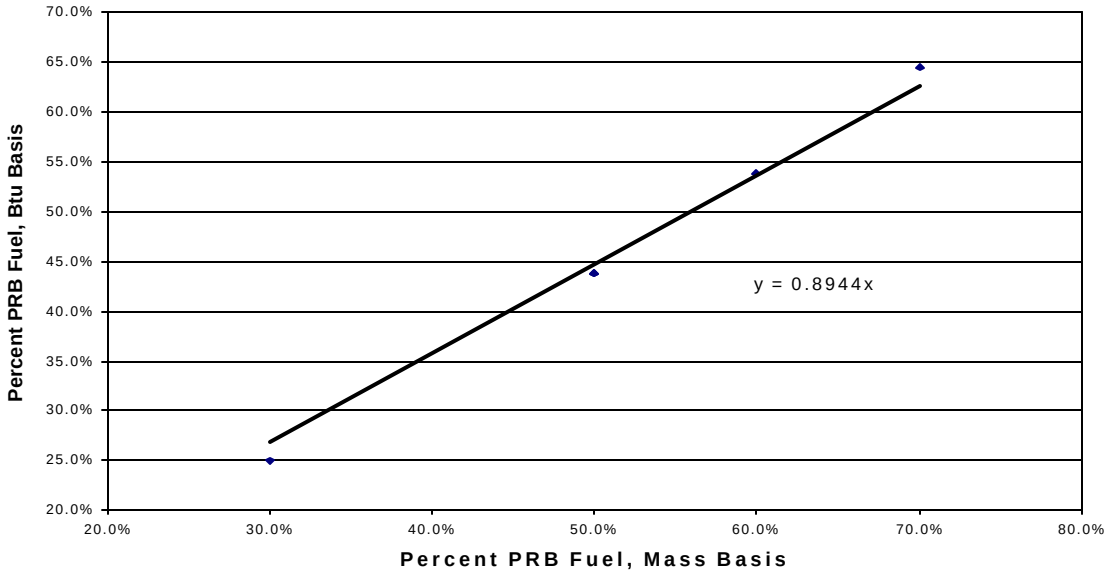


**Figure 1. Relationship Between Mass Percent PRB and Heat Input Percent PRB**

Note that the heat input percentage is about 89 percent of the mass input percentage.

**Table 4. Combustion Conditions Measured During PRB Testing at BGS Boiler #7**

| Date | | 5/16/00 | 5/17/00 | 5/18/00 | 5/19/00 | 5/23/00 |
|---|---|---|---|---|---|---|
| **PARAMETER** | **UNITS** | | | | | |
| Total Coal Flow | kpph | 137.05 | 139.61 | 133.95 | 136.11 | 139.28 |
| Average O2 | percent | 2.63 | 2.88 | 2.66 | 2.87 | 3.11 |
| Megawatts Gross | MW | 167.53 | 164.32 | 168.68 | 153.44 | 169.99 |
| Megawatts Net | MW | 154.44 | 151.24 | 155.34 | 140.93 | 156.41 |
| Throttle Steam Pressure | psig | 2147.39 | 2114.15 | 2330.14 | 2085.30 | 2153.24 |
| Main Steam Temperature | F | 1006.71 | 1003.83 | 996.57 | 1000.36 | 995.84 |
| Main Steam Flow | kpph | 1082.82 | 1063.09 | 1097.50 | 995.21 | 1104.32 |
| HP Turbine Exhaust Pressure | psig | 401.04 | 393.61 | 406.91 | 367.57 | 415.82 |
| Cold Reheat Enthalpy | Btu/lbm | 1310.25 | 1310.84 | 1309.79 | 1312.87 | 1311.43 |
| Feedwater Flow | kpph | 1136.03 | 1112.45 | 1150.75 | 1039.67 | 1157.84 |
| Reheat Steam Pressure (Hot) | psig | 380.58 | 373.31 | 385.66 | 348.87 | 390.49 |
| Feedwater Pressure | psig | 2374.99 | 2335.72 | 2550.50 | 2283.44 | 2383.04 |
| Exit Gas Temperature | F | 357.73 | 357.73 | 336.15 | 323.42 | 369.00 |
| Reheat Temperature - Hot | F | 992.81 | 996.00 | 973.87 | 990.42 | 1002.68 |
| Average Combustion Air Temp | F | 557.90 | 550.89 | 544.25 | 544.03 | 558.98 |
| Unburned Carbon | % | 19.18% | 9.91% | 12.30% | 16.34% | 12.46% |

Emissions were determined by portable Testo instrumentation supplied by FWDC. This instrumentation was calibrated before the testing, during the testing (on May 18), and then following the testing. Calibrations were made at the FWDC laboratories in Livingston, NJ, and at Clean Air Engineering in Pallatine, IL.

Table 5 reports the data from Testo measurements taken, corrected for calibrations. Note that the $NO_x$ data include $NO_x$, NO, and $NO_2$.

**Table 5. Testo Measurements Taken During the PRB Testing at BGS Boiler #7**

| Date | | 5/16/00 | 5/17/00 | 5/18/00 | 5/19/00 | 5/23/00 |
|---|---|---|---|---|---|---|
| Parameter | Units | | | | | |
| O2 | % dry | 3.76 | 3.44 | 3.21 | 3.99 | 4.49 |
| NOx | ppmv dry | 723.77 | 704.29 | 761.09 | 600.36 | 702.16 |
| CO | ppmv dry | 13.78 | 16.05 | 8.64 | 31.51 | 17.28 |
| NO | ppmv dry | 709.32 | 695.73 | 752.27 | 594.12 | 693.99 |
| NO2 | ppmv dry | 12.60 | 6.21 | 5.84 | 6.47 | 8.78 |
| SO2 | ppmv dry | 1148.42 | 1168.74 | 1879.37 | 921.51 | 1080.55 |

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**Results of the Analysis**

The basis of the analysis is a series of heat and material balances, along with emissions calculations. The heat and material balance data demonstrate that the PRB coal, as expected, creates an efficiency penalty for BGS boiler #7. Figure 2 shows a general increase in unburned carbon in the flyash as a function of PRB percentage. The LOI results are consistent with the reduced residence time of the coal in the primary furnace. Such LOI problems were not encountered with the biomass. However they indicate that two highly volatile fuels that reduce residence time in the furnace could be difficult

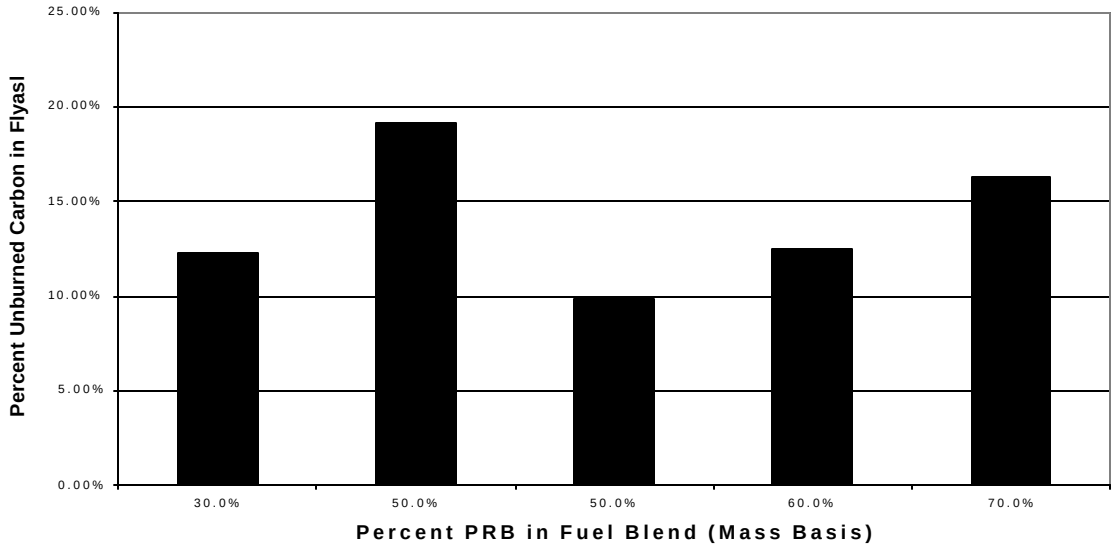


**Figure 2. Unburned Carbon as a Function of Percent PRB Coal in Fuel Blend**

if the furnace has limited volume. Bailly #7 boiler has a limited volume furnace..

There were several influences on boiler efficiency, working together to decrease the effectiveness of the fuel blend. As shown in Table 3, there was a significant increase in fuel moisture as well as a decrease in heat content. This increase in fuel moisture, in turn, increased the volume of combustion products produced. The decrease in boiler efficiency caused more fuel to be fired, further increasing the volume of gaseous combustion products. This reduced the gas residence time in heat transfer portions of the unit—the furnace, boiler, economizer, and air heater—thereby reducing heat transfer effectiveness. This raised the air heater exit temperature on the gas side, further causing a decrease in boiler efficiency. The unburned carbon in the flyash also was caused by the reduced residence time, and contributed to the decrease in efficiency.

The $NO_x$ and $SO_2$ emissions shown are calculated on the basis of the USEPA F-Factor. They are then checked against a direct mass balance calculation of lbs $NO_x$ or $SO_2$/hr divided by the heat input ($10^6$ Btu/hr) determined directly from the heat and mass balances. The F-Factors used are based upon the USEPA $O_2$ methodology rather than the $CO_2$ methodology. These F-Factors are specific to the fuels being burned.

Figure 3 presents the F-Factors calculated for each fuel blend, and shows also F-Factors for 100 percent PRB coal and 100 percent high sulfur coal. Figure 4 shows a comparison of F-Factor $NO_x$ emissions and heat balance $NO_x$ emissions. The closure between the F-Factor emissions as calculated, and the emissions determined directly from the heat and material balances, demonstrates the utility of the techniques employed.

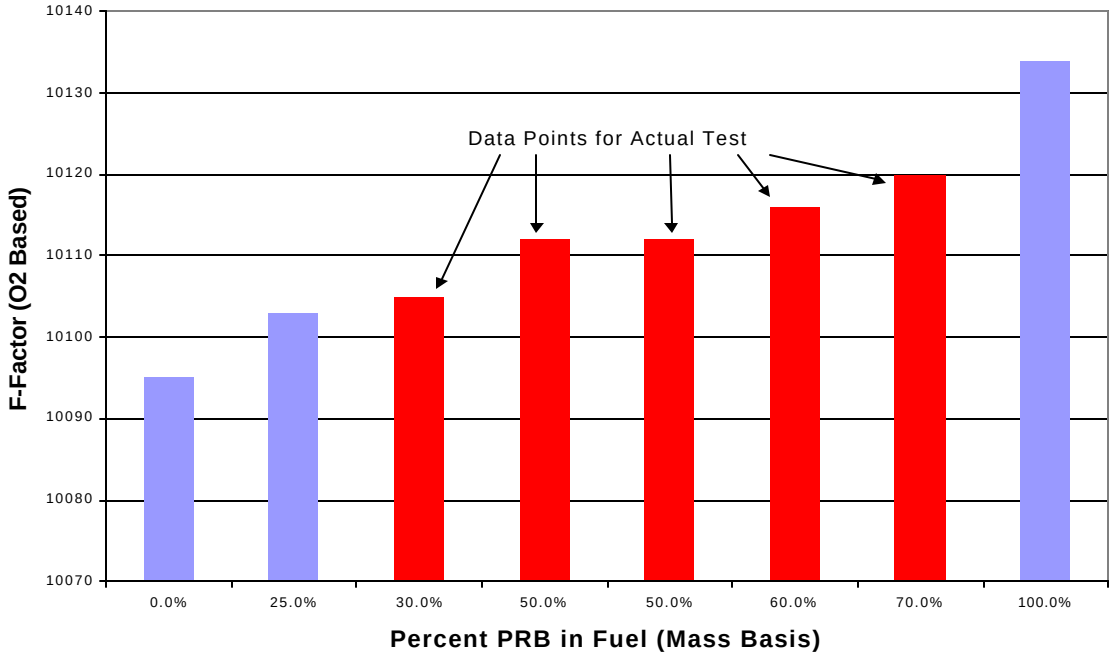


**Figure 3. F-Factors Calculated for the BGS Tests of PRB Coal**

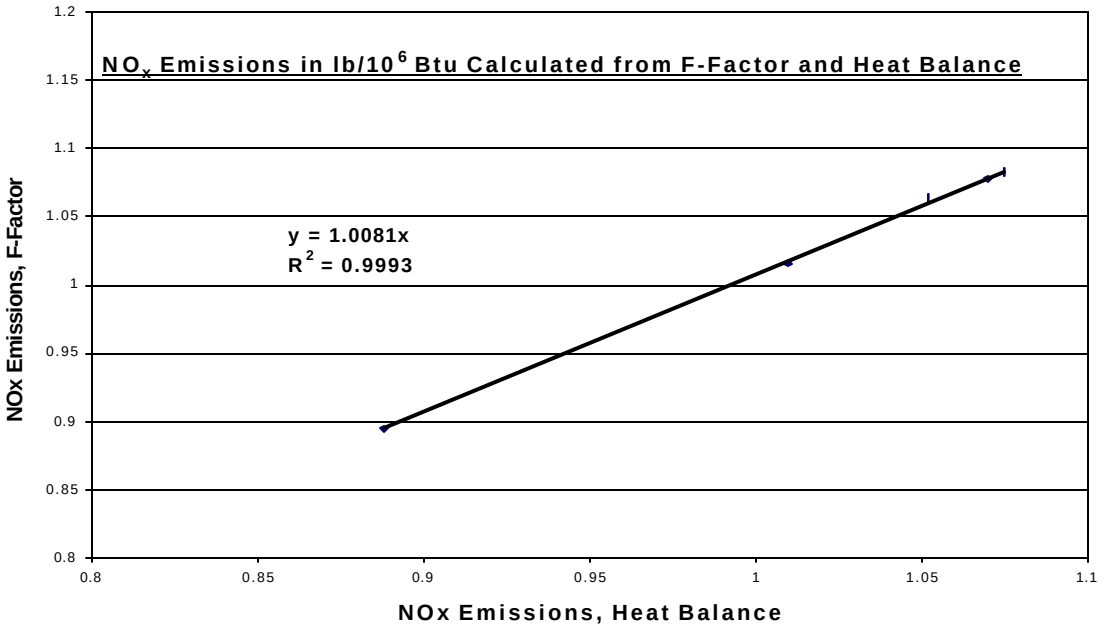


**Figure 4. Comparison of $NO_x$ Emissions Calculated by F-Factor and Heat Balance**

These comparisons provide a basis for pursuing the $NO_x$ emissions analysis. Table 6 presents a summary of the $NO_x$ emissions measured during the PRB test program.

**Table 6. Basic NOx Emissions Results from PRB Testing at BGS Boiler #7**

| Test Date | % PRB | | | |
|---|---|---|---|---|
| | Mass | Btu | Firing Rate | NOx |
| | | | (MMBtu/hr) | (lb/MMBtu) |
| 16-May | 50.0% | 43.80% | 1570.15 | 1.05 |
| 17-May | 50.0% | 25.00% | 1537.91 | 1.01 |
| 18-May | 30.0% | 43.80% | 1537.91 | 1.08 |
| 19-May | 70.0% | 53.90% | 1430.56 | 0.89 |
| 23-May | 60.0% | 64.50% | 1606.85 | 1.07 |

These data can be converted into a regression-type equation as shown below. Note, however, that there are only five observations. The statistics suggest a robust equation, however that must be tempered by the reality of a few observations. The regression analysis shown in equation [1] is based upon mass percentage cofiring.

$$NO_x \text{ (lb/}10^6 \text{ Btu)} = 0.000867(FR) - 0.23(PRB) - 0.191 \quad [1]$$

Where FR is firing rate ($10^6$ Btu/hr of fuel) and PRB is fraction PRB in the fuel blend (expressed as a decimal). The apparent low value for firing rate is tempered by the fact that the unit typically fires 1,100-1,200x$10^6$ Btu/hr.

The probability that each term is random is as follows:

- Equation as a whole: 0.017
- Firing rate: 0.017
- Fraction PRB coal: 0.045

Note that the functions of PRB and wood waste are highly similar; and the functions of PRB and the blend of wood waste and petroleum coke are also similar. If the furnace were of sufficient volume, then a combination could be increasingly effective as a NOx reduction strategy. However the lack of furnace volume as illustrated by the increased LOI made further efforts to cofire wood waste with PRB blends—or to burn a blend of

wood waste and petroleum coke with a coal blend dominated by PRB—impractical and potentially significantly limiting with respect to boiler capacity.

### Project 7 – Testing Cofiring of Switchgrass by Nebraska Public Power District/Sandia

This project was cancelled.

### Project 8 – Waste Plastics Cofiring at Duke Power

This project was cancelled.

### Project 9 – Plastics/Fiber/Pulp Waste Cofiring with SCE&G

This project was cancelled.

### Project 10 – Urban Wood Waste Cofiring in Pittsburgh, PA

This project was completed.

### Project 11 – Toxic Emissions from Cofiring Evaluation

This project was cancelled.

### Project 12 – Fuel/Powerplant Model Development

This project was cancelled and the funds were redirected towards the relocation of the Seward project.

### Project 13 – $CO_2$ Utilization in Algal Systems

This project has been completed.

### Project 14 – Combustion Tests and Combustor Development

This project was cancelled.

### Project 15 – Support for Ash Sales from Cofiring Plants

This project was cancelled.

### Project 16 – $CO_2$ Capture and Disposal Options

This project has been completed.