Progress Report: Cofiring Projects for Willow Island and Albright Generating Stations

Prepared by:

Allegheny Energy Supply

an Allegheny Energy company

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DESIGNING AN OPPORTUNITY FUEL WITH BIOMASS AND TIRE-DERIVED FUEL FOR COFIRING AT WILLOW ISLAND GENERATING STATION AND COFIRING SAWDUST WITH COAL AT ALBRIGHT GENERATING STATION

Quarterly Technical Report

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ABSTRACT`

During the period October 1, 2002 – December 31, 2002, Allegheny Energy Supply Co., LLC (Allegheny) completed the first year of testing at the Willow Island cofiring project. This included data acquisition and analysis associated with certain operating parameters and environmental results. Over 2000 hours of cofiring operation were logged at Willow Island, and about 4,000 tons of sawdust were burned along with slightly more tire-derived fuel (TDF). The results were generally favorable. During this period, also, a new grinder was ordered for the Albright Generating Station to handle oversized material rejected by the disc screen.

This report summarizes the activities associated with the Designer Opportunity Fuel program, and demonstrations at Willow Island and Albright Generating Stations. It details the test results at Willow Island and summarizes the grinder program at Albright.

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EXECUTIVE SUMMARY

The Tenth Quarter of the USDOE-Allegheny Energy Supply Co., LLC (Allegheny) Cooperative Agreement, October 1, 2002 through December 31, 2002, was characterized by completion of the first year of testing at Willow Island Generating Station, and the ordering of a new grinder for Albright Generating Station. The primary results of the testing, which are the focus of this report, are as follows:

> Nearly 4,000 tons of sawdust were cofired along with over 5,000 tons of TDF. Sawdust was fired at 0 to 9 percent of the fuel blend (mass basis), and TDF was fired at 0 to 7 percent of the fuel blend (mass basis). Loads varied from 100 to 187 MW_e (net).
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> Operating results of the testing showed that adding sawdust to the fuel blend increased the coal feeder speeds on a percentage basis, however the unit never ran out of feeder capacity. Boiler efficiencies were impacted slightly. Cofiring did not increase the excess O_2 or stoichiometric ratio used in combustion; further it did not increase the temperature of the flue gas exiting the air heater. Cofiring did not cause the unburned carbon content of the flyash to increase. Cofiring did increase the losses associated with moisture in the fuel and hydrogen in the fuel. These increases were modest. When cofiring was evaluated in terms of impacts on net station heat rate, the impacts were on the order of an increased NSHR of 32 Btu/kWh when cofiring at 10 percent sawdust (mass basis). Cofiring did not cause a reduction in flame temperature within the cyclone barrels; it did, however, contribute to a reduction in furnace exit gas temperature (FEGT).
>
> Environmental results of the testing showed that cofiring contributed to reductions in SO_2 emissions, although the normal variations in coal quality made such analyses less than robust. Results also showed that cofiring reduced mercury emissions and contributed a reduction of some 12,000 tons fossil CO_2 equivalent to Allegheny Energy's voluntary greenhouse gas reduction program. Expected NO_x reductions did not materialize, however. NO_x emissions were not influenced by cofiring.

1.0. 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 Allegheny project is designed to demonstrate both direct combustion approaches to cofiring.

1.1. THE WILLOW ISLAND DEMONSTRATION

Allegheny Energy Supply, LLC will demonstrate blending wood waste and tire-derived fuel to create a new opportunity fuel for cofiring in cyclone boilers, and integrating this fuel combination with a separated overfire air system for maximum NO_x management. This project also will demonstrate the use of biomass-TDF blends to reduce SO_2 and fossil CO_2 emissions along with trace metal emissions. The demonstration will occur at Willow Island Generating Station Boiler #2. It is a 188-MW_e cyclone boiler operated in a pressurized mode and equipped with a "hot side" electrostatic precipitator (ESP). This demonstration, located in Willow Island, WV, has numerous unique features to significantly advance cofiring technology. Allegheny Energy, using Foster Wheeler Development Corporation, has completed a feasibility study for the project and plans to move directly into Phase II—construction and operation of the demonstration system.

Cofiring of wood wastes with coal has been demonstrated as an effective means for using biomass in cyclone boilers; demonstrations have occurred at the Allen Fossil Plant of TVA, the Michigan City Generating Station of NIPSCO, and the Bailly Generating Station (BGS) of NIPSCO. In these demonstrations, NO_x, SO_2, and fossil-based CO_2 emissions reductions occurred. In each case, the volatility of the wood waste created the mechanism for NO_x reduction, while the use of a sulfur-free fuel reduced SO_2 emissions. Testing at BGS opened a new area of investigation: designing blends of opportunity fuels to optimize the impacts of cofiring. At BGS, urban wood waste is mixed with petroleum coke at a specified blend to optimize NO_x emissions management while accomplishing the goals of fossil CO_2 emissions reductions. The NO_x emissions reductions at BGS are ~30 percent when firing the designed opportunity fuel blend.

The Willow Island demonstration will blend sawdust with TDF to create a new opportunity fuel for cofiring in a cyclone boiler equipped with a separated overfire air system. This demonstration will create a second opportunity fuel blend that maximizes NO_x emissions reductions from the combustion process and that can be integrated into the overall NO_x emissions management strategy using overfire air. At the same time, SO_2 emissions will be reduced along with fossil CO_2 emissions and heavy metal emissions. The Willow Island plant "hot-side" ESP requires the use of a sodium additive to enhance the resistivity of the flyash particles. This demonstration will examine the potential of biofuel cofiring to obviate the need for such additives in the control of particulates and opacity—capitalizing upon the potassium and sodium content of the biomass ash.

The demonstration program involves optimizing the sawdust-TDF-coal blend for maximum impact in the cyclone combustion process. Further, it involves optimizing this blend to capitalize upon the overfire air system for NO_x management. It is estimated that the project will fire at least 10 percent wood waste, along with about 10 percent TDF in the project.

While this demonstration involves integrating past successful programs, it provides a significant enhancement of cofiring and the use of biomass. If successful, it will be the first demonstration where cofiring has been explicitly integrated into an overall NO_x control strategy as a significant contributor. Further, if successful, it provides a means for cyclone boiler owners and operators to consider NO_x management strategies other than end-of-pipe solutions or expensive fossil-based combustion strategies to achieve compliance with current and proposed regulations.

Further, this will be the first cofiring demonstration where the boiler is equipped with a "hot side" electrostatic precipitator—an ESP installed between the economizer and the air heater rather than after the air heater. Such "hot side" ESP's conventionally use sodium additives to improve the resistivity of the flyash and enhance its capture. Biomass, with its concentrations of potassium and sodium, may reduce or eliminate the need for such additives. This demonstration will address that condition and, as a consequence, advance the use of cofiring in coal-fired boilers.

1.2. THE ALBRIGHT DEMONSTRATION

The Albright Generating Station demonstration provides a means for comparing the NO_x reduction results obtained at Willow Island Generating Station—in a cyclone boiler—to those that can be obtained in a pulverized coal boiler. The Albright Generating Station Boiler #3 is a 140 MW_e boiler, comparable in capacity to the Willow Island boiler. It burns a similar eastern bituminous coal. Of critical importance, the Albright boiler is equipped with a low-NO_x firing system including a separated overfire air system.

The Electric Power Research Institute (EPRI) has developed a demonstration of sawdust cofiring in a PC boiler at the Seward Generating Station. A favorable biomass fuel supply potential and the favorable technology potential has led Allegheny to decide to relocate the cofiring demonstration to the Albright Generating Station. The relocation of the separate injection demonstration from Seward Generating Station to Albright provides opportunities to extend the knowledge base concerning cofiring—capitalizing upon the configuration of Albright Boiler #3. Specifically cofiring has not been applied to a generating station equipped with low NO_x firing separated overfire air system. In relocating the demonstration from Seward to Albright, Allegheny Energy and USDOE have capitalized upon such an opportunity.

1.3. THE COMBINED RESULTS

The combination of the Willow Island demonstration at the cyclone boiler and the comparative data developed at the Albright demonstration in a tangentially-fired pulverized coal boiler will provide definitive data concerning the emissions reduction potential of biomass cofiring in units already equipped with low NO_x firing systems. As such, these data will help define the potential, and limits, of biomass cofiring as an emissions reduction strategy. At the same time these demonstrations will provide a means for evaluating biomass cofiring as a cost-effective strategy for voluntary fossil CO_2 emissions reductions. Finally these projects will demonstrate additional environmental benefits of cofiring.

2.0. TECHNICAL PROGRESS

Overall progress has included concluding contract negotiations with Foster Wheeler and, consequently, with the specialty subcontractors. With these contracts in place, progress has been significant on both projects.

2.1. TECHNICAL PROGRESS ON COMBUSTION AT WILLOW ISLAND GENERATING STATION

Allegheny Energy Supply Co., LLC. (Allegheny Energy), under contract to the US Department of Energy (USDOE) to perform a long term demonstration of biomass cofiring at its Willow Island and Albright Generating Stations, contracted with Foster Wheeler to design, construct, and test sawdust cofiring facilities at these locations. Testing was performed at the Albright Generating Station in 2001, while the system at Willow Island was constructed. Biomass cofiring testing at Willow Island Generating Station commenced in 2002. This report summarizes the results of that test program.

The basis of the program at Willow Island was the contract with USDOE to evaluate designer opportunity fuels in cyclone boilers—designer fuels that may be single alternative fuels (e.g., sawdust) or combinations of alternate fuels (e.g., wood waste with petroleum coke, wood waste with tire-derived fuel). As a consequence, the program was designed to test cofiring of sawdust alone, and in combination with tire-derived fuel (TDF) at this West Virginia location.

The test program developed for Willow Island Generating Station is unique. It is a *commercial* demonstration, with testing occurring over a 2-year time window. The cofiring is integrated into overall plant operations, rather than tested as a single event or series of events. Consequently it combines the commercial operations with the data gathering associated with test programs.

2.1.1. The Willow Island Cofiring System

The TDF cofiring system at Willow Island was previously installed by Allegheny Energy, and is not described here. The sawdust cofiring system was designed and installed by Foster Wheeler. It consists of a walking floor truck receiving station, a disc screen to size the biomass at ¼” x 0” particles, a grinding system to reduce oversized particles to the desired size, a live bottom or walking floor bin to store the biomass, a variable speed twin auger system for transporting reclaimed sawdust to the feed belt connecting the sawdust to the main coal belt, and that feed belt which is equipped with a load cell to meter the sawdust feed at desired rates.

The critical capacities of the sawdust cofiring system are as follows:

Truck receiving: 2.5 trucks/hr
Sawdust screening: 50 ton/hr

Sawdust storage: 400 tons[1]
Sawdust reclaim maximum flow rate: 75 ton/hr[2]

The installation was completed in the first quarter of 2002, with the replacement of motors on the twin augers. Following installation, and the spring outage for the plant, testing commenced. Figures 1 – 4 depict the sawdust cofiring system.

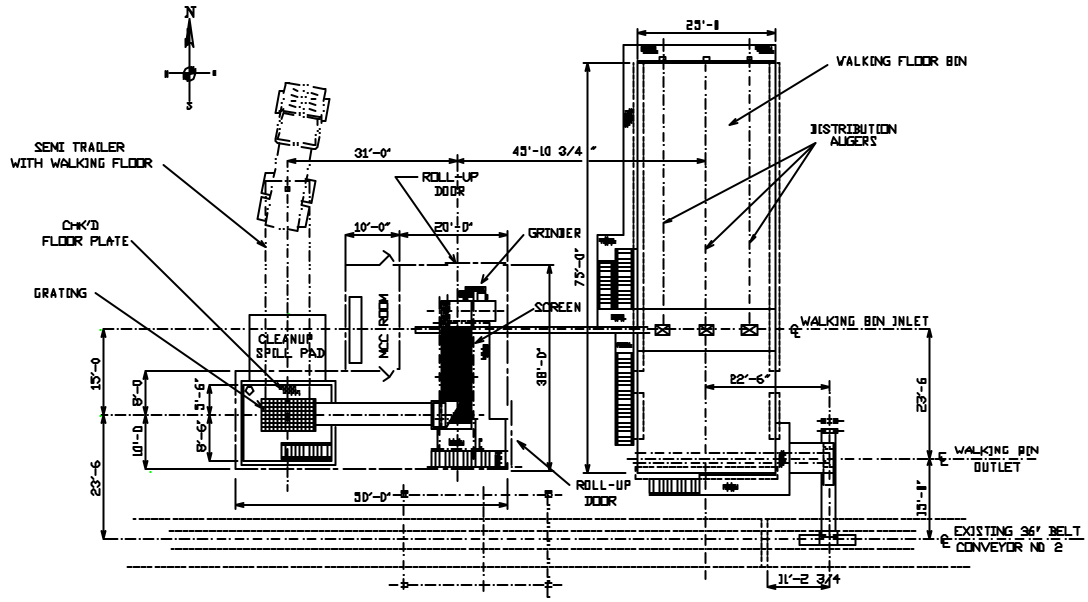

Figure 1. Plan View of the Sawdust Cofiring System at Willow Island

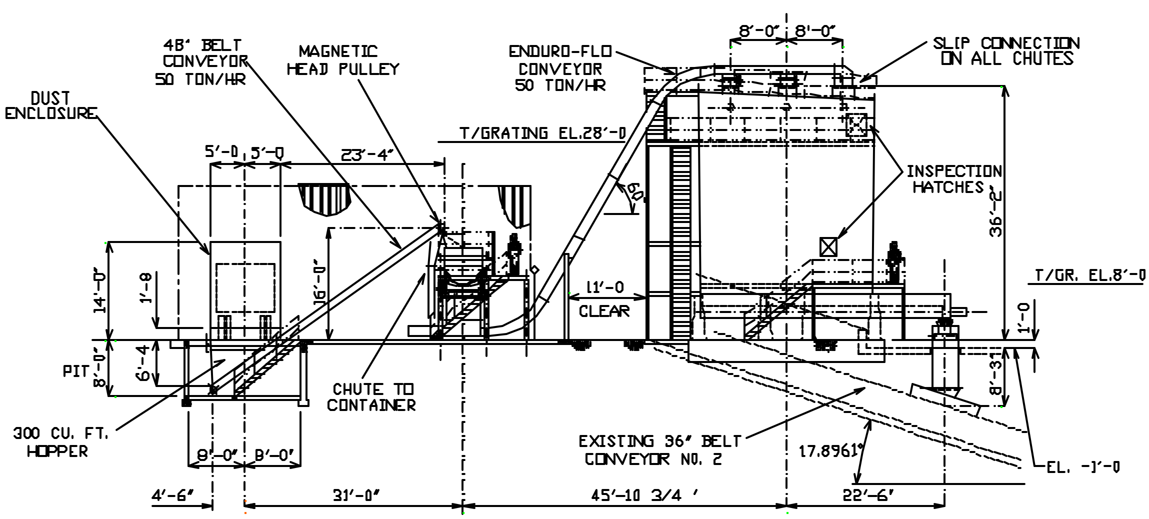

Figure 2. Elevation View of the Sawdust Cofiring System at Willow Island

Figure 3. Construction Picture Showing Installation of Disc Screen (above), Grinder (below) and Conveyor from Screening to the Walking Floor Bin

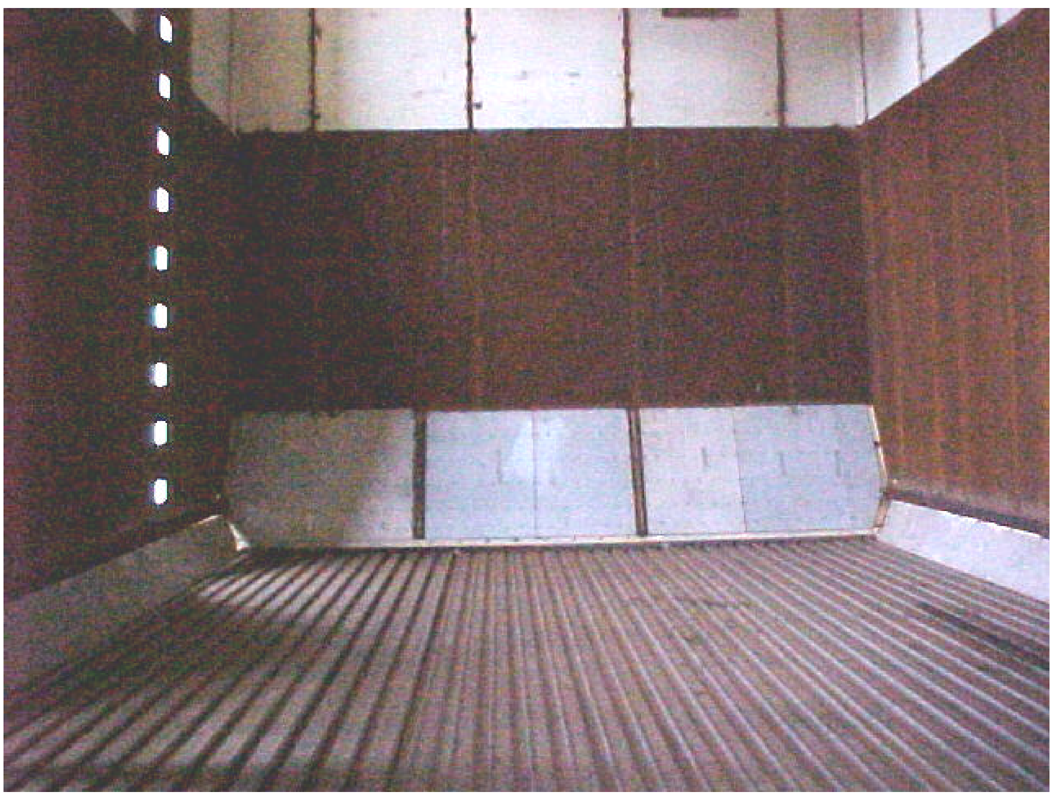

Figure 4. Inside the Live Bottom Walking Floor Bin

2.1.2. Test Program Parameters

The test program was based upon extensive preliminary research including extensive fuel characterization, furnace modeling, and reviews of cofiring results at other test programs involving cyclone boilers: Bailly Generating Station of NIPSCO, Michigan City Generating Station of NIPSCO, and Allen Fossil Plant of TVA. The test resulting program developed for the Willow Island Generating Station involved evaluating both operational and environmental concerns. Operational issues included the following:

The influence of cofiring on the ability of the Willow Island #2 boiler to achieve capacity

The impact of sawdust cofiring, and combined sawdust/TDF cofiring, on boiler efficiency—including an assessment of the influence of cofiring on the factors influencing boiler efficiency such as excess O_2 or stoichiometric ratio, air heater exit temperature, and unburned carbon in the flyash or loss on ignition (LOI)

The impact of sawdust cofiring, and combined sawdust/TDF cofiring, on net station heat rate (NSHR) expressed in Btu/kWh, including the critical concern of the influence of cofiring on main steam temperatures

The impact of sawdust cofiring, and combined sawdust/TDF cofiring, on flame temperatures and furnace exit gas temperatures (FEGT)

The environmental issues associated with the cofiring testing included the following:

The influence of cofiring sawdust and combined sawdust/TDF on NO_x emissions

The influence of cofiring sawdust on mercury emissions

The influence of cofiring sawdust on reductions of greenhouse gas (fossil CO_2 equivalent) emissions

The influence of cofiring sawdust, and the combination of sawdust and TDF, on CO emissions and opacity

The test program was designed not only to measure these influences but also to determine statistically significant trends, and to explain specific results as measured.

2.2. TEST METHODOLOGY

2.2.1. Test Program Overview

During the year 2002, Allegheny Energy fired almost 4,000 tons of sawdust at the Willow Island Generating Station, along with over 5,000 tons of TDF. The sawdust cofired was more than any other USDOE-funded cofiring test program to date. It resulted in the generation of 3.7×10^6 kWh of green—renewable—electricity. Table 1 summarizes the consumption of sawdust by month at the Willow Island Generating Station.

Table 1. Consumption of Sawdust at Willow Island Generating Station in 2002

Month	**Tons of Sawdust Consumed**
January – May	283.7
June	373.8
July	732.3
August	534.0
September	637.4
October	532.0
November	652.8
December	238.3
TOTAL	3984.3

During these months 55 test periods were obtained, when the boiler was operating in a condition facilitating the development of test data. These 55 test periods represent some 200 hours of operation. During these test hours, the basic test parameters were varied significantly as shown in Table 2.

Table 2. Variability of Basic Test Parameters During the Willow Island Test Period

	Percent Sawdust	Percent TDF	Gross Load (MW)	Net Load (MW)
Average	5	2	166.3	157.2
Minimum	0	0	108.3	100.3
Maximum	9	7	196.6	186.7

These tests represent a broad range of conditions for evaluating the commercial implications of biomass cofiring and designer opportunity fuels in cyclone boilers.

2.2.2. Test Identification and Data Gathering

The test methodology involved operating the boiler with normal operating procedures; no specific conditions were required of the operators. The tons of all fuels loaded to the bunkers were reported in the coal logs for all days. The coal logs determined what days were considered test days. As an operating assumption, if a particular blend of coal was loaded by 1200 hours on a given day, it was assumed that the blend—or reasonably close to the blend--would be in the boiler by 1800 hours on that day. The Willow Island bunkers, like most bunkers, rathole; and the material loaded at the top rapidly decends to the discharge system. To the greatest extent possible, periods of time analyzed were selected if a given blend was loaded into the bunkers on consecutive days. While this assumption leads to uncertainty in the data, it is necessary given the fact that the coal is flowed through the bunkers to the cyclones; separate injection is not possible. Further, given the operating conditions at the station and the uncertainties of fuel supply, it was not practical to hold a single blend for 5 days.

The basic methodology then involved leaving the unit in automatic generation control (AGC), and acquiring operating data during the entire time frame of the testing. Acquisition of the data was by computer program; electronic data were stored and retrieved as needed, consistent with the cofiring percentages reported in the coal logs. The retrieved data were then reviewed to determine periods of stable operating loads. Operating periods chosen were typically on the order of 2 hours with many being as long as 4 hours and one being over 8 hours.

2.2.2.1. Operational Data Acquisition

The operational data acquired were those associated with constructing heat and material balances. Specific data included the following:

Feedwater pressure, temperature, and flow
Main steam pressure, temperature, and flow
Cold reheat steam pressure and temperature
Hot reheat steam pressure, temperature, and flow
Reheat attemperation pressure, temperature, and flow
Excess O_2 at the furnace
Excess O_2 at the air heater exit
Temperatures of the flue gas exiting the economizer and exiting the air heater
Temperatures of the ambient air, air entering the air heater, and air exiting the air heater
FEGT
Coal feeder speeds (percentage basis)

Certain assumptions were made to augment these data. Cold reheat flow was assumed to be equal to hot reheat flow minus reheat attemperation flow. The temperature of the flue gas entering the air heater was assumed to be equal to the temperature of the gas exiting the economizer minus 50^oF. This correction is the assumed temperature loss in the hot-side ESP. During low load conditions, the reheat steam flows reported by the control system are typically higher than the main steam flows. In these cases, the hot reheat steam flow was assumed to be 89.6 percent of the main steam flow; this assumption was based upon an analysis of the boiler heat balance drawing.

Because FEGT was considered a critical parameter, a Diamond Power Gastemp? probe was purchased and installed at the nose of the boiler. The Gastemp? probe was then connected to the Bailly control system for continuous recording of FEGT data.

In addition to the acquisition of continuous operating data, the analyses were based upon extensive characterization of the sawdust, coal, and TDF burned at the Willow Island Generating Station. These characterizations were performed at the beginning of the program. Bottom ash (slag) unburned carbon was assumed to be almost 0—0.15 percent. Unburned carbon in the flyash was based upon the LOI measurements for the week during the test period. Since flyash contains only 30 percent of the solid products of combustion from cyclone firing, and since the LOI values were reasonable in all cases, this parameter was not extensively analyzed. Feedwater and steam enthalpies were calculated using the ASME Steam Properties software.

2.2.2..2. Environmental Data Acquisition

Once the test period was determined, Certified Emissions Monitoring System (CEMS) data were obtained consistent with the test period. The CEMS data obtained were as follows:

NO_x, ppmv
NO_x, lb/10^6 Btu
SO_2, ppmv
SO_2, lb/10^6 Btu
Opacity
Load

CO data also were obtained, but not from the CEMS. It was recognized that NO_x values reported from the CEMS as lb/10^6 Btu are based upon an F-Factor, obtained from USEPA literature and installed in the monitoring equipment. It was also recognized that the F-Factor is based upon the ultimate analysis of the fuel as fired, and the most precise F-Factor is calculated for each blend. F-Factors for lower rank fuels are lower than those for higher rank coals; consequently blends of coal and sawdust can have lower F-Factors than the coal alone. When using CEMS data, this can result in overstating the NO_x and SO_2 emissions. In order to determine whether the F-Factor would unduly bias results upward when cofiring sawdust with coal, F-Factors were calculated for the coal alone, and for all coal/sawdust/TDF blends. Using the O_2-based F-Factor calculation, an operational equation for corrections was developed:

$$F_{WI} = 36028.99 - 262.76(\%C) - 263.96(\%W) - 266.38(\%TDF) \quad [1]$$

Where F_{WI} is the F-Factor for Willow Island coal, %C is the mass percent coal in the fuel blend, %W is the mass percent sawdust in the fuel blend, and %TDF is the mass percent TDF in the fuel blend. This is an operational equation only; its parameters have no fundamental basis. However the equation shows that the sawdust and the TDF both have the potential to reduce the F-Factor used to calculate NO_x and SO_2 emissions in lb/10^6 Btu. Given equation [1], the NO_x emissions reported by the CEMS were adjusted for the specific fuel blend and then compared to the original values reported by the CEMS. The results of this comparison are shown in Figure 5. Note that there is almost no correction associated with the fuel-specific F-Factors. On this basis the CEMS data are used directly throughout the remainder of this report.

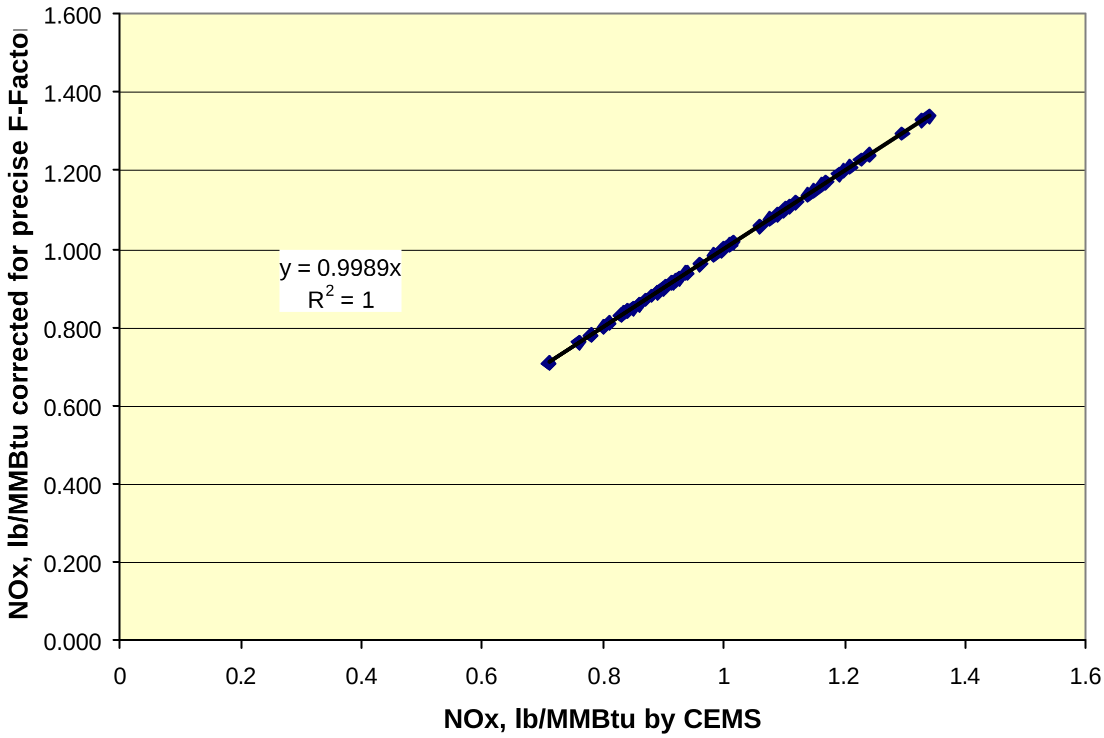

Figure 5. Comparison of NO_x Reported by the CEMS, and NO_x Reported, and Corrected for Fuel-Specific F-Factors

Fossil CO_2 emission reductions were analyzed based upon the tons of sawdust fired. Mercury emissions were analyzed based upon a comparison of the sawdust with reports to USEPA by Allegheny Energy.

2.3. Analytical Techniques

The data were then analyzed by constructing a series of simplified heat and material balances about the Willow Island #2 boiler. These balances were integrated with the CEMS data to depict the emissions simultaneously with the operating data. Note that the percentage sawdust and TDF shown in the heat balances is on a heat input basis.

In addition to the heat and material balances, theoretical flame temperatures were calculated using CET-89, the thermodynamic combustion code developed by NASA and used widely throughout the combustion industry. Theoretical flame temperatures were calculated, in absolute temperatures, based upon the analysis of the fuel blend, the stoichiometric ratio, and the temperature of the air exiting the air heater. The estimate of actual flame temperature within the cyclone barrel was taken to be 90 percent of the theoretical flame temperature on an absolute basis. This estimate is consistent with cyclone firing literature, and consistent with measurements made at both the Allen Fossil Plant and Paradise Fossil

Plant of TVA during extended combustion tests. Additional cyclone modeling was performed using a Foster Wheeler simplified model to evaluate additional issues.

Once the basic analyses were performed, trends in the data were then evaluated using statistical analysis, focusing upon regression analysis and curve fitting. In this way, the influences of cofiring could be readily depicted.

2.3. OPERATIONAL RESULTS FROM COFIRING AT WILLOW ISLAND

Operational results from cofiring sawdust, and combinations of sawdust and TDF, included the influences of these fuels on the ability of the unit to make capacity, to operate in an efficient manner, to achieve desired temperatures, and to impact fuel costs. In all of these cases the cofiring system met or exceeded expectations.

2.3.1. Impact of Cofiring on System Capacity

As expected, the cofiring of sawdust modestly increased the use of boiler feeder capacity as is shown in Figure 6. The sawdust, having both a lower calorific value, and a lower bulk density, speeds up the feeders to the cyclones. However the increases in feeder speeds never caused the unit to experience a capacity limitation. The scatter in the data shown in Figure 7 reflect the influenc

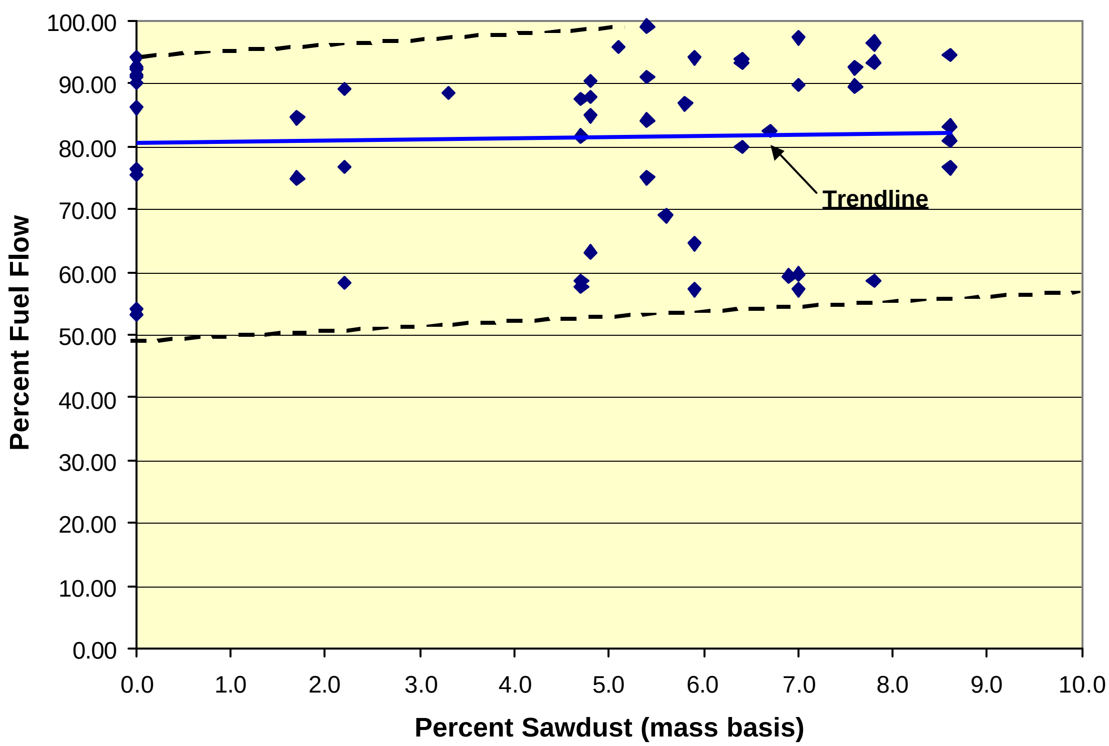

Figure 6. The Influence of Sawdust Cofiring on Fuel Feeding Capacity

Because the fuel feeding capacity is a function of both fuel quality (Btu/ft^3 of fuel) and load, a simplified regression equation was created as shown below:

$$CF = 2.281 + 0.505(\%W) + 0.462(MW_g) \quad [2]$$

Where CF is percentage coal flow, %W is percent sawdust cofiring on a mass basis, and MW_g is the load expressed in gross megawatts generated. The coefficient of determination (r^2) for this equation is 0.96. The probability that the %W term occurs randomly is 0.00014 and the probability that the influence of load occurs randomly is $6.2x10^{-40}$.

2.3.2. Impact of Cofiring on System Efficiency

The impact of cofiring on system efficiency includes both boiler efficiency, expressed as a percentage, and net station heat rate expressed as Btu/kWh. Evaluations of efficiency include both assessments of specific operating parameters—excess O_2 or stoichiometric ratio, air heater exit temperature, and loss on ignition—and on efficiency as a whole.

2.3.2.1. Boiler Efficiency

Boiler efficiency was evaluated by calculating a heat and material balance about the boiler for each test. Heat and material balances were calculated using molar calculations and the "losses" methodology. The overall influence of sawdust cofiring, and sawdust/TDF cofiring, on boiler efficiency is very small. Regression analysis shows that the maximum degradation in boiler efficiency caused by cofiring is 0.03 percent efficiency loss/percent wood cofiring on a mass basis. When cofiring at 10 percent (mass basis) the maximum efficiency loss would be 0.3 percent. The regression analysis was not robust, however; variability in the coal being fed, along with other factors, contributed to a low coefficient of determination.

The influence of specific parameters on efficiency became of significance for analytical purposes. Factors analyzed included excess O_2 or stoichiometric ratio, air heater exit temperature, loss on ignition, and then selected components of the losses calculation: dry gas loss, fuel moisture content, and hydrogen content in the fuel.

Excess O_2 at the furnace exit, or stoichiometric ratio (SR) for combustion, was the first variable analyzed. The use of excess air as a function of fuel was again analyzed by regreession analysis. A specific function was created showing that the SR decreased by $1.6x10^{-5}$ for every percent wood cofired in the fuel blend. The SR decreased by 0.0005 for every percent TDF in the fuel blend. The r^2 for the equation created is 0.81, and all factors are statistically significant. The percentage wood and the percentage TDF in the fuel blend has virtually no influence on the SR.

Cofiring does not influence the use of excess air, as shown above. Cofiring also does not influence the air heater exit temperature If anything, there was a slight (favorable) downward trend in air heater exit temperature as a function of sawdust cofiring. That trend is not significant, however; essentially there is no influence. Further, The inclusion of sawdust into the fuel blend had no influence on unburned carbon in the flyash, or loss on ignition (LOI.

The heat and material balances for operations above 177 MW_e gross load were used to evaluate the influences of dry gas loss, moisture in the fuel, and hydrogen in the fuel. These cases indicate that the influence of sawdust and TDF is the increase in moisture in the fuel and hydrogen in the fuel. The latter results from the higher hydrogen/carbon atomic ratios associated with the sawdust and the TDF.

2.3.2.2. Impact of Cofiring on Net Station Heat Rate

The overall impact of cofiring on net station heat rate is not readily apparent from operating data; the influences are quite minor. Of significance to the heat rate determination is the influence of cofiring on main steam temperatures. In summary, cofiring did not reduce main steam temperatures when operating at any condition. In virtually all cases the main steam temperature was between 1000^oF and 1020^oF, regardless of fuel blend or load. Hot reheat steam temperatures also were not influenced by cofiring sawdust or sawdust/TDF blends as well.

The only method for analyzing the impact on net station heat rate, then, is to analyze based upon a theoretical turbine heat rate and apply the boiler efficiency to that. Assuming a turbine heat rate of 8900 Btu/kWh and a typical boiler efficiency when firing only coal of 87.7 percent, an ideal NSHR of 10,150 can be calculated. At 10 percent sawdust, and an efficiency loss of 0.29 percent (based upon equation [3]), and a constant turbine heat rate, the calculated NSHR would be 10,182; there would be an increase in NSHR of 32 Btu/kWh. As a practical matter, the measurements made do not provide sufficient information to quantify this with test data. However it is consistent with other tests conducted at Albright Generating Station Boiler #3, and at other locations as well.

2.4. Temperature Influences of Cofiring at Willow Island #2 Boiler

Both flame temperatures (T_f) and furnace exit gas temperatures (FEGT) are of concern when cofiring sawdust and sawdust/TDF blends. Flame temperatures are essential to maintaining the slag in a condition where it will readily flow through slag taps to slag tanks. Furnace exit gas temperatures significantly influence deposition of inorganic matter in the boiler—and particularly influence where that deposition will occur.

2.4.1. Flame Temperature Influences of Cofiring at Willow Island #2 Boiler

Flame temperatures experienced minimal impact from cofiring activities. T_f values are not readily measured directly, however they can be calculated using the combustion code developed by NASA.

These calculations employ Gibbs Free Energy minimization calculations to account for dissociation of CO_2 into CO and O, and other similar high temperature reactions. Experience with one HVT probe direct measurement of T_f values at Paradise Fossil Plant showed that estimated actual flame temperatures are about 90% of the theoretically calculated T_f values resulting from the CET-89 computer code, on an absolute temperature basis. Experiments measuring the slag temperatures in a cyclone using optical pyrometry at the Allen Fossil Plant confirmed this as a reasonable approximation.

Theoretical and estimated actual flame temperatures have been calculated for 10 full load cases where the sawdust cofiring ranged from 0 to 9 percent (mass basis), and the TDF cofiring ranged from 0 to 6 percent (mass basis). These cases are shown in Table 3.

Table 3. Estimated Flame Temperatures for Full Load Firing at Willow Island #2 Boiler

Case		Load	% Cofiring		Theoretical T_f		Est. Actual T_f	
Date	Time	(MW)*	Sawdust	TDF	K	^oF	K	^oF
03/11	0304	194.71	0	6	2335.1	3744.2	2100	3325
07/02	1826	183.52	3	0	2345.4	3762.7	2110	3340
07/23	1738	183.00	4	0	2349.5	3770.1	2115	3350
08/02	2000	190.14	0	0	2356.2	3782.2	2120	3360
09/20	0935	189.44	7	4	2355.5	3780.9	2120	3355
09/22	1730	184.05	6	3	2346.0	3763.8	2110	3340
09/23	1620	188.07	6	5	2357.9	3785.2	2122	3360
10/10	0954	188.81	8	0	2342.9	3758.2	2110	3335
10/30	0906	189.52	8	0	2356.6	3782.7	2120	3360
11/04	0911	189.48	9	0	2350.7	3772.3	2115	3350
* Gross Megawatts electric generated								

Note that there is very little variation in flame temperature as a function of fuel at full load. Two regression equations have been constructed to estimate flame temperature at Willow Island #2 boiler, as shown below:

$$T_f = 3670 + 5.9*\%C) + 4.8(\%W) + 6.2(\%TDF) + 3.7(\%L) - 617(SR) + 0.38(T_{air}) \quad [3]$$

And

$$T_f = 4248 - 579(SR) + 0.30(T_{air}) \quad [4]$$

Where T_f is theoretical flame temperature (^oF), %C is percent coal in the fuel blend (mass basis), %W is percent sawdust in the fuel blend (mass basis), %TDF is percent tire-derived fuel in the total fuel blend (mass basis), %L is percent limestone in the total fuel blend (mass basis), SR is stoichiometric ratio, and T_{air} is temperature of the combustion air (^oF). Theoretical flame temperatures, rather than estimated actual flame temperatures, were used for these calculations because theoretical flame temperatures are the basis for estimating actual flame temperatures. The r^2 for equation [3] is 0.999 and the r^2 for equation [4] is 0.937. Interestingly, the calculation of the significance values for the fuel variables shows that these are not significant contributors to flame temperature. Table 5 presents the probabilities that all variables in equation [3] occurred randomly. Probabilities <0.05 are significant; probabilities <0.01 are highly significant.

It is interesting that the higher moisture biomass has little impact on flame temperature despite its lower calorific value and its moisture content. The reason is fuel volatility, and the consequent rate of weight loss. Shafizadeh and DeGroot (1977) developed the necessary explanatory equation as shown below:

$$F_i = (dw/dt)h \qquad [5]$$

Where F_i is flame intensity, dw/dt is the rate of weight loss of a sample of fuel with respect to time, when being subjected to thermogravimetric analysis (TGA) at a heating rate of 20^{o}C/min, and h is the heat content of the fuel (cal/g). This equation shows that, while the biomass fuels are lower in calorific value and higher in moisture, the rate of weight loss resulting from their high volatility is sufficient to compensate and to generate high flame temperatures. Consequently, in all cases tested at Willow Island Generating Station #2 boiler the flame temperatures were sufficient to support good slag formation. In no case did was the flame temperature compromised by the practice of cofiring.

2.4.2. Furnace Exit Gas Temperature Influences of Cofiring at Willow Island #2 Boiler

The practice of cofiring at Willow Island caused a decrease in FEGT as is shown in Figure 7. Note the trend shown in this figure based upon sawdust addition.

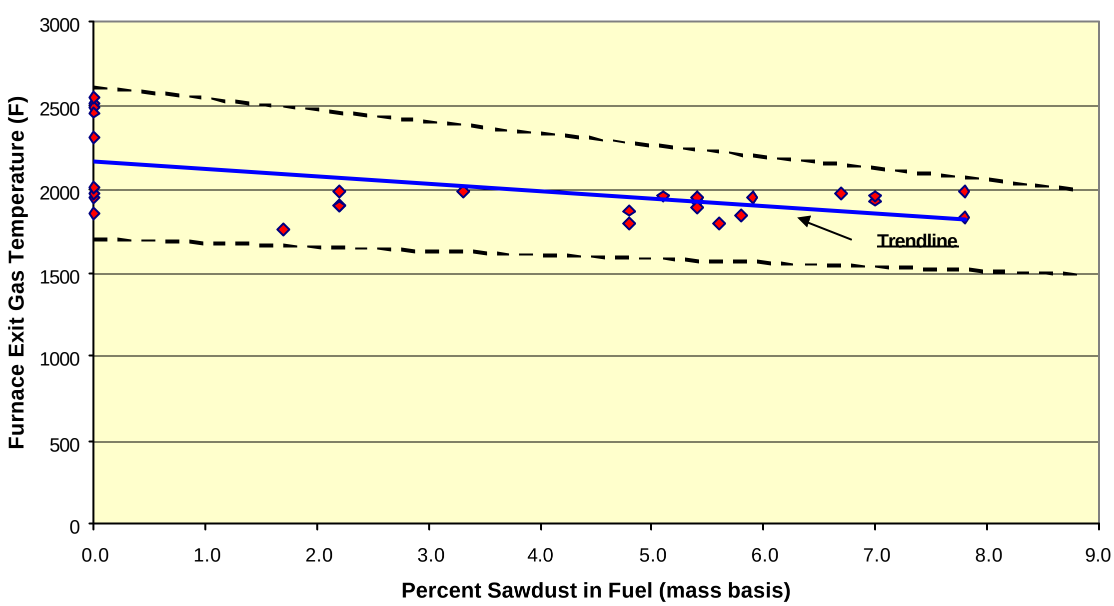

Figure 7. The Influence of Sawdust Cofiring on Furnace Exit Gas Temperature

Note that the trend is quite flat as the percent sawdust exceeds 5 percent. It is useful to observe that, while this trend occurred, the main steam and reheat steam temperatures did not decrease also. That was caused by a modest increase in flue gas volume when sawdust was added to the fuel blend.

Operationally, then, the cofiring project has demonstrated benefits without incurring significant capacity, efficiency, or temperature penalties.

2.5. ENVIRONMENTAL CONSEQUENCES OF COFIRING AT WILLOW ISLAND #2 BOILER

Cofiring biomass—sawdust—and TDF has the potential to accomplish environmental benefits for Willow Island Generating Station. Specific considerations include:

- SO_2 reduction
- NO_x reduction
- Mercury reduction
- Greenhouse gas reduction

Some of these benefits were obtained; others remained elusive during the first year of sawdust cofiring at Willow Island Generating Station.

2.5.1. SO_2 Reduction from Cofiring at Willow Island #2 Boiler

Biomass cofiring is expected to reduce SO_2 emissions; sawdust is virtually sulfur free. Figure 8 summarizes the SO_2 emissions as a function of biomass cofiring. Note that there is a trend towards SO_2 reduction, however there is significant scatter in the results as a consequence of natural variability in the coal being burned. Consequently the r^2 for the trend line is weak—about 0.27.

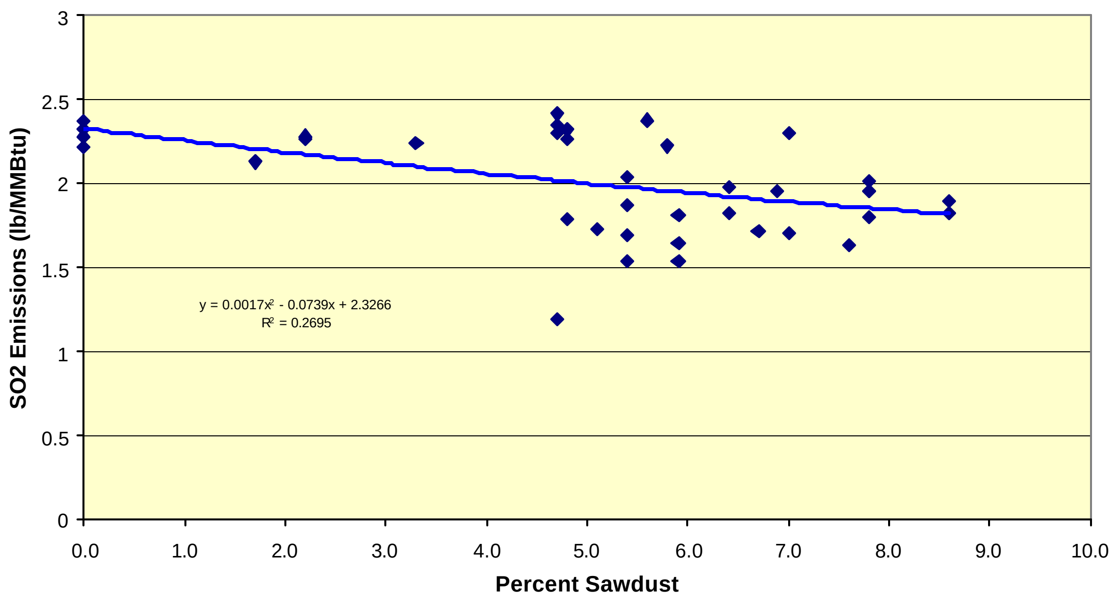

Figure 8. SO_2 Emissions as a Function of Sawdust Cofiring at Willow Island #2 Boiler

A multiple linear regression equation can be created, however it lacks any hint of robustness. What is clear from these data is the fact that coal composition has a natural variability. Further, as sources vary from day to day as a function of reclaim, a precise assessment of SO_2 reduction can not be statistically quantified. It is sufficient to note that the biomass is sulfur-free, and the TDF is relatively low in sulfur; and these will contribute to a reduction in this pollutant.

2.5.2. NO_x Emissions Resulting from Cofiring at Willow Island #2 Boiler

Cofiring sawdust, and combinations of sawdust and TDF, did not achieve the expected reductions in NO_x emissions. The sawdust and TDF both reduced the fuel nitrogen entering the cyclone barrel. The sawdust and TDF did not increase, or decrease, flame temperatures significantly but they did decrease FEGT. NOx data showed significant variability, and regression analysis yielded no equations that were robust. The variability in the NO_x emissions could well be a function of the inherent variability of the coal. The conclusion was that can be said is that cofiring did not reduce NO_x emissions.

It is useful to attempt to understand why NO_x emissions did not respond to cofiring at Willow Island Generating Station, given the success in using cofiring for NO_x trim at Albright Generating Station, and at such cyclone boilers as Bailly Generating Station Unit #7, Michigan City Generating Station Unit #12, and Allen Fossil Plant Units #1 and #2.

Previous research has demonstrated that the NO_x reduction mechanism associated with sawdust cofiring involves creating a highly volatile fuel-rich region to enhance staged combustion. For cyclone boilers, this mechanism has worked because such boilers typically are fired with significantly more excess air—and consequently higher stoichiometric ratios—than is practiced at Willow Island Generating Station.

Operation of the cyclone boiler at Willow Island causes the cyclone to be operated in a fuel staged condition. This is further augmented by the split damper installation at Willow Island. Internal staging within the cyclone barrel is maximized, as is the purpose of the split damper design common to many cyclone installations. To evaluate this possibility, Foster Wheeler applied a simplified cyclone model to consider the stoichiometric and temperature profile of a Willow Island cyclone barrel when operated at full load. Further, results were compared to temperature modeling by Reaction Engineering. The model employed by Foster Wheeler was developed to evaluate biomass cofiring at other installations. Inputs to this model include the fuels, the stoichiometric ratios, and all values associated with calculating heat and material balances. Further inputs include the physical dimensions of the cyclone barrel.

The model used by Foster Wheeler simplifies cyclone combustion by using a zoning approach. It makes the assumption that the gas moves with plug flow between regions, and is well mixed within each region. These assumptions do not hold for cyclones as a whole, however they adequately describe the center of the cyclone where the gas is passing through the cyclone barrel towards the re-entrant throat. These assumptions are more appropriate when cofiring is employed, because cofiring improves mixing in the cyclone barrel. Upon development, the temperature aspects of the model were calibrated with measurements at both Paradise Fossil Plant and Allen Fossil Plant.

The temperature profile of the Willow Island cyclones is depicted in Figures 9 and Figure 10. By comparison, the REI temperature profile for the 90 percent coal/10 percent sawdust case is shown in

Figure 11. Note the similarities of the temperature profiles between Figures 9, 10, and 11. All show the highest temperature very close to the re-entrant throat. These data indicate the fact that the cyclone barrels at Willow Island employ significant internal staging, achieving many if not most of the benefits of staged combustion by the methods employed with normal operations. This accounts for a significant number of full load operating hours when NO_x emissions at Willow Island Generating Station are at or below 1.0 lb/10^6 Btu. Many of the benefits normally brought through cofiring biomass in a cyclone boiler are already being achieved by current operating procedures.

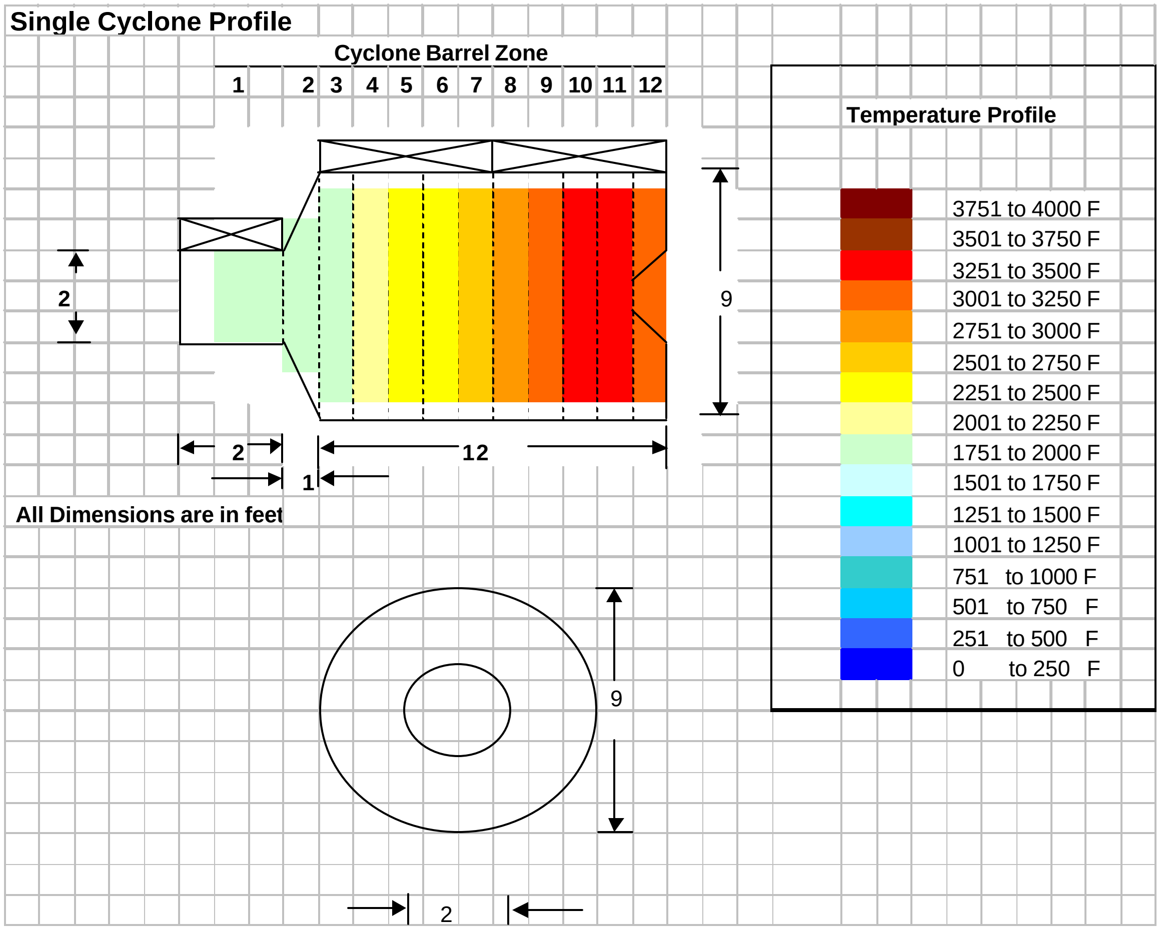

Figure 9. Single Cyclone Barrel Temperature Profile for Willow Island #2 Boiler

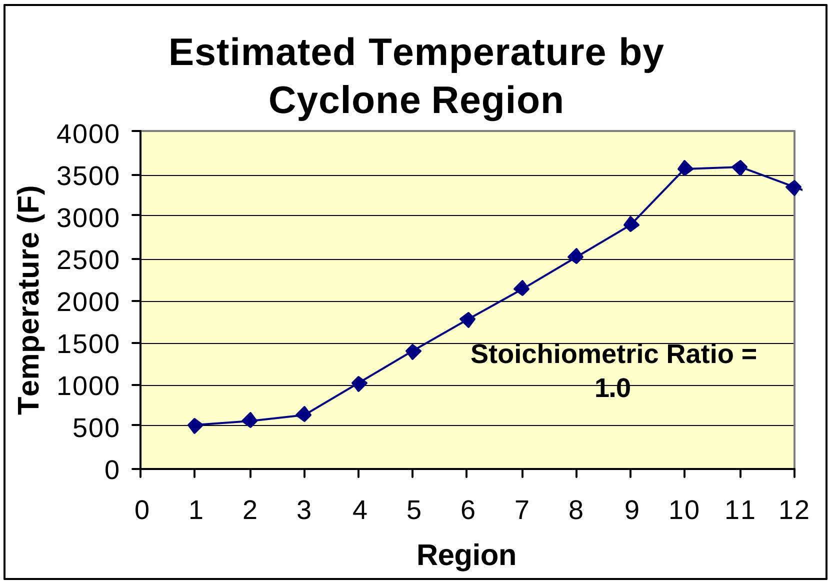

Figure 10. Calculated Cyclone Barrel Temperatures by Cyclone Zone at Willow Island #2 Boiler

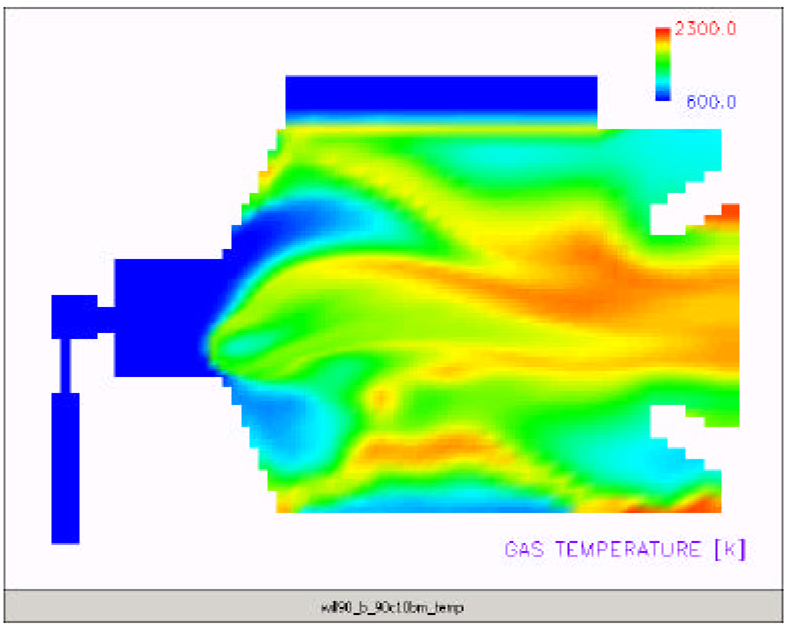

Figure 11. Reaction Engineering Temperature Profile of the Willow Island Cyclone Boiler Firing 90 Percent Coal/10 Percent Sawdust

2.5.3. Mercury Emissions Impacts of Biomass Cofiring at Willow Island

Careful testing of the sawdust being fired at Willow Island Generating Station shows that the sawdust contains 0.003 – 0.009 mg/kg of mercury. This compares to 0.18 mg/kg of mercury in the coal, as reported in the Toxic Release Inventory data. Cofiring reduces mercury emissions by reducing the feed of mercury to the boiler.

2.5.4. Greenhouse Gas Emissions Impacts of Biomass Cofiring at Willow Island

It has been shown that cofiring reduces fossil CO_2 emissions directly by 1.0 – 1.1 tons CO_2/ton biomass burned. Further, it has been shown that cofiring reduces fossil $_{CO2}$ equivalent emissions by an additional 2 tons for every ton of sawdust burned in a power plant—avoiding methane formation in landfills and other land applications.

The cofiring of sawdust at Willow Island has reduced greenhouse gas emissions by >4,000 tons CO_2 directly, and by a total of over 12,000 tons fossil CO_2 equivalent in the year 2002. Since Allegheny Energy has committed to a voluntary reduction of greenhouse gases, this project has made a contribution to the overall corporate target.

2.6. CONCLUSIONS

The first year of cofiring at Willow Island Generating Station has involved over 2000 hours of firing sawdust and sawdust/TDF mixtures. As such, it has demonstrated that there are no negative impacts on boiler capacity, only minor impacts on boiler efficiency, potentially positive impacts on combustion and furnace temperatures, and favorable impacts on fuel costs.

The first year of cofiring at Willow Island Generating Station has demonstrated that the use of sawdust and TDF can reduce SO_2 emissions, however it has not had the beneficial impact on NOx emissions that were anticipated. Cofiring, however, has had favorable impacts on mercury emissions and greenhouse gas emissions.

3.0. PROGRESS AT THE ALBRIGHT GENERATING STATION

Progress at the Albright Generating Station involved placing an order with Industrial Biomass, Inc. for a 2-stage grinder to be installed during the first calander quarter of 2003. This grinder will reduce oversized material rejected by the disc screen and should resolve many of the operating difficulties at the Albright site.

4.0. EXPECTED PROGRESS DURING THE 11TH QUARTER OF THE ALLEGHENY ENERGY COFIRING PROGRAM

The eleventh project quarter, from January 1, 2003 through March 31, 2003 is expected to see the following progress, as shown in Table 4.

Table 4. Anticipated Progress at Willow Island and Albright Demonstration Sites

Progress at Willow Island	Progress at Albright
Continued testing of cofiring	Installation of new grinder
Continued testing of trifiring	Resumption of testing

REFERENCES

Shafizadeh, F. and W. DeGroot. 1977. Thermal Analysis of Forest Fuels. in Fuels and Energy From Renewable Resources (Tillman, D.A., K.V. Sarkanen, and L.L. Anderson, eds.) Academic Press, New York. pp. 93 – 114.