Cofiring Woody Biomass at Allegheny Energy: Results from Willow Island and Albright Generating Stations

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Abstract

Allegheny Energy Supply Co., LLC, with support from the US Department of Energy (USDOE) National Energy Technology Laboratory (NETL) and the Office of Energy Efficiency and Renewable Energy (EERE), has constructed and operated two cofiring demonstrations at the Willow Island Generating Station and at the Albright Generating Station. This program has demonstrated cofiring at both a 188 MW cyclone boiler and at a 140 MW tangentially fired (T-fired) pulverized coal boiler. Between the two units, over 6,000 tons of sawdust have been fired with eastern bituminous coals. In the case of Willow Island, cofiring was performed with tire-derived fuel (TDF) as well. These 6,000+ tons of sawdust represent generating nearly 6 million kWh of renewable energy; and they represent a total reduction in greenhouse gas emissions equivalent to some 18,000 tons of fossil CO_2. The Willow Island program was designed to develop a designer opportunity fuel combining sawdust with TDF to achieve a highly volatile, low nitrogen and low sulfur opportunity fuel for cyclone firing. The Albright program was designed to test the cofiring of sawdust in a pulverized coal boiler equipped with close coupled overfire air (CCOFA) and separated overfire air (SOFA) to evaluate the ability of biomass to reduce NO_x emissions in a boiler with low-NO_x firing capability. Both test programs have been successful. This paper reviews the operational and environmental results of both programs, providing an evaluation of biomass cofiring as a fuels-based tool for addressing environmental issues including NO_x, SO_2, and mercury emissions. It addresses future test programs that are planned for these units as well.

0.0. Introduction

Allegheny Energy Supply Co., LLC., supported by the National Energy Technology Laboratory (NETL) and the Office of Energy Efficiency and Renewable Energy (EE-RE) of USDOE, has implemented cofiring at two generating stations: Willow Island Generating Station and Albright Generating Station. In both cases the objective of cofiring was to generate cost-effective and environmentally friendly renewable energy.

This objective included reducing airborne emissions including mercury, SO_2, and NO_x. The focus of the Willow Island project included integrating sawdust with tire-derived fuel to achieve a designer opportunity fuel. This followed on the work at Bailly Generating Station, where urban wood waste was blended with petroleum coke to achieve a highly desirable opportunity fuel (Tillman, 2001). The focus at Albright Generating Station was to integrate the practice of cofiring with the use of separated overfire air (SOFA) to achieve a combined approach to NO_x reduction.

Both installations have been installed and have been operated as test and demonstration units for a significant period of time. The Albright cofiring system shown in Figure 1 was relocated from Seward Generating Station in the first and second quarters of 2001. It was tested extensively in the third and fourth quarters of 2001, and periodically in 2002. Selected results from this installation have been reported previously (see, for example, Tillman et. al., 2002a; Tillman, 2001). The Willow Island cofiring system shown in Figure 2 was designed and installed in 2001 and the first quarter of 2002. Its design and installation have been reported previously (see Tillman et. al., 2002b). The Albright system focuses upon separately injecting the sawdust into the pulverized coal boiler while the Willow Island system focuses upon adding sawdust to the coal on the main belt leading to the bunkers feeding the cyclone burners.

Figure 1. Cofiring Installation at Albright Generating Station. Housed in the Structure are the Fuel Receiving, Screening, Metering, and Pneumatic Transport Systems.

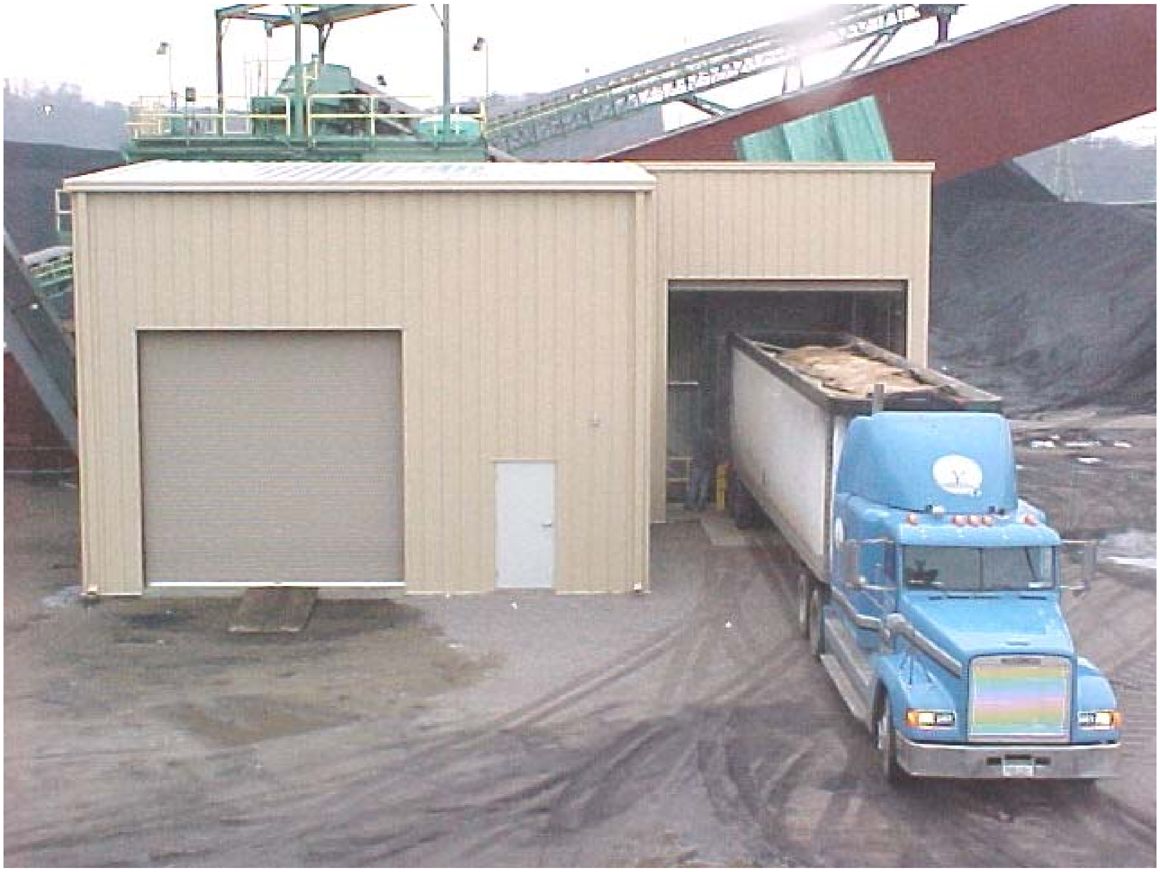

Figure 2. Cofiring Installation at Willow Island Generating Station. This Installation Includes Fuel Receiving, Screening, and Grinding of Oversized Particles in the Main Building (shown), and Fuel Storage, Reclaim, and Metering (to the main belt) in the Walking Floor Bin (not shown).

Both of these systems were designed to be robust—to withstand commercial operating conditions and to be operated with a minimal labor and maintenance commitment. Further, both of these systems were designed with multi-year design lives, consistent with obtaining operating and maintenance experience relevant to commercial rather than test systems.

1.0. Results at Willow Island Generating Station

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. Approximately 4,000 tons of sawdust have been burned, generating about 3,800 MWh of renewable energy and reducing fossil CO_2 emissions by over 12,000 tons (CO_2 equivalent).

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.

As expected, the cofiring of sawdust modestly increased the use of boiler feeder capacity as is shown in Figure 3. 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.

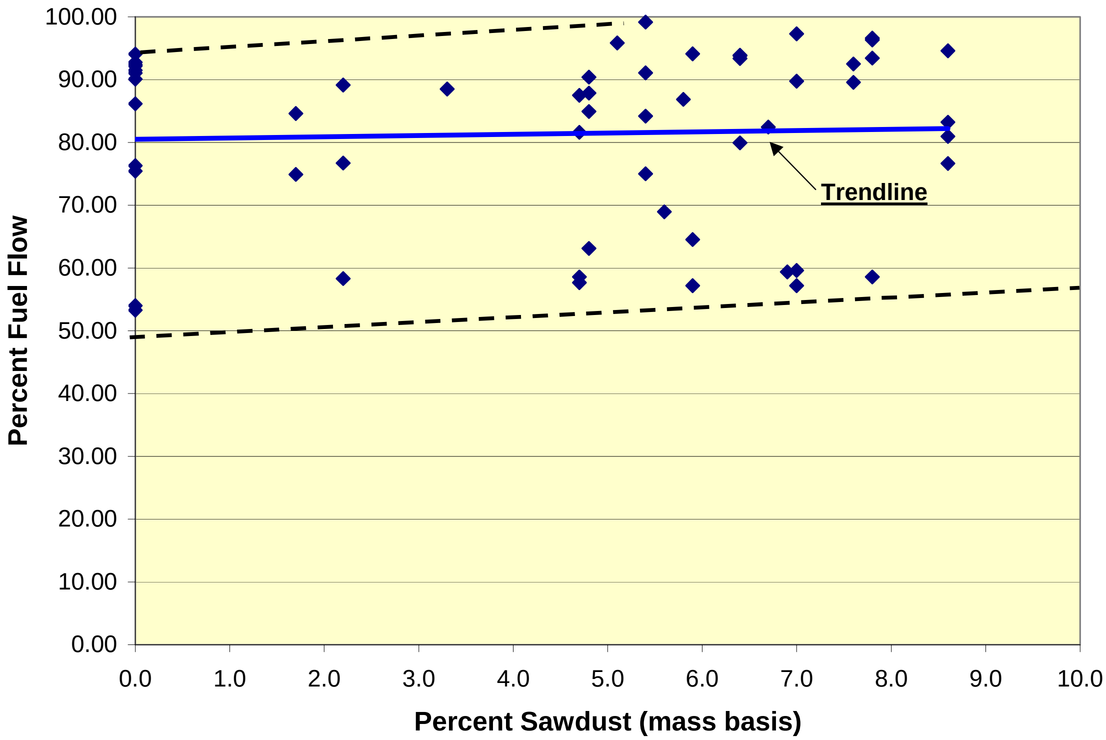

Figure 3. The Influence of Sawdust Cofiring on Fuel Feeding Capacity

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:

$$CF = 2.281 + 0.505(\%W) + 0.462(MW_g) \qquad [1]$$

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 6.2×10^{-40}.

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. 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 and robust equation was created showing that the SR decreased by 0.0005 for every percent TDF in the fuel blend. A similar factor applied to cofiring TDF. The percentage wood and the percentage TDF in the fuel blend has virtually no influence on the SR. 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. These accounted for the 0.03 percent decrease in boiler efficiency for every percent (mass basis) sawdust included in the fuel feed. TDF had even less impact on boiler efficiency.

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. Cofiring did not reduce main steam temperatures when operating at any condition. In virtually all cases the main steam temperature was between 1000^{o}F and 1020^{o}F, 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, an ideal NSHR of 10,150 can be calculated. At 10 percent sawdust, and an efficiency loss of 0.29 percent), 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.

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.

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. 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 1.

Table 1. Estimated Flame Temperatures for Full Load Firing at Willow Island

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:

$$T_f = 3670 + 5.9*(\%C) + 4.8(\%W) + 6.2(\%TDF) + 3.7(\%L) – 617(SR) + 0.38(T_{air}) \qquad [2]$$

And

$$T_f = 4248 – 579(SR) + 0.30(T_{air}) \qquad [3]$$

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 [2] is 0.999 and the r^2 for equation [3] is 0.937. Interestingly, the calculation of the significance values for the biomass and TDF fuel variables shows that these are not significant contributors to flame temperature. 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:

$$F_i = (dw/dt)h \qquad [4]$$

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.

The practice of cofiring at Willow Island caused a decrease in FEGT as is shown in Figure 4. Note the trend shown in this figure based upon sawdust addition.

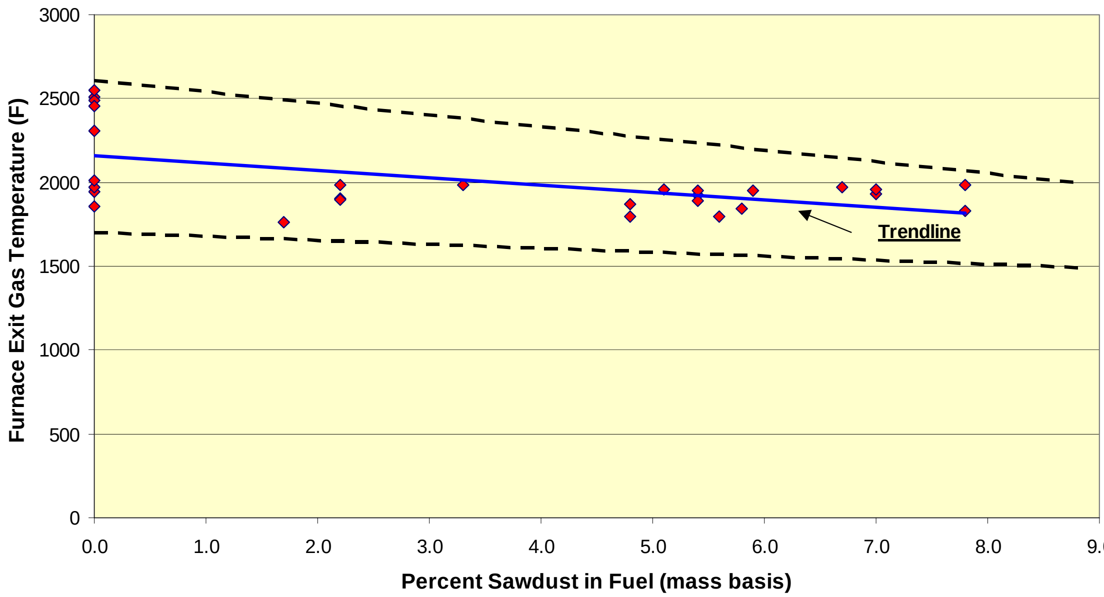

Figure 4. The Influence of Sawdust Cofiring on Furnace Exit Gas Temperature

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.

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, and Greenhouse gas reduction.

Biomass cofiring reducd SO_2 emissions; sawdust is virtually sulfur free. Figure 5 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.

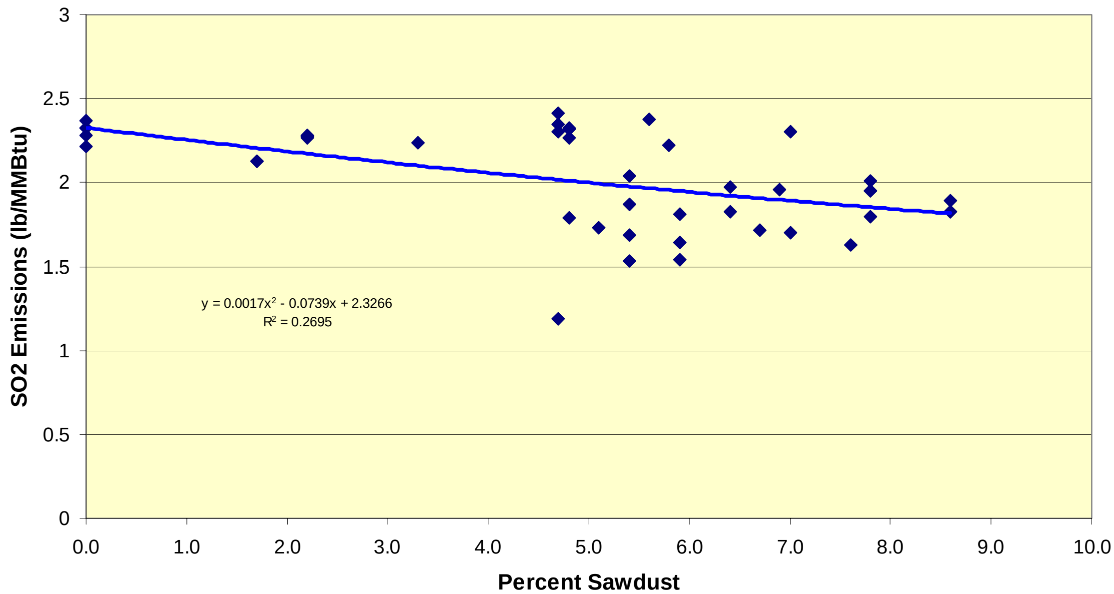

Figure 5. SO_2 Emissions as a Function of Sawdust Cofiring at Willow Island

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. NO_x 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, or increase, NO_x emissions.

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. Opacity and CO emissions were not impacted by cofiring at Willow Island Generating Station.

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.

2.0. Cofiring Results at Albright Generating Station

The testing at Albright Generating Station demonstrated that biomass cofiring—using separate injection—could have minimal impacts on operations while reducing airborne emissions. Significantly the PC boiler at Albright, at 140 MW_e, is comparable in capacity to the 188 MW_e cyclone boiler at Willow Island.

Testing at the Albright Generating Station involved the consumption of over 2,000 tons of sawdust in a unit equipped with a SOFA system. The biomass resulted in generation of approximately 1,700 MWh of green—renewable—power. It accomplished the reduction of over 6,000 tons of fossil CO_2 (equivalent) greenhouse gas.

Testing at the Albright Generating Station occurred in short (e.g. <8-hour) tests along with a 100-hr performance test to determine the reliability of the cofiring system. Both the short term and the 100-hr tests were highly successful. The cofiring did not compromise boiler capacity despite testing during summer capacity alerts. The cofiring did not compromise the performance of the induced draft (ID) fan, the system most susceptible to problems associated with cofiring on hot days. The impact of cofiring on boiler and unit efficiency was comparable to that experienced by Willow Island; for every 10 percent cofiring (mass basis), the unit took a net station heat rate penalty of 35 Btu/kWh.

Emissions reductions occurred in all tested airborne emissions areas: SO_2, NO_x, and mercury. SO_2 was reduced proportional to the percentage cofiring on a heat input basis; when cofiring at 10 percent (mass basis) the equivalent cofiring level on a Btu basis was 4.7 percent. SO_2 emissions were reduced by >4.5 percent under those circumstances.

The practice of cofiring at the Albright Generating Station caused a significant reduction in NO_x emissions measured in lb/10^6 Btu as shown in Figure 6. Note that there is a substantial spread in the data, caused by natural variations in the following parameters: instantaneous coal composition, cofiring percentage, excess O_2, and SOFA positions. Within the load range tested, load did not appear to be a significant contributor to the formation or control of NO_x. In general, cofiring at 10 percent by mass (4.7 percent by heat input) caused about a 15 percent reduction in NO_x, measured in lb/10^6 Btu. In other words, for every percent sawdust fired on a heat input basis, NO_x was reduced by ≥3 percent. NO_x emissions were consistently measured as low as 0.25 lb/10^6 Btu when cofiring and maximizing the use of the SOFA system.

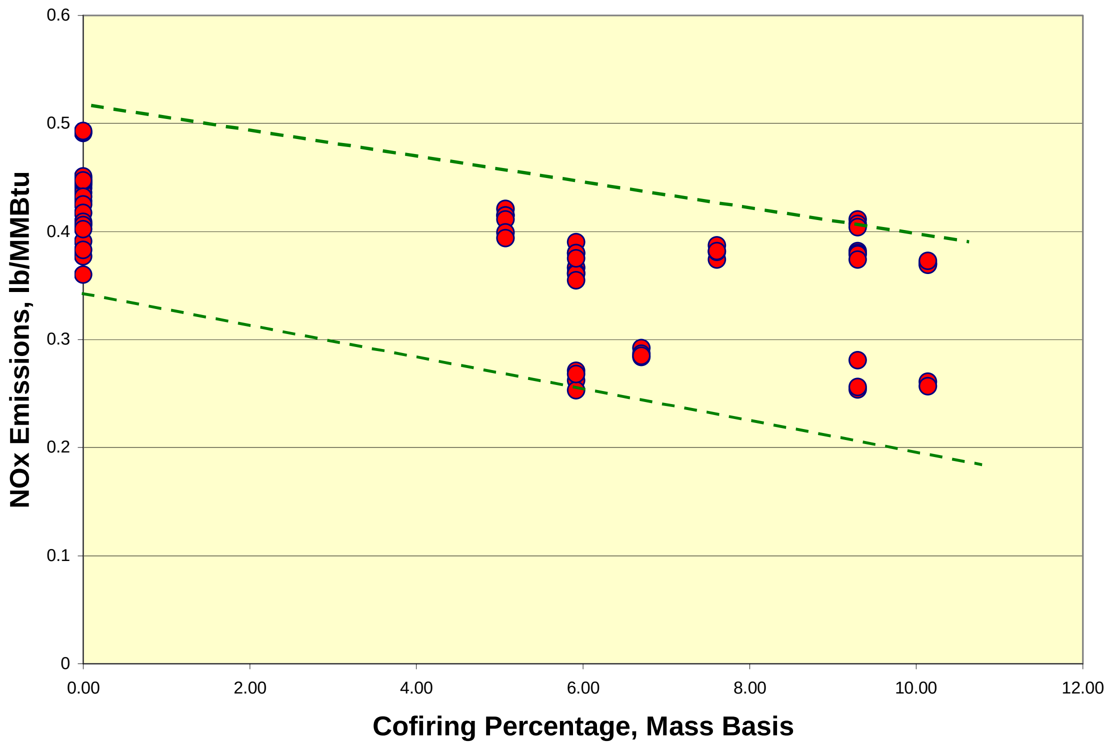

Figure 6. NO_x reduction during cofiring testing at the Albright Generating Station

The data generated during the testing were converted into a single, robust, regression equation as shown below. The equation, based upon 68 individual data points. The r^2 for this equation is 0.873.

$$NO_x\ (lb/10^6\ Btu) = 0.361 - 0.0043(W\%) + 0.0217(O_2\%) - 0.00055(SOFA) \qquad [5]$$

Where NO_x is measured in lb/10^6 Btu, W% is sawdust percentage in the fuel on a mass basis, O_2% is the percentage excess oxygen measured at the furnace exit, and SOFA is the total percentage of the three SOFA dampers expressed as percent open. Note that the range of W terms is 0 – 10, the range of O_2% terms is 2.8 – 4, and the range of SOFA terms is 15 – 240. This may explain the difference in the coefficients. The equation is quite robust; all parameters measured were subjected to statistical testing to determine whether the specific term could have occurred as a random event. The probability that any term could occur as a random event was, in all cases, $<1 \times 10^{-4}$.

Interestingly, the cofiring not only reduced NOx emissions directly, but it also supported increased use of the SOFA system. Testing demonstrated that the SOFA dampers could

be opened to a wide-open position without compromising unburned carbon in the flyash. This resulted from the volatility in the sawdust compared to the coal.
Mercury emissions reductions occurred in a manner that was virtually identical to that associated with cofiring at Willow Island Generating Station. Opacity and CO emissions were not impacted by cofiring.

4.0. Conclusions

The cofiring program at Willow Island and at Albright has been successful in demonstrating the long-term viability of this approach as a low-cost approach to generating significant amounts of renewable and environmentally friendly electricity. In cofiring over 6,000 tons of woody biomass, Allegheny has generated about 5,500 MWh—5,500,000 kWh—of renewable power. At the same time Allegheny has reduced greenhouse gas emissions by over 18,000 tons of fossil CO_2 (equivalent) by displacing coal, and by using the biomass in the most environmentally friendly and efficient manner. SO_2 emissions have been consistently reduced, and NO_x emissions were reduced in the case of Albright Generating Station. Mercury emissions were reduced while opacity and CO emissions were not impacted.

The operational data show that the environmental benefits were achieved without a significant efficiency penalty, measured in net station heat rate, and without any capacity penalty. These two test programs will be continued. Incremental improvements are continuously being made at Willow Island Generating Station. A new grinder is being installed to facilitate operations at Albright Generating Station. These programs illustrate, with experience, the potential of woody biomass cofiring as a significant and cost-effective approach to generating environmentally friendly electricity.

5.0. References

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