

Pilot-Scale Air Toxics R&D Assessment of Creosote-Treated and PCP-Treated Wood Cofiring for Pulverized Coal Utility Boiler Applications

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ABSTRACT

This paper presents air toxics emissions test results from a pilot-scale cofiring study of pentachlorophenol- (PCP) and creosote-treated woods to provide data for pre-permitting requirements for utilities interested in biomass cofiring as a means of increasing renewable energy while reducing greenhouse gases and other emissions for pulverized coal-fired utility boilers. These PCP/creosote-treated wood cofiring tests included a comprehensive assessment of air toxics, including dioxins, furans, polycyclic aromatic hydrocarbons (PAH), heavy metals (Hg, Sb, As, Cd, Cr, Co, Pb, Ni, and Se), formaldehyde and other volatile organic compounds, HCl, and particulates. This pilot-scale testing measured 'uncontrolled' emissions from the combustor (upstream of flue gas cleanup devices) and showed that PCP/creosote-treated wood could be successfully cofired at 10% heat input without increases in air toxic emissions as compared to a baseline eastern bituminous coal. Air toxics emissions were typically very low, and often near or below detection limits, largely as a result of the good air/fuel mixing and high furnace temperatures associated with pulverized coal combustion. One expected result was an increase in uncontrolled HCl emissions as a result of the higher chlorine content in the treated woods, although even at 10% cofiring levels, HCl emissions were within the range of other U.S. coals. This paper is presented to provide independent data that industry, environmental groups, and regulators may consider in evaluating the opportunities for treated wood cofiring test burns and commercialization in full-scale coal-fired boilers in an environmentally acceptable manner.

Key words: Biomass Cofiring; Pulverized Coal; Chemically-Treated Woods; Air Toxics Emissions

1. Introduction

Biomass cofiring in large industrial and utility coal-fired boilers is a practical, attractive approach for increasing renewable energy, particularly given the wide availability, existing capital investment, and performance of coal-fired boilers for providing efficient, low-cost power [1-10]. Biomass cofiring activities at the U.S. Department of Energy (DOE), National Energy Technology Laboratory (NETL), and other organizations have been driven by the diverse interests of biomass stakeholders and coal-fired utilities in anticipation of the possibility of future regulations in global climate change or renewable energy portfolio standards. Other utility interests include green pricing programs, helping industrial customers solve waste problems, assisting regional development in rural and urban areas, and evaluating biomass cofiring as part of an overall strategy to decrease costs, add capacity, or help achieve SO₂/NO_x emissions compliance. Although some utility cofiring is successfully practiced in the U.S. and abroad, establishing long term reliability and improving economics through process optimization are still significant needs. Major issues include biomass fuel handling equipment as well as fireside impacts, such as carbon burn-out, ash fouling, ash disposal, emissions, and other factors that influence overall plant integration, availability, efficiency, and cost that often are site-specific and vary significantly. For these reasons, cofiring must be underpinned by coal-fired utilities and innovative partnering with biomass fuel providers to offer multiple benefits to reduce risk and address stringent environmental regulations under an increasingly cost competitive environment brought about by utility deregulation.

Many treated woods, such as telephone poles, transmission poles, and railroad ties are a potentially attractive renewable fuel for cofiring given their typically very low moisture (< 10%), sulfur (< 0.3%), nitrogen (< 0.4%), and ash (< 2%) contents as well as high heating value (over 21 kJ/g, over 9000 Btu/lb) and bulk density compared to other biomass fuels. Such treated woods are readily available with millions of tons across the U.S., and often have very high landfill disposal costs (e.g., up to \$80/ton) to utilities and other industries. Increasingly, landfills in certain regions are considering the possibility of turning away such treated woods.

In some respects, treated woods offer a significant opportunity relative to premium low-cost biomass feedstocks, such as lumbermill sawdusts. While lumbermill sawdusts are also favorably low in sulfur, nitrogen, and ash content, they typically have low heating values (due to higher moisture) and low densities that are important in terms of the cost of delivery, storage, and handling. While competition for lumbermill sawdust and other biomass residues may drive a local market where utilities might be expected to pay \$10-20/tonne or more, the high landfill costs of treated woods could enable even more favorable economics. For example, cofiring treated woods as part of utility generated waste (e.g., spools, cross arms) could reduce out-of-pocket landfill costs while helping local industries and customers deal more economically with treated wood waste disposal issues. Thus, coal-fired utilities could consider cofiring treated woods along with other biomass fuels such as sawdusts and urban wood wastes to reduce power generation costs while utilizing renewable energy and reducing emissions of greenhouse gases. Of course, a key barrier is showing the environmental viability of treated wood fuel cofiring from a permitting perspective.

Of particular concern is the presence of PCP and creosote chemicals used for wood preservation. Utilities, environmental groups, and regulators need to be confident that treated woods can be successfully cofired in coal-fired boilers without harmful air toxics emissions, especially trace organics such as dioxins, furans, polycyclic aromatic hydrocarbons (PAH), and formaldehyde. Thus, it was determined that a comprehensive pilot-scale air toxics study for cofiring PCP/creosote-treated wood would be helpful to address potential environmental concerns.

2. Experimental

PCP/creosote-treated wood cofiring tests were conducted in a state-of-the-art pilot-scale Combustion and Environmental Research Facility (CERF) that has been designed for a wide range of combustion and pollution control studies of most solid, liquid, and gaseous fuels [11]. The CERF consists of various components as shown in Figure 1. Originally built in 1989 to investigate the combustion properties of deeply-cleaned coals for pulverized coal boiler applications, the CERF's capabilities have been continuously expanded to support a wide range of combustion and environmental control R&D projects. Specialized probes for gas/particulate sampling, temperature measurement, in-situ flame viewing system, in-situ measurements of surface temperature and emissivity have been developed along with various panels and probes for the study of ash slagging/fouling behavior on tube surfaces at controlled metal temperatures. CERF activities are complemented by other NETL R&D facilities for fuel processing, combustion, and emissions studies, as well as 3-Dimensional Computational Fluid Dynamics (CFD) modeling. Typically, the CERF R&D involves outside parties that bring fuels, concepts, or materials for evaluation. For example, the CERF has served as a host site for high-temperature exposures of over sixty ceramic and alloy samples from researchers at other DOE national laboratories, universities, and industry manufacturers in support of advanced power systems under development. Cooperative efforts with U.S. industry have evaluated novel NO_x control processes using the CERF. Over twenty coals from the U.S., as well as from India, Russia, Ukraine, and Indonesia have been tested. The CERF has cofired various biomass fuels, such as lumbermill sawdust, furniture waste sawdust, pallets, nonrecyclable paper, cow manure, switchgrass, and hybrid willow.

In planning the CERF treated wood cofiring tests, input from numerous organizations was obtained, including various utilities and the Electric Power Research Institute, as well as local and state regulators from the Allegheny County Health Department and State of Pennsylvania Department of Environmental Protection. This input helped specify CERF test conditions and comprehensive air toxics sampling along with QA/QC measures to improve data quality in conjunction with NETL's extensive air toxics experience in assessing mercury and other hazardous air pollutants (HAPs) from coal-fired boilers over the last decade. This diverse organizational participation resulted in a cofiring test program that included an assessment of dioxins, furans, polycyclic aromatic hydrocarbons (PAH), heavy metals (e.g., mercury, antimony, arsenic, cadmium, chromium, cobalt, lead, manganese, nickel, and selenium), formaldehyde and other

aldehydes, ketones, other organic volatile compounds, total hydrocarbons, hydrogen chloride, and particulates.

CERF tests were conducted using a baseline Upper Freeport bituminous coal with 10% cofiring (energy basis) with PCP-treated and creosote-treated wood. Although 10% cofiring is higher than what some utilities envision for treated wood cofiring (e.g., 5% heat input or less) based on expected day-to-day biomass resource availability and practical need for multiple biomass feedstocks, this 10% level allowed a more stringent assessment of potential air toxics issues.

The CERF testing focused on measuring 'uncontrolled' emissions from the combustor (upstream of the baghouse) in an effort to directly evaluate differences between the baseline coal and treated wood cofiring cases. Three sampling ports were installed at the baghouse inlet to enable isokinetic single-point sampling using standard probes. These sampling ports consisted of a series of 3-inch tees in the CERF's 3-inch schedule-10 stainless steel flue gas piping section that was also heavily heat traced with temperature controllers to maintain the sampling locations near 150 C (300 F).

Specific protocols for air toxics sampling that were followed included EPA Method 23 (dioxins/furans and PAH), Method 25A (total hydrocarbons), Method 26A (particulate matter and HCl), Method 29 (metal HAPs), Method SW-846 M0011 (aldehydes and ketones), and Method SW-846 M0030 (volatile organics sampling train). Conventional procedures were followed for method blanks, field blanks, etc. in the approved QA/QC sampling plan while additional measures, such as blind external audit samples and additional analyses for sample recovery determinations, were incorporated to improve data quality and provide more insight. Major flue gas components were continuously monitored downstream of the 3-isokinetic sampling locations using standard process gas analyzers for SO₂ (infrared), NO_x (chemiluminescent), CO (infrared), O₂ (paramagnetic), and CO₂ (infrared) emissions using a sintered metal filter and ice bath sample conditioning system.

Utility-grade Upper Freeport coal was obtained and pulverized to normal pc grind specifications of less than 2% plus 50-mesh and about 70% minus 74-micron (200-mesh) using a hammermill. The pulverized coal product drums were carefully sampled, analyzed, and used so that the variation in particle size (minus 74-micron), ash content, and other properties were minimized for baseline coal and subsequent treated wood/coal blend testing for the air toxics study.

Whereas the standards for coal particle size distribution for pc combustion are very well established, biomass particle sizing for cofiring applications is site-specific due to the influence of many factors. Boiler temperature/flow profiles, biomass injection location, and biomass fuel variability, such as particle density, moisture, aspect ratio, and chemical composition (volatile matter and char characteristics) that play a key role in establishing biomass combustion behavior relative to the achievable residence times for coarser biomass particles. In recognition of the differing residence times and flow behavior between pulverized coal and biomass particles, 3-dimensional computational fluid

dynamics (CFD) modeling studies are also being conducted to address scalability issues [12].

PCP-treated and creosote-treated telephone poles were initially processed with a conventional wood chipper to about 3-inch chunks before further size reduction using a prototype collision mill by Mesa Reduction Engineering and Processing, Inc. (MREP). While this MREP processing would be more than sufficient for full-scale cofiring applications, further size reduction was required based on preliminary CERF cofiring tests. Because the CERF is down-fired with 3-m (9 ft) height and radiant furnace average linear gas velocities of less than 2 m/sec, most biomass particles need to be finer than about 1-mm (16-mesh) to prevent still-burning sparklers from entering the bottom ash hopper and CERF convective section. In contrast, full-scale boilers are much taller than pilot units, and commonly up-fired with furnace gas velocities over 10 m/sec (30 ft/sec), allowing the potential for increased residence time. For example, biomass cofiring at particle sizes up to about 6-mm (¼-inch) have been shown in utility cofiring demonstration tests and confirmed with biomass combustion modeling [4,10,13-14]. Recognizing the central point that each pulverized coal combustor will have a critical cut-off in terms of allowable biomass topsize and moisture, this study sought to conduct air toxics assessments for cofiring at realistic combustion conditions without overgrinding the treated woods.

3. Combustion Results & Discussion

Table 1 summarizes fuel analyses for the baseline Upper Freeport (a medium-volatile, moderate-sulfur bituminous coal) along with the PCP- and creosote-treated woods. Of note are the very low sulfur, nitrogen, and ash contents as well as high volatility of the treated woods. Compared to many other biomass fuels, treated woods have much lower moisture contents and much higher heating values, largely as a result of the chemical treatments for wood preservation. Of note is that the treated woods actually have higher heat contents than subbituminous coals (e.g., Powder River Basin) and other low rank coals that are widely used for power generation.

Preliminary CERF cofiring tests were conducted to specifically assess the treated wood particle size issue and the extent of size reduction required to ensure minimal sparklers and increases in bottom ash or fly ash unburned carbon. In this manner, CERF testing would be consistent with expected utility practices where biomass grinding specifications would be based on avoiding troublesome sparklers and undesirable elevations in fly ash loss-on-ignition. Final Pulva hammermill settings were established based on achieving occasional sparklers during cofiring in conjunction with combustion profiles. Owing to the greater difficulty in grinding, the PCP-treated wood resulted in a coarser distribution than the creosote-treated wood under similar processing conditions with the Pulva hammermill. Both fuels were finally processed to less than 1% minus 16-mesh, the PCP-treated wood contained about 68% plus 50-mesh as compared to the creosote-treated wood that was about 35% plus 50-mesh.

Combustion profiles were established with high-volume particulate sampling at varying distances (effectively representing different residence times) from the CERF burner to help verify proper treated wood sizing. Table 2 shows typical combustion results comparing loss-on-ignition (LOI) profiles for treated wood cofiring with baseline coal at similar burner conditions. The CERF flame root position was determined by inserting a thermocouple through the center of the burner and recording the standoff distance at about 980 C (1800 F). As expected, the high volatility of the treated woods decreased the flame root position during cofiring, resulting in earlier ignition as compared to the baseline coal flame. In addition, LOI data confirmed that treated wood particles were properly sized as indicated by the slightly improved combustion expected from cofiring a low-ash, high-volatile biomass fuel.

4. Emissions Results & Discussion

CERF air toxics tests were conducted at about 110 kWt (370 kBtu/hr) with burner settings and temperatures typical of pulverized coal combustors, to compare the baseline Upper Freeport coal with 10% treated wood blends. These conditions included 20% total excess air, secondary air swirl number of 0.5, primary air/secondary air ratio of about 0.2, and a furnace exit gas temperature (FEGT) near 1100 C (2000 F). Three sets of tests (sampling periods) were obtained and averaged for the various methods tabulated below.

Table 3 presents a summary of flue gas emissions data, averaged for each fuel during the air toxics sampling periods. Of note are the reduced SO₂ and NO_x emissions when cofiring the treated woods. These reductions are consistent with expectations and general trends reported elsewhere, including various pilot-scale and utility biomass cofiring projects [4,7,8,10,13]. Much of this reduction is due to the fact that the treated woods are considerably lower in sulfur and nitrogen content as compared to the baseline coal as shown in Table 1. In addition, the NO_x emissions reductions are also consistent with the high-volatility of the treated wood fuel coupled with the decreased flame root position when cofiring.

Of importance is that both CO and total hydrocarbon (THC) emissions were reduced during treated wood cofiring, although baseline CO levels were somewhat higher than typical CERF testing. The CO emission results are consistent with achieving good combustion during treated wood cofiring as also shown in preliminary CERF testing in Table 2. Table 3 also reveals a reduction in particulate emissions during cofiring that is consistent with the reduced ash loading of the treated woods as compared to the baseline coal.

An expected result was an increase in uncontrolled hydrogen chloride (HCl) emissions as a result of the higher chlorine content in the treated woods. While elevations in HCl are very undesirable from the standpoint of corrosion on boiler tube surfaces, it is noteworthy that even at 10% cofiring levels, HCl emissions were within the range of other U.S. coals. Whereas the baseline Upper Freeport coal had an average chlorine content of 0.058 wt%, several Illinois basin bituminous coals have chlorine contents in the 0.2-0.3 wt% range. In terms of corrosion, it should be noted that while the treated woods are very low in ash

and alkali which is very beneficial, the higher HCl emissions could be problematic if the treated woods were used in combination with high-alkali biomass fuels (e.g., straws) during cofiring, especially with higher-alkali coals or coal-fired boilers already exhibiting corrosion and slagging/fouling difficulties. However, recent experimental studies have reported that higher levels of flue gas SO₂ (from the coal sulfur) and resultant tendency for alkali sulfation reactions in preference to the more troublesome alkali chloride formations in ash deposits during cofiring [13].

Table 4 summarizes aldehyde and ketone results on a part-per-billion (ppb) and emissions factor (g/MJ) basis, and illustrates the encouraging results with treated wood cofiring relative to the baseline coal. Of note are the very low levels of aldehydes and ketones that were at or below the detection limits of just a few ppb. Average formaldehyde and other aldehyde/ketone levels were barely detectable in the 0.2 to 3 ppbv (corrected to 3% dry O₂ basis) corresponding to equivalent, uncontrolled levels of less than 3.2E-07 to 2.4E-06 g/MJ based on detection limits.

Air toxics results for numerous compounds measured with the volatile organics sampling train (VOST) were also favorable, with very low emissions levels observed with the baseline coal and treated wood cofiring cases. One complication that did arise in the analytical sample characterization was the presence of several polyalkylsiloxane compounds attributable to the gasketing material used in the CERF.

Table 5 summarizes the uncontrolled emissions factors (g/MJ) for total polychlorinated dibenzo-*p*-dioxin (PCDD), total polychlorinated dibenzofuran (PCDF), and polycyclic aromatic hydrocarbons (PAH). These emissions levels were extremely low and show very favorable results with treated wood cofiring emissions factors that were somewhat lower than the baseline coal. These results are reinforced further upon examination of the various 3-8 congeners of dioxin and furans, and individual PAH compounds that were sampled as shown in Tables 6-8. For comparison, Tables 6-8 reports emissions in terms of nanograms (for dioxin and furan) or micrograms (for PAH) per dry normal (20 C, 760 torr) cubic meter corrected to 3% O₂. Of significance is that the vast majority of compounds were 'non detects' and where quantification was possible, the treated wood cofiring cases were typically somewhat lower than the baseline coal.

Table 9 summarizes uncontrolled emissions factors (g/MJ) for various heavy metals. As expected, treated wood cofiring metal HAPs results were similar to the baseline coal, with some metals showing very slightly higher or lower levels that may not be statistically significant. Although the treated woods have a much lower ash loading as compared to the baseline coal as shown in Table 1, the 10% treated cofiring levels did not appear to significantly alter metal HAPs results.

The pilot-scale CERF results clearly indicate that treated woods can be successfully cofired with pulverized coal from an environmental perspective. Because the above results provide uncontrolled emissions comparisons, it is possible that treated wood cofiring could be equally, if not more attractive, from a practical control standpoint. For example, when considering that various pollution control technologies, such as wet

scrubbers, spray dryers, fabric filters, and electrostatic precipitators (for primary SO₂, NO_x, and particulate control) also provide secondary benefits for removing some trace pollutants`.

While treated wood cofiring offers the expected benefits of reduced sulfur, nitrogen oxides, and particulates based on fuel composition, the CERF results provide encouraging data relative to air toxics that could impact regulatory decisionmaking and public acceptance. While coal-fired utility boilers are not presently regulated for heavy metals and trace organics in the U.S., the U.S. Environmental Protection Agency (EPA) and other organizations are looking closely at this issue. Consequently, considerable efforts have been undertaken by NETL and others to better quantify and assess hazardous air pollutants (HAPs) for coal-fired power plants [15-17]. The CERF baseline coal results were generally consistent with air toxics data from coal-fired utility boilers in terms of the very low, and often nondetectable, trace organics, including dioxin, furan, and PAH, largely as the result of the high-temperatures and other characteristics of pulverized coal flames that provide excellent combustion. Future work will evaluate these CERF results in more detail and provide comparisons with available literature and address scalability issues.

5. Summary

Pilot-scale cofiring studies were conducted to examine combustion and environmental considerations with pentachlorophenol- (PCP) and creosote-treated woods. In addition to reducing sulfur and nitrogen oxides as well as particulates, treated wood cofiring air toxics data was very encouraging. The test program showed extremely low levels (and often, nondetectable) levels of dioxins, furans, polycyclic aromatic hydrocarbons (PAH), heavy metals (e.g., mercury, antimony, arsenic, cadmium, chromium, cobalt, lead, manganese, nickel, and selenium), formaldehyde and other aldehydes, ketones, numerous organic volatile compounds, and total hydrocarbons.

Experimental results confirmed that PCP/creosote-treated wood could be successfully cofired at 10% energy-basis without increases in air toxic emissions. In many instances, the uncontrolled air toxics emissions factors for treated wood cofiring were actually somewhat lower than the baseline pulverized coal testing. It is hoped that this pilot-scale CERF air toxics data may help stakeholders deal with pre-permitting issues to allow future full-scale test cofiring burns, and assist in the commercialization of PCP/creosote-treated wood cofiring in an environmentally acceptable manner.

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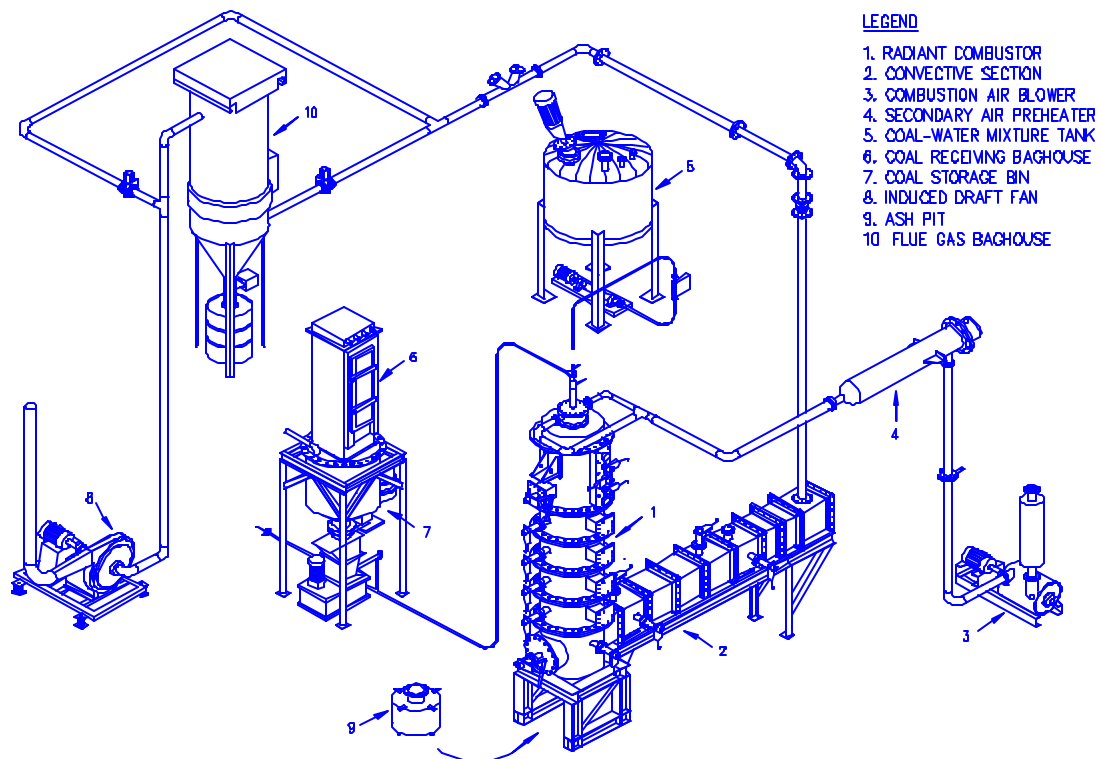


Figure 1. NETL Combustion and Environmental Research Facility

Table 1
Analyses of Upper Freeport Coal and Treated Wood Fuels

	Upper Freeport Coal	Creosote Treated Wood	PCP Treated Wood
Proximate (wt%)			
Moisture	1.25	5.62	5.01
Volatile Matter	21.85	83.54	88.40
Fixed Carbon	61.42	9.56	6.02
Ash	15.48	1.28	0.47
Higher Heating Value (MJ/kg)	29.81	21.47	21.94
Ash Content g/MJ	5.193	0.593	0.215
Sulfur Content g/MJ	0.567	0.069	0.073
Nitrogen Content g/MJ	0.421	0.103	0.030

Table 2
Combustion Profiles for Baseline Coal and Treated Wood Cofiring

	Upper Freeport Coal	10% Creosote Wood	10% PCP Wood
Burnout Profile, % LOI Basis			
Furnace Location			
Port 3 - 114 cm from burner	35.7	31.2	34.2
Port 4 - 160 cm from burner	28.0	23.7	29.9
Port 5 - 206 cm from burner	16.7	15.2	18.8
Port 6 - 252 cm from burner	13.4	13.9	12.9
Baghouse Inlet (Fly Ash)	11.1	9.0	8.3
Flame Root Position (cm)	10.9	8.4	8.9

Table 3
Flue Gas Emissions Results for Treated Wood Cofiring

Flue Gas (dry basis @3%O ₂)	Baseline UF Coal	10% Creosote Wood	10% PCP Wood
SO ₂ (ppm)	1209	1120	1102
NO _x (ppm)	574	474	496
CO (ppm)	92	75	69
HCl (ppm)	44	61	128
Total Hydrocarbons (ppm) (expressed as propane)	2.0	1.6	1.5
Particulate (g/dNm ³)	8.9	5.5	6.9

Table 4
Aldehyde and Ketone Emissions Results, Average of 3 Tests

	Baseline UF Coal	10% Creosote Wood	10% PCP Wood
Emissions Factor (g/MJ) Basis			
Acetaldehyde	< 8.12E-07	~ 1.51E-06	< 7.42E-07
Acetophenone	< 2.43E-06	< 1.81E-06	< 1.73E-06
Formaldehyde	~ 9.23E-07	9.41E-07	~ 1.06E-06
Isophorone	< 3.66E-07	< 3.19E-07	< 3.54E-07
Propionaldehyde	< 4.01E-07	< 3.50E-07	< 3.87E-07

Flue Gas Composition (dry ppb @3% O₂)

Acetaldehyde	< 1.4	~ 2.7	< 1.3
Acetophenone	< 1.5	< 1.2	< 1.1
Formaldehyde	~ 2.3	2.4	~ 2.6
Isophorone	< 0.21	< 0.18	< 0.19
Propionaldehyde	< 0.53	< 0.46	< 0.43

Notes: < indicates the value is below the detection limit
 ~ estimated value, indicates the measured value is below the
 quantitation limit or the measured value is above the calibration range

Table 5
Total Dioxin, Furan, and PAH Emissions Factor Results, Average of 3 Tests

	Baseline UF Coal	10% Creosote Wood	10% PCP Wood
Total PCDD (g/MJ)	1.73E-11	2.57E-12	5.51E-12
Total PCDF (g/MJ)	7.32E-12	ND	1.33E-12
Total PCDD/PCDF (g/MJ)	2.46E-11	2.57E-12	6.84E-12
Total PAH (g/MJ)	4.21E-08	2.44E-08	ND

Table 6
Dioxin Results, Average of 3 Tests (ng/dNm³ @3% O₂)

	Baseline UF Coal	10% Creosote Wood	10% PCP Wood
2,3,7,8-TCDD	ND	ND	ND
Other TCDD	ND	ND	ND
1,2,3,7,8-PeCCD	ND	ND	ND
Other PeCCD	1.07E-02	4.38E-03	6.05E-03
1,2,3,4,7,8-HxCDD	ND	ND	ND
1,2,3,6,7,8-HxCDD	ND	ND	ND
1,2,3,7,8,9-HxCDD	ND	ND	ND
Other HxCDD	7.84E-03	ND	ND
1,2,3,4,6,7,8-HpCCD	1.09E-02	ND	1.97E-03
Other HpCCD	3.67E-03	ND	0.0
OCDD	2.25E-02	3.93E-03	9.43E-03
Total PCDD	5.56E-02	8.31E-03	1.74E-02

Table 7
Furan Results, Average of 3 Tests (ng/dNm³ @3% O₂)

	Baseline UF Coal	10% Creosote Wood	10% PCP Wood
2,3,7,8-TCDF	ND	ND	ND
Other TCDF	ND	ND	ND
1,2,3,7,8-PeCDF	ND	ND	ND
2,3,4,7,8-PeCDF	ND	ND	ND
Other PeCDF	6.86E-03	ND	1.78E-03
1,2,3,4,7,8-HxCDF	6.72E-03	ND	ND
1,2,3,6,7,8-HxCDF	9.40E-04	ND	ND
1,2,3,7,8,9-HxCDF	ND	ND	ND
2,3,4,6,7,8-HxCDF	5.24E-04	ND	ND
Other HxCDF	3.19E-03	ND	ND
1,2,3,4,6,7,8-HpCDF	5.24E-03	ND	2.41E-03
1,2,3,4,7,8,9-HpCDF	ND	ND	ND
Other HpCDF	ND	ND	ND
OCDF	ND	ND	ND
Total PCDF	2.34E-02	ND	4.19E-03

Table 8
PAH Results, Average of 3 Tests (ug/dNm³ @3% O₂)

	Baseline UF Coal	10% Creosote Wood	10% PCP Wood
Acenaphthene	ND	ND	ND
Acenaphthylene	ND	ND	ND
Anthracene	ND	ND	ND
Benzo(a)anthracene	ND	ND	ND
Benzo(b)fluoranthene	ND	ND	ND
Benzo(k)fluoranthene	ND	ND	ND
Benzo(g,h,i)perylene	ND	ND	ND
Benzo(a)pyrene	ND	ND	ND
2-Chloronaphthalene	ND	ND	ND
Chrysene	ND	ND	ND
Dibenz(a,h)anthracene	ND	ND	ND
Fluoranthene	ND	ND	ND
Fluorene	ND	ND	ND
Indeno(1,2,3,-cd)pyrene	ND	ND	ND
2-Methylnaphthalene	0.068	ND	ND
Naphthalene	0.067	0.079	ND
Phenanthrene	ND	ND	ND
Pyrene	ND	ND	ND
Total PAHs	0.134	0.079	ND

Table 9
Heavy Metals Emissions Factors (g/MJ), Average of 3 Tests

	Baseline UF Coal	10% Creosote Wood	10% PCP Wood
Antimony	7.36E-06	6.38E-06	8.26E-06
Arsenic	4.21E-04	3.42E-04	4.50E-04
Cadmium	5.84E-06	4.65E-06	6.36E-06
Cobalt	2.38E-04	1.14E-04	2.37E-04
Lead	1.34E-04	9.96E-05	1.47E-04
Manganese	1.17E-03	6.68E-04	1.17E-03
Mercury	9.18E-06	9.40E-06	8.29E-06
Nickel	2.01E-04	1.23E-04	1.49E-04
Selenium	6.61E-05	3.96E-05	5.55E-05

