



# Coal Characteristics and Biomass Cofiring in Pulverized Coal Boilers

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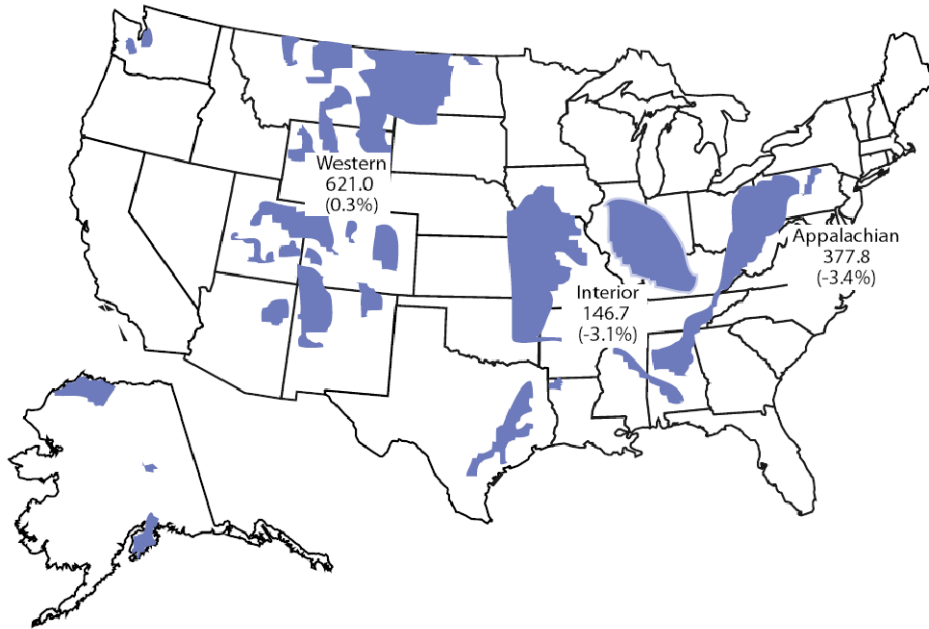
## **ABSTRACT**

Biomass cofiring is proposed as one means for meeting Renewable Portfolio Standards (RPS) with dispatchable power. Frequently it is proposed as a low capital cost approach to meeting such requirements. Cofiring biomass at 15 or 20 percent means that 80 – 85 percent of the fuel is still coal. In order to address critical issues of emissions management, deposition and corrosion, and operational concerns, attention must be paid to the characteristics of the coal, relative to the biomass selected. Some coals are more readily used in cofiring applications than others. Attention must be given not only to the heat content and moisture content, but also to the following: sulfur content (functioning of the ESP), chlorine content (deposition; also influenced by sulfur content), iron content (slagging, relationship to the calcium in the biomass), ash content, and more. This paper considers cofiring from the perspective of coal characteristics and identifies certain coal characteristics as more favorable to cofiring than others. The paper also examines the coal characteristics issue as a function of the type of biomass being fired (wood waste, switchgrass, straws, other agricultural materials), the firing method (wall-fired, tangentially-fired), and post-combustion equipment (precipitators vs. baghouses, scrubbers, SCRs). Focus is on the combustion process and its consequences.

## **INTRODUCTION**

Coal combustion is used to generate over half of the electricity used in the United States; all types of coal are used. These include (not exhaustive) bituminous coals from the Northern, Central, and Southern Appalachian coal fields; bituminous coals from the Illinois Basin and associated deposits in Indiana and Western Kentucky; western bituminous coals from deposits in Colorado and Utah; subbituminous coals from the Powder River Basin (PRB) and other subbituminous coal fields; and lignites from North Dakota, Texas, Louisiana, and Mississippi. Figure 1 depicts the deposits of coal in the US, including the quantities mined in the year 2007. Note that coal mining in the western US has eclipsed mining in the eastern US. Figure 2 depicts the production of coal by type. Note that subbituminous coal—notably PRB coal—has effectively become a very strong element if not the backbone of the US coal industry.

**Figure ES1. Coal Production by Coal-Producing Region, 2007**  
 (Million Short Tons and Percent Change from 2006)  
 Regional totals do not include refuse recovery  
**U.S. Total: 1,146.6 Million Short Tons (-1.4%)**



Source: Energy Information Administration, *Annual Coal Report, 2007*, DOE/EIA-0584(2007) (Washington, DC, February 2009).

Figure 1. Coal Production by Region in the US, 2007.

Source: Energy Information Administration, USDOE. *Annual Coal Report, 2007*.

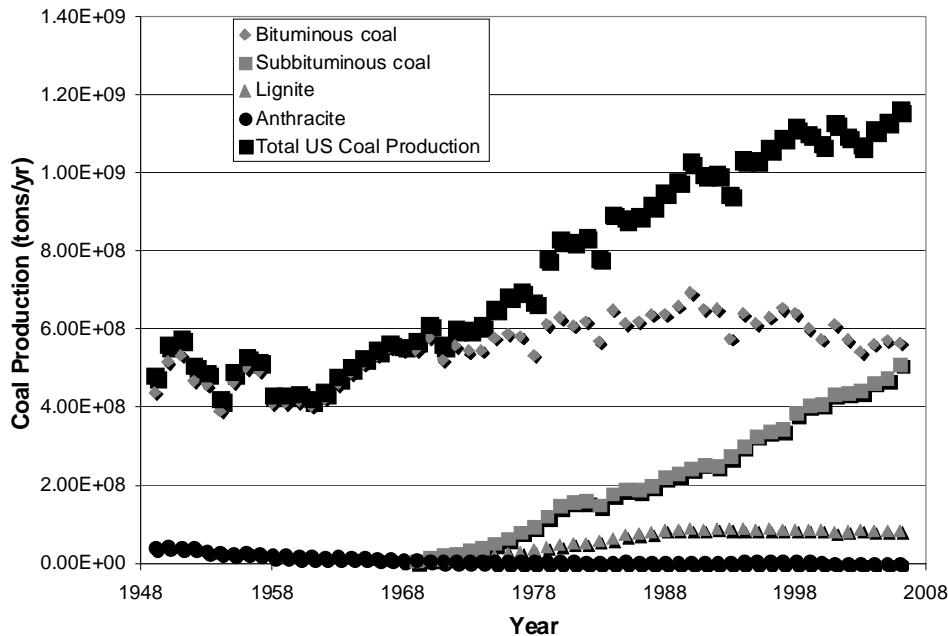


Figure 2. Coal Production by Type in the US, 1948 – 2007.

Source: Energy Information Administration, USDOE. *Annual Coal Report, 2007*.

Since 1970, new coal-fired units installed have been very large. On average they generate  $>4 \times 10^6$  lb/hr of high pressure (typically 2400 psig)/high temperature (typically  $>1000^\circ\text{F}$ ) main

steam and include a reheat cycle. Frequently the main steam is 3500 psig/1025°F and the boiler capacities can range up to  $10 \times 10^6$  lb/hr of main steam. On occasion, the boiler and turbine are designed to utilize two stages of reheat steam rather than one. These generating stations, then, are very large investments and they are the backbone of the electricity generating system in the US. Coal-fired plants in the US consume some  $1.1 - 1.2 \times 10^9$  tons of coal annually in the generation of electricity.

With impending RPS legislation at the national level, this fleet of large power plants will be asked to accommodate some percentage of biomass fuels—in cofiring applications. Of the renewable energy sources, biomass in direct combustion applications has proven to be the most dispatchable—the most capable of responding to customer needs in a system without energy storage. Of the other renewable, only hydroelectric and geothermal power are completely dispatchable. Wind and solar power are at the mercy of the whims of nature.

## FUEL PROPERTIES AND THEIR INFLUENCE ON COFIRING IMPACTS

Considering cofiring of biomass with coal, and the influence of coal characteristics, can be done given the properties of various coals (see Table 1) and various biomass fuels (see Table 2). A summary of selected parameters is shown in Table 3. It is recognized that, for certain properties (e.g., reactivity), the blend does not necessarily behave as the weighted average of the two fuels. However, for many parameters, the average provides some understanding.

Given these analyses, one can evaluate the influence of coal properties on cofiring as is shown in Tables 4a and 4b, and in Table 5. Note the dramatic differences between cofiring with Central Appalachian coal and PRB. With Central Appalachian coal, the woody biomass elevates the base/acid ratio and puts the  $\text{Fe}_2\text{O}_3/\text{CaO}$  ratio in the range where significant eutectic effects are common, and where slagging is exacerbated. Note that, with the PRB and the lignite in particular, the impacts of cofiring are less severe—as is expected.

**Table 1:  
Typical Coal Analysis**

Parameter	Central Appalachian (Long Fork)	Illinois Basin	Powder River Basin (Black Thunder)	N.Dakota Lignite
<b>Proximate Analysis (wt. % A.R.):</b>				
Moisture	7.16	5.98	25.84	26.74
Ash	11.52	10.63	5.05	12.52
Volatile Matter	31.23	35.11	31.56	31.58
Fixed Carbon	50.09	48.28	37.55	29.16
<b>Ultimate Analysis (wt. % A.R.):</b>				
Carbon	66.93	60.68	51.89	31.80
Hydrogen	4.43	4.77	3.55	4.51
Oxygen	7.55	13.61	12.77	26.35
Nitrogen	1.34	1.09	0.67	0.59
Sulfur	1.07	3.24	0.23	0.84
Moisture	7.16	5.98	25.84	26.74
Ash	11.52	10.63	5.05	9.17
Chlorine (%)	0.12	0.30	0.01	--
Higher Heating Value (Btu/lb, A.R.)	12,114	10,334	8,943	7,613
<b>Ash Elemental Analysis (% Dry):</b>				
Al <sub>2</sub> O <sub>3</sub>	26.25	16.49	16.20	14.01
BaO	0.13	--	0.67	--
CaO	2.31	6.71	22.84	13.69
Fe <sub>2</sub> O <sub>3</sub>	8.38	20.41	6.02	7.39
K <sub>2</sub> O	3.26	1.66	0.56	0.51
MgO	1.42	0.77	5.22	2.51
MnO	0.07	0.06	0.01	0.12
Na <sub>2</sub> O	0.71	1.09	1.44	0.60
P <sub>2</sub> O <sub>5</sub>	0.56	0.45	1.57	0.39
SiO <sub>2</sub>	51.99	39.19	32.76	38.17
SrO	0.19	--	0.36	--
TiO <sub>2</sub>	1.07	0.84	1.28	1.15
SO <sub>3</sub>	2.20	5.43	10.10	14.41

**Table 2:  
Typical Biomass Analysis**

	Wood waste	Switchgrass	Corn Stover
<b>Proximate Analysis (wt. % A.R.):</b>			
Moisture	42.00	9.84	8.00
Ash	2.31	8.09	6.90
Volatile Matter	47.79	69.14	69.74
Fixed Carbon	7.90	12.93	15.36
<b>Ultimate Analysis (wt. % A.R.):</b>			
Carbon	29.16	42.00	42.60
Hydrogen	2.67	5.24	5.06
Oxygen	23.19	33.97	36.52
Nitrogen	0.60	0.69	0.83
Sulfur	0.07	0.17	0.09
Moisture	42.00	9.84	8.00
Ash	2.31	8.09	6.90
Chlorine (%)	0.01	0.18	0.24
Higher Heating Value (Btu/lb, A.R.)	5,028	7,002	7,000
<b>Ash Elemental Analysis (% A.R.):</b>			
Al <sub>2</sub> O <sub>3</sub>	3.55	4.51	3.80
BaO	--	--	--
CaO	45.46	5.60	8.80
Fe <sub>2</sub> O <sub>3</sub>	1.58	2.03	1.80
K <sub>2</sub> O	8.52	11.60	17.30
MgO	7.48	3.00	3.40
MnO	--	--	--
Na <sub>2</sub> O	2.13	0.58	1.50
P <sub>2</sub> O <sub>5</sub>	7.44	4.50	2.70
SiO <sub>2</sub>	17.78	65.18	52.10
SrO	--	--	--
TiO <sub>2</sub>	0.50	0.24	0.13
SO <sub>3</sub>	2.78	0.44	3.70

Table 3. Comparison of Selected Parameters

Parameter	Central Appalachian	Illinois Basin	Powder River Basin	Lignite	Wood waste	Switchgrass
HHV, Btu/lb A.R.	12,114	10,334	8,943	7,613	5,028	7,002
lb/10 <sup>6</sup> Btu of Fuel	83	97	112	131	199	143
Fe <sub>2</sub> O <sub>3</sub> /CaO	3.63	3.04	0.26	0.54	0.03	0.36
lb Cl/10 <sup>6</sup> Btu	0.10	0.29	0.01	0.01	0.03	0.26
lb (Na <sub>2</sub> O + K <sub>2</sub> O)/10 <sup>6</sup> Btu	0.38	0.28	0.11	0.13	0.49	1.41
lb S/10 <sup>6</sup> Btu	0.88	3.14	0.26	1.10	0.14	0.24
lb H <sub>2</sub> O/10 <sup>6</sup> Btu	5.91	5.79	28.89	35.12	83.53	14.05
lb ash/10 <sup>6</sup> Btu	9.51	10.29	5.65	12.05	4.59	11.55
lb fuel N/10 <sup>6</sup> Btu	1.11	1.05	0.75	0.77	1.19	0.99
VM/FC Ratio	0.62	0.73	0.84	1.08	6.05	5.35
Cl/S molar ratio	0.12	0.10	0.05	0.01	0.21	1.17

Table 4a: Cofiring Wood with Central Appalachian Coal

Parameter	0% Wood Cofiring	5% Wood Cofiring (Heat Input Basis)	10% Wood Cofiring (Heat Input Basis)	20% Wood Cofiring (Heat Input Basis)
Mass Percentage of Wood	0%	11.25%	21.12%	37.59%
Heating Value of Blend (Btu/lb)	12,114	11,317	10,618	9,450
Base/Acid	0.20	0.22	0.24	0.29
Fe <sub>2</sub> O <sub>3</sub> /CaO	3.63	2.43	1.78	1.10
lb Cl / 10 <sup>6</sup> Btu	0.10	0.10	0.09	0.08
lb (Na <sub>2</sub> O + K <sub>2</sub> O) / 10 <sup>6</sup> Btu	0.38	0.39	0.39	0.41
lb SO <sub>2</sub> / 10 <sup>6</sup> Btu	0.88	0.85	0.81	0.73
lb Fuel/ 10 <sup>6</sup> Btu	83	88	94	106
lb H <sub>2</sub> O/ 10 <sup>6</sup> Btu	5.91	9.79	13.67	21.43
lb ash/ 10 <sup>6</sup> Btu	9.51	9.26	9.02	8.53
lb fuel N/ 10 <sup>6</sup> Btu	1.11	1.11	1.11	1.12
VM/FC	0.62	0.73	0.84	1.09
Cl/S molar ratio	0.12	0.12	0.13	0.13

**Table 4b: Cofiring Wood with PRB**

	<b>5% Wood Cofiring (Heat Input Basis)</b>	<b>10% Wood Cofiring (Heat Input Basis)</b>	<b>20% Wood Cofiring (Heat Input Basis)</b>
<b>Mass Percentage of Wood</b>	8.56%	16.50%	30.78%
<b>Heating Value of Blend (Btu/lb)</b>	8,608	8,297	7,738
<b>Base/Acid</b>	0.76	0.80	0.90
<b>Fe<sub>2</sub>O<sub>3</sub>/CaO</b>	0.25	0.23	0.20
<b>lb Cl / 10<sup>6</sup> Btu</b>	0.01	0.01	0.01
<b>lb (Na<sub>2</sub>O + K<sub>2</sub>O) / 10<sup>6</sup> Btu</b>	0.13	0.15	0.19
<b>lb SO<sub>2</sub> / 10<sup>6</sup> Btu</b>	0.25	0.25	0.23
<b>lb Fuel/ 10<sup>6</sup> Btu</b>	116	121	129
<b>lb H<sub>2</sub>O/ 10<sup>6</sup> Btu</b>	31.63	34.36	39.82
<b>lb ash/ 10<sup>6</sup> Btu</b>	5.59	5.54	5.44
<b>lb fuel N/ 10<sup>6</sup> Btu</b>	0.77	0.79	0.84
<b>VM/FC</b>	0.94	1.05	1.29
<b>Cl/S molar ratio</b>	0.05	0.06	0.07

**Table 5. Comparison of the Impact of Wood Waste Cofiring at 20% (Heat Input Basis) with Various Coals**

<b>Parameter</b>	<b>Central App</b>	<b>Illinois Basin</b>	<b>PRB</b>	<b>Lignite</b>
<b>Mass Percentage of Wood</b>	37.59%	33.94%	30.78%	27.46%
<b>Heating Value of Blend (Btu/lb)</b>	9,450	8,533	7,738	6,903
<b>Base/Acid</b>	0.29	0.64	0.90	0.53
<b>Fe<sub>2</sub>O<sub>3</sub>/CaO</b>	1.10	1.75	0.20	0.44
<b>lb Cl / 10<sup>6</sup> Btu</b>	0.08	0.24	0.01	0.02
<b>lb (Na<sub>2</sub>O + K<sub>2</sub>O) / 10<sup>6</sup> Btu</b>	0.41	0.35	0.19	0.20
<b>lb SO<sub>2</sub> / 10<sup>6</sup> Btu</b>	0.73	2.54	0.23	0.91
<b>lb Fuel/ 10<sup>6</sup> Btu</b>	105.82	117.19	129.23	144.86
<b>lb H<sub>2</sub>O/ 10<sup>6</sup> Btu</b>	21.43	21.34	39.82	44.81
<b>lb ash/ 10<sup>6</sup> Btu</b>	8.53	9.15	5.44	10.56
<b>lb fuel N/ 10<sup>6</sup> Btu</b>	1.12	1.08	0.84	0.86
<b>VM/FC</b>	1.09	1.14	1.29	1.54
<b>Cl/S molar ratio</b>	0.13	0.10	0.07	0.02

The tables above are based upon cofiring with woody biomass—the most favorable of the renewable fuels. More problems arise when the cofired fuel is an agricultural product. Such

products can bring significant concentrations of chlorine, nitrogen, and other problematic elements. Cofiring a high chlorine biomass with a low sulfur coal—particularly given the concentrations of potassium typically found in agricultural biomass—could invite significant corrosion issues. It becomes critical to evaluate the properties of the coal being fired, as well as the biomass; and it is essential to evaluate the potential interactions between the fuels.

Cofiring programs have also involved additional opportunity fuels including tire-derived fuel at the Allen Fossil Plant of TVA, Willow Island Generating Station of Allegheny Energy Supply Co., LLC, and Bailly Generating Station of NIPSCO. Both of these demonstrations, supported by USDOE, have been reported on extensively in the literature (see, for example, Tillman 2001; Tillman, 2004). These fuels can bring additional issues to the evaluation of cofiring consequences. The petroleum coke, for example, brings significant sulfur to the process. This requires a scrubber. However, in PC and cyclone boilers it can mitigate the corrosive effects of chlorine by driving sulfation reactions.

The most commonly identified corrosion mechanism when cofiring is the reaction of chlorine with alkali metals – potassium and sodium. Chlorides form the most stable alkali-bearing species in the gas phase, as KCl and NaCl. Potassium chloride is most significant when cofiring or firing biomass alone. These compounds can deposit on pendant tubes and other heat transfer surfaces as a highly aggressive, corrosive material. Thermodynamic calculations have shown that alkali chloride products are formed first, followed by the sulfation reaction – see Figure 3. Sulfation is the reaction where chlorine is displaced with sulfur in the alkali compound. This reaction is well known and understood for biomass firing. While alkali sulfate is not benign, it can reduce the corrosivity of the deposit.

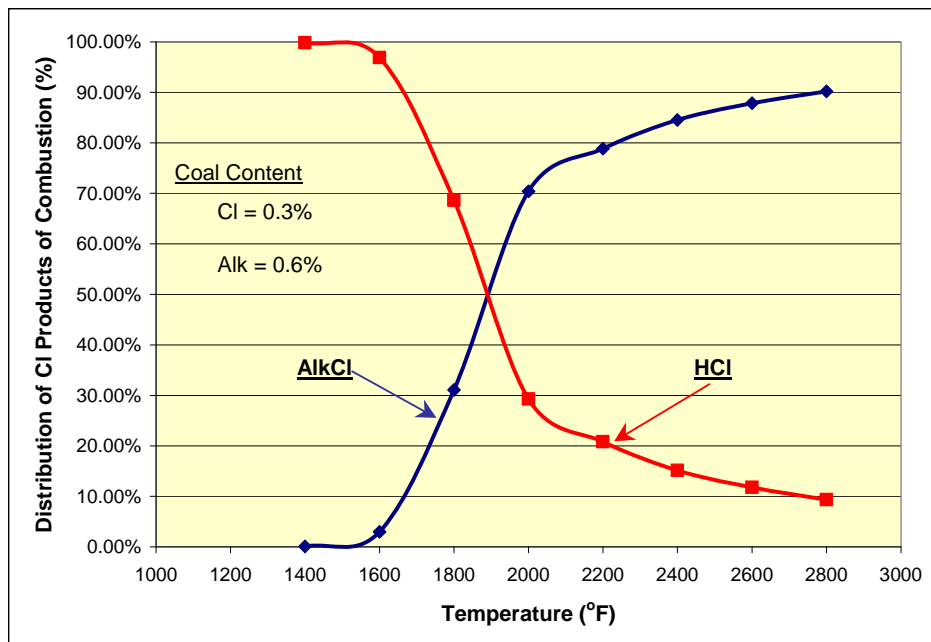


Figure 3: Formation of Chlorine-Based Products of Combustion as a Function of Temperature Given Sufficient Available Alkali Metals to Promote Reactions.

At the same time the inorganic constituents of petroleum coke include significant concentrations of vanadium. This can cause formation of alkali vanadates which are also problematical. When

petroleum coke is completely combusted, a significant portion of the vanadium is converted to its highest oxidation state of vanadium pentoxide ( $V_2O_5$ ). Vanadium pentoxide itself has a relatively low melting point of 1274°F and can cause fouling of convective pass surfaces. Even worse, vanadium pentoxide can form eutectics with reactive alkalis that result in corrosion.

Like petroleum coke, tire-derived fuel can increase the heat content of the blend and can reduce the moisture content of the blend. It contains less sulfur, but its ash contains high concentrations of zinc which can also be problematical depending upon the fuel blend being fired.

## CONCLUSIONS

Cofiring analyses typically focus heavily on the properties of the biomass. However the coal remains the dominant fuel, and its specific characteristics cannot be overlooked. This simple fact is too often overlooked in the assessments of cofiring. There are some combinations of specific coals and specific biomass fuels that should not be fired; there are other combinations which include opportunity fuels that also should not be fired. Alternatively there are combinations that work out very favorably for the utility.

## REFERENCES

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