Global Thermal Coal Attributes

An Analysis

U.S. Thermal Coal Comparison to World Coals[1]

The use of coal as fuel for power generation is influenced by its properties, which vary significantly across the range of coals available in the global marketplace. A comparison of coal properties from around the World and the United States indicates that U.S. coals from the western U.S. appear to have a distinct advantage over traded coals currently used in the Asia/Pacific Rim area, while coals mined in the eastern part of the United States have advantages over other coals used in the European region and the Middle East. An analysis of U.S. thermal coals and other coals from other parts of the World has been made for this report.

I. Discussion of Thermal Coal Attributes

It is important to establish the coal properties that impact the operating and maintenance costs, performance, and emissions of coal-fired thermal power plants.

1. **Cost per BTU, or thermal unit, delivered to the customer's facility**: Impacts the cost of power generation by dictating the tonnage of coal needed.
2. **Efficiency in the power generation process**: Some coal properties will impact both the combustion efficiency (i.e., unburned carbon in ash) and the overall efficiency of the power cycle. With respect to the latter, coal properties will impact parasitic loads associated with operation of the plant auxiliary equipment, including fuel handling and grinding, fans to supply air for combustion of the coal, operation of the emissions control equipment, and ash handling. Further, the propensity for fuel ash to accumulate on boiler heat transfer components will impact efficiency and plant reliability. Ash buildup on heat transfer surfaces can reduce the plant efficiency.

[1] ***NOTE***: The comparisons presented in this paper are based ***only*** on the physical and chemical properties of the coals examined. Design, operation, age, and maintenance conditions of the operating equipment in specific plants will play a ***significant*** role in their operation and overall efficiency.

3. **Maintenance**: Variation in coal physical properties will impact the rate of wear of coal handling and grinding systems, which in turn affect the maintenance requirements (and costs) associated with those plant components. The volume of coal ash, and its properties that needs to be handled will directly impact maintenance requirements for ash handling equipment and particulate matter emissions levels. In addition to impacting efficiency by accumulating on boiler heat transfer surfaces, coal ash also affects maintenance requirements for those components (due to corrosion and erosion) and reduce plant reliability.

Specific plant cost and operating parameters that are impacted by coal properties include:

1. **Plant CO_2 emissions**: The carbon content of coal per unit of heating value contributes to CO_2 emissions. Additional contributors to CO_2 emissions per unit power output are moisture and ash content in the coal, which both negatively impact plant efficiency.
2. **Plant Nitric Oxides (NOx) emissions**: NOx emissions are impacted by a coal's nitrogen and oxygen contents, as well as the ratio of fixed carbon-to-volatile matter in terms of coal properties. Coals with lower nitrogen and higher oxygen contents, as well as lower ratios of fixed carbon-to-volatile matter, will lead to lower potential for NOx emissions.
3. **Plant sulfur dioxide (SO_2) emissions**: SO_2 emissions are dictated by the fuel's sulfur content. For plants equipped with flue gas desulfurization (FGD), lower sulfur content coal will require less sorbent (limestone or lime), which lowers operating costs and requires less plant parasitic power. Also, the quantity of sludge produced in the FGD system will be lower for lower sulfur coals.
4. **Carbon in ash**: This parameter, which is an indicator of combustion efficiency, impacts the salability of ash products for construction applications (i.e., concrete). Lower fixed carbon-to-volatile matter and higher oxygen content in the coal promotes burnout of residual carbon in the fuel particles, leading to lower carbon in the flyash. An additional parameter that can affect this is the free swelling index – a measure of how the coal particle swells when heated. Coals with lower free swelling index can contribute to better combustion efficiency and less carbon in the flyash.
5. **PM (Particulate matter)**: Higher ash-content coals creates the potential for higher stack particulate emissions. Where electrostatic precipitators (ESPs) are installed for particulate emissions control, less flyash means less power is required to operate the ESP system, which results in more efficient plant operation. The carbon content of the flyash after combustion also impacts the ESP's collection efficiency and could result in higher PM emissions. Higher ash content coals generate more ash that has to be landfilled, if not utilized, thereby increasing operating costs.
6. **Turndown**: Turndown is the fraction of rated output that a power plant can achieve in stable operation. Part-load operation is especially important when the plant is forced into cycling when intermittent renewable power is on the grid. Achievable turndown is a function of the flame stability of a given coal type at part-load operation. This is influenced by the fixed carbon-to volatile matter ratio and the oxygen content of the coal.
7. **Ash deposits and fouling of heat transfer surfaces**: Coal ash properties play a critical role in the overall efficiency, maintenance, and reliability of coal-fired power plants. Specifically, certain chemical constituents found in coal ash (e.g., Na, K, Fe, Ca, and Si) along with the fusion (melting) properties of the ash can impact the amount of ash deposits accumulating on heat transfer surfaces, the deposits' heat transfer characteristics and bonding strength, and finally erosiveness of the flyash. Certain ash chemistries can lead to the potential to accumulate ash on heat transfer surfaces,

especially when the ash has strong adhesiveness, along with high reflectivity ashes can reduce the amount of heat transferred to the working fluid. This reduces overall system efficiency resulting in higher-fuel consumption and ultimately higher emissions including CO_2.

II. Other Coal Applications

U.S. coals have other overseas markets besides for power generation. The second largest global market for coal is to produce coke for steel making. While the U.S. steel industry has shifted away from the blast furnace process, which requires coke, the overseas market for coking coal remains strong and presents a large tonnage opportunity for U.S. coal exports. Volatile matter, ash, and sulfur contents are key parameters for high-quality coking coal, along with additional parameters specific to coke making, such as high-temperature swelling properties and resultant coke strength. Overseas coking coal markets are largely served by Appalachian coals, including high-, medium-, and low-volatile bituminous coal.

Appalachian coal is also used overseas for less common applications, such as metallurgical electrodes (served by anthracite from Appalachia), non-ferrous reductants (also an anthracite application), and silicon metal smelters (low-ash content Central- and Southern Appalachian bituminous coal).

III. Comparison of U.S. Coals to World Coals

An analysis of coal property data[2] indicates that most western U.S coals appear to be superior to other imported coals being used by Asian Pacific Rim countries, while most eastern U.S. coals appear to be superior to the imported coals being used in Europe and the Middle East. The table below provides a high-level comparison of the attributes of coals from different regions of the United States compared to coals from Australia, Indonesia, South Africa, Russia, India, Brazil, and Columbia

1. Western U.S. Coals: The coals included under this category are mined in the states of CO, WY, NM, AZ, UT, and MT. The vast majority of these coals typically fall into two classifications: high-volatile bituminous, mostly found in UT, AZ, NM, and CO, and subbituminous, mostly found in WY and MT with some seams also present in NM.

   Western U.S. bituminous coals (AZ, NM, UT, and CO) are characterized by their medium- to high heating values (~10,000 – 11,000 Btu/lb. as received), low sulfur and ash contents, and high reactivity. These properties make these coals excellent steam coals for power generation in that they combust easily, thus yielding high-combustion efficiency (i.e., low carbon in ash produced). This makes flyash from these coals excellent for use as concrete feedstock, while having low particulate, sulfur, and nitric oxide emissions. The ash properties of western U.S. bituminous coals also make them suitable for reliable and low-maintenance power plant operation as their ash is characterized by high-melting temperatures compared to Indonesian coals and low levels of chemicals that promote heating surface fouling. For the export market, subject to west U.S. coast

[2] World and U.S. coal analysis data are from "Clean Combustion Technologies," Alstom Power, 2009 edition

port availability, they can be formidable competitors to the coals (Australian, Indonesian and Chinese) typically used in the Asian (e.g., Japan, South Korea, Taiwan, and China) power markets. The major advantage of the western coals to the Australian coals is due to their high reactivity and lower sulfur content. Their higher reactivity allows for lower emissions, better combustion efficiency (i.e., lower combustible loses), lower maintenance (e.g., lower power along with lower wear and tear for the coal pulverization equipment), and lower slagging and fouling of the heating surfaces. In terms of CO_2 emissions, they are fairly equal/similar to those of Australian coals.

The western U.S. subbituminous coals (WY, MT, and NM) are characterized as having lower heating values (8,000 – 9,000 Btu/lb.), higher moisture, lower cost (strip mining), and lower ash contents. They are also known for their very low sulfur content, low NOx emissions from combustion, high reactivity, low-ash content, low abrasion, and ease (lower power content) of pulverization. Some coals, however, have ash with lower melting temperatures and high amounts of components that can contribute to high ash deposition rates. Without proper operating conditions performance of the power could be impacted, however approximately 40% of the U.S. coal generation fleet has operated successfully for decades using western U.S. subbituminous coals due to their low sulfur and NOx emissions, high reactivity that allows for high turndown and fast load response, low carbon levels in the ash allowing for its recycling into concrete, and low parasitic power losses. In comparison to Australian bituminous coals, their lower heating value requires higher tonnage to be transported for the same heat content; however, they overcome this disadvantage due to their superior reactivity and lower emissions. Lower sulfur emissions means lower consumption or possibly elimination of limestone or lime reagent for SO_2 emissions control in some markets when blended, while their low-NOx emissions could mean elimination of ammonia/urea injection used in selective catalytic reduction systems. Western U.S. subbituminous coals are similar to Indonesian coals although the latter often has lower heating value (approximately 1,000 Btu/lb.) and there have been reports that their quality (heating value) has been declining recently due to higher water content.

2. Eastern U.S. Coals: Eastern U.S. coals are mostly bituminous with a majority falling under the High Volatile category per ASTM standards. They are characterized by their high heating value that ranges from 11,500 – 14,000 Btu/lb., however there can a good variation in sulfur content, ash fouling characteristics, reactivity, ash content, and emissions. Eastern coals can be a formidable competitor to the steam market in Europe, the Middle East, and India. When compared to coals available for the market (e.g., Russia, South Africa, and India), they provide similar, if not superior heating value; excellent ash fouling characteristics; good, if not, superior combustibility: lower particulate emissions, and a variety of options (i.e., sulfur content) when it comes to emissions.

Table: Comparison of U.S. and typical world coal properties and utilization performance

Superior
Similar
Inferior

	Region	Coal Rank	Area	HHV Btu/lb. ***	CO_2	NOx	SO_2	C in Ash	PM	Turn down
USA	**Western**	B*	CO	14,166	**Neutral**	**Higher**	**Low**	**Neutral**	**Low**	**Neutral**
		B*	AZ	10,800	**Neutral**	**Low**	**Low**	**Low**	**Low**	**High**
		SB**	WY	8,320	**Neutral**	**Low**	**Low**	**Low**	**Low**	**High**
		SB**	WY	9,345	**Neutral**	**Low**	**Low**	**Low**	**Low**	**High**
		B*	UT	12,600	**Neutral**	**Low**	**Low**	**Low**	**Low**	**High**
	Midwest	B*	IL	11,376	**Neutral**	**Neutral**	**Higher**	**Neutral**	**Neutral**	**Neutral**
		B*	IL	11,833	**Neutral**	**Neutral**	**Higher**	**Neutral**	**Neutral**	**Neutral**
		B*	KY	11,816	**Neutral**	**Neutral**	**Higher**	**Neutral**	**Neutral**	**Neutral**
	Eastern	B*	PA	14,313	**Neutral**	**Higher**	**Neutral**	**High**	**Low**	**Low**
		B*	PA	13644	**Neutral**	**Higher**	**Higher**	**High**	**Low**	**Low**
		B*	VA	14,350	**Neutral**	**N.A.**	**N.A.**	**High**	**Low**	**Low**
		B*	WV	12,797	**Neutral**	**Higher**	**Low**	**Low**	**Low**	**High**
		B*	KY	13,611	**Neutral**	**Low**	**Higher**	**Low**	**Low**	**Low**
Australia		B*	Qld	10,130	**Neutral**	**Higher**	**Low**	**High**	**High**	**Low**
		B*	Qld	13,000	**Neutral**	**Higher**	**Low**	**High**	**Low**	**Low**
		B*	NSW	11,620	**Neutral**	**Higher**	**Low**	**High**	**Neutral**	**Low**
Brazil	**Rio Grande do Sul**	SB**		6,048	**Higher**	**N.A.**	**N.A.**	**Neutral**	**Low**	**Low**
Colombia	**Cerrejon Norte**	B*		12,900	**Neutral**	**N.A.**	**N.A.**	**Neutral**	**Low**	**Low**
India	**Renusagar**	SB**		7,233	**Higher**	**Higher**	**Low**	**High**	**High**	**Low**
Indonesia	**Export**	SB**		9,092	**Neutral**	**Low**	**Low**	**Low**	**Low**	**High**
Russia	**Kuznetsk**	B*		12,926	**Neutral**	**Higher**	**Low**	**High**	**Neutral**	**Low**
South Africa		B*		10,972	**Neutral**	**Higher**	**Low**	**Neutral**	**High**	**Low**

* B: Bituminous

** SB: Subbituminous

*** BTU/lb.: British Thermal Units/pound (weight)