Policy Brief

China

International Best Practices Regarding Coal Quality

RAP Energy solutions for a changing world

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International Best Practices Regarding Coal Quality

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Abbreviations and Acronyms

ASTM American Society for Testing and Materials

BTU British Thermal Unit

CO_2 Carbon Dioxide

EPA United States Environmental Protection Agency

ETS European Trading System

H_2SO_4 Hydro Sulfuric Acid

HGI Hardgrove Index

kCal Kilocalories

MEP Ministry of Environmental Protection

MMBtu One Million British Thermal Units

MW Megawatt

NDRC National Development and Reform Commission

NO_x Nitrogen Oxides

NSR New Source Review

NYMEX New York Mercantile Exchange

PM Particulate Matter

RMB Renminbi

RS Rupee (India)

SO_2 Sulfur Dioxide

SO_3 Sulfur Trioxide

SO_x Sulfur Oxides

I. Introduction

Coal continues to be the dominant fuel choice for power generation around the world. While hydraulic fracturing and new drilling techniques have increased natural gas supplies, coal consumption continues to rise, especially in Asia. China and India alone are responsible for nearly all of the growth in global coal consumption since 2000. We know that the emissions characteristics of coal combustion are substantially influenced by the type and processing of coal used; it is also true that the quality of coal affects the profitability of a particular power plant and can facilitate or hinder the plant's ability to meet environmental requirements.

The main variables that influence coal quality are its ash[1] and sulfur content. Ash and sulfur are inorganic and have no heating value. The higher the ash content, the lower the heating value of raw coal (i.e., coal straight from the mine mouth). Many lower heating-value coals, or "lower rank" coals, as they are referred to in the industry, have ash content of 40% or higher. Removing the ash through washing or additives increases coal's heating value. This processing has several other benefits, which directly affect the profitability of a coal plant, its ability to meet environmental requirements, and its ability to avoid future economic risks. The presence of ash and sulfur in the boiler combustion chamber is linked to increased scheduled and unscheduled maintenance and decreased capacity factors (meaning fewer hours of generating electricity). Further downstream, higher ash concentrations (products of incomplete combustion) coat ductwork and increase the quantity of solids that have to be collected by emissions control devices and then disposed of in landfills. Ash and sulfur deposits on plant duct work increase corrosion and shorten the plant's expected life. Improving coal quality by lowering its ash and sulfur content is, therefore, both environmentally and economically beneficial and is an advisable course of action to pursue.

The purpose of this paper is to examine ways in which China can improve the quality of the coal it burns for electric generation, thereby gaining both environmental and economic benefits. We will look at the lifecycle of coal, the benefits and costs of using higher quality coal, and points where pressure may be applied to increase the use of high quality coal. We conclude with several recommendations that can help Chinese regulators encourage the use of better quality coal.

1 Ash is found in all coals. In raw, unburned coal, ash is comprised of crustal materials (i.e., dirt and small rocks) as well as inorganic compounds, such as salts and metals. Ash has little to no heating value, so when coal is burned, the ash, now called fly ash, travels through the boiler and duct work, and is collected in emissions control devices, with finer particles being directly emitted to the atmosphere.

II. Life Cycle of Coal[2]

There are a number of steps in the lifecycle of coal: extraction, processing, transport, use/combustion, and disposal. The description below is a general description for illustrative purposes, not meant to be exhaustive.

Extraction

Coal is extracted (i.e., mined) in one of two different methods: surface or "opencast" mining and underground or "deep" mining. The choice of method is mainly driven by geology. Surface mining is used when the coal seam is near the surface; the coal seam is exposed by blasting away and removing the surface layer of rock and dirt, and then the coal seam is systematically drilled and removed. Underground mining is used when the coal seams are deeper underground; the coal seams are accessed by drilling tunnels hundreds of feet underground, and the coal is then mined and brought to the surface.

Processing

From the earliest days of mining, people have attempted to improve its quality by removing impurities, such as rock and slate, or by sizing and washing the coal. Generally, in contemporary practice, the first step is to wash the coal, which involves chemical processes that separate dirt, vegetation, and raw rock from coal. The process reduces the amount of ash and sulfur content of the coal and increases the heating value of the coal. It also produces a byproduct called slurry or sludge, which is comprised of the water and chemicals used to wash the coal. Slurry is a highly toxic substance that is collected and stored at the mine site, giving rise to environmental concerns about groundwater contamination. Washing is frequently followed by an additional mechanical process wherein the coal chunks are crushed and ground and then separated into different grades of coal. Throughout the washing and crushing process, the coal may be sampled to measure ash, moisture levels, kCal (BTU), sulfur, iron, calcium, sodium, and various other elements. In China, coal washing was emphasized by the 9th Five Year Plan, and again in the new Air Law.[3]

Transport

Once processed, coal must be shipped from the mine to the point of consumption; this happens by train, truck, barge, and conveyor belts, although some generation plants are built near the mine mouth to lower transport costs. Transportation of coal is a significant issue in China, where most of the coal mines are located in the northwest and the coal must be transported to the consumption centers in the southeast. Some estimates suggest that over 0.56 billion tons of coal are shipped each year over long distances (average greater than 500 km).

Coal transport is an expensive and environmentally harmful activity. The United States Energy Information Agency reports that, in 2010, transportation costs made up 38.6% of the total cost of a delivered short ton of coal in the U.S.[4] Furthermore, the diesel engines used by many of the trucks and trains that transport coal emit into the air significant amounts of oxides of nitrogen (NO_X) and particulate matter. In addition, there is the dust and particulate matter that comes off the coal as it is transported long distances.[5]

2 See: Lockwood (2012). Epstein, et al. (2011). World Coal Association (2012).

3 Article 44 of existing Air Law "the State shall promote coal washing and processing, lower the sulfur and ash contents of coal, and restrict the mining of coal with sulfur and high ash contents". Article 89 permits fines to be imposed on new mines that fail to include coal washing.

4 Xiaolon (2012).

5 U.S. Energy Information Administration. (2012).

Combustion

The majority of the coal that is mined globally is "thermal" coal, that is, coal burned to produce steam and used mainly in electricity production.[6] Coal combustion "releases over 70 harmful chemicals into the environment and contributes significantly to global warming."[7] Prior to combustion, coal is pulverized into a coarse powder to improve the efficiency with which it burns. Roughly 90% of coal-fired generation capacity worldwide uses pulverization techniques.[8] Some of the more notable byproducts of burning coal are ozone precursors[9], sulfur dioxide, particulate matter, nitrogen oxides, mercury, and carbon dioxide. In addition to gases, there is also a solid byproduct from burning coal called coal ash, which is discussed below. Generators can install mitigation equipment, such as scrubbers to reduce the emissions of harmful pollutants.

Disposal

As mentioned earlier, the combustion of coal produces a solid byproduct called coal ash. A number of different substances fall under the label "coal ash": fly ash, bottom ash, boiler slag, and flue gas desulfurization gypsum, among others. Once the coal ash is collected, it is often impounded and stored in a storage pond or in a landfill or can be used for various industrial purposes.

6 The other type of coal is called metallurgical coal and is used to create coke, a product required in the making of iron and steel. See World Coal Association (2012).

7 Lockwood (2012).

8 World Coal Institute (2005).

9 Ozone is not directly emitted by coal plants, but compounds such as NO_X and hydrocarbons, which are directly emitted, contribute to the formation of ozone downwind from coal plants.

III. Benefits and Costs Associated With Improved Coal Quality

There can be both benefits and costs associated with the use of higher quality coal in electricity generation. RAP's position is that the benefits far outweigh the costs.

Benefits

All coals contain inorganic materials, such as sodium, chlorine, and sulfur. During the combustion process, the inorganic materials form ash that is deposited in a dry (called fouling) or wet (called slagging) state in the boiler's combustion chamber. The quantity and types of compounds present in the ash dictate the necessary frequency of cleaning the boiler's tubes (to maintain their design heat transfer rate), as well as how often the boiler must be shut down for more extensive maintenance. These inorganic compounds can be removed by the application of mineral additives to the coal prior to its combustion or by washing the coal at either the mine mouth or at the coal plant itself. The industry term for improving coal quality is called "beneficiation." Beneficiation improves the coal's quality and produces both environmental and economic benefits.

(1) Improve Heat Rates

The higher the ash content of coal, the lower the heating value of that coal. By removing the ash through washing, the coal's heating value can be improved dramatically. This means that less coal must be burned to produce a comparable amount of electricity. Thus, power plants that use higher quality coal will have an economic and performance advantage over those that use lesser quality coal.

(2) Improve Plant Operations

Beneficiation results in a variety of improvements to power plant operations, which directly affect the profitability of a coal plant, its ability to meet environmental requirements, and its ability to avoid future economic risks.

Applying mineral additives containing aluminum can reduce ash fouling and slagging in pulverized coal boilers by up to 78%.[10] Wet pretreatment can reduce the amount of ash that adheres to boiler tubes, thus reducing fouling. Dry additives, such as alumina, can make the ash less sticky and thus reduce the amount of ash that forms on boiler surfaces. Reducing the ash content of coal also makes the coal less abrasive.

Reducing the presence of ash and sulfur in the boiler combustion chamber is good. By reducing the amount of ash accumulation, operators can reduce the amount of scheduled and unscheduled maintenance required to remove the ash accumulation. Reducing the abrasiveness of the ash and sulfur deposits on plant duct work can reduce corrosion that shortens the plant's expected life.

Higher ash content in the fuel affects every piece of plant equipment that handles and processes coal, such as conveyors, pulverizers, crushers, storage, etc. The increased load on this equipment also increases the quantity of plant-site energy needed simply to operate the plant, which takes away from the quantity of electricity that can be transmitted for sale, thus increasing the plant's operating costs and decreasing its profit potential.

Beneficiation also has benefits for the operation of emissions control devices. About 80% of the ash in coal eventually travels through the combustion process and, along with the flue gas, is captured by the emissions control equipment. Coal washing reduces the amount of ash produced and collected by particulate control devices, thereby extending the life of the particulate control

10 Vutharulu (1999).

devices. Washing coal also helps to extend the life of ash disposal landfills. Beneficiation also extends the life of emissions control equipment by reducing the amount of pollutants the devices need to capture. Washing or processing coal before it is combusted can also permit the power plant to design and purchase smaller emissions control devices, thus reducing capital costs.

Thus, power plant owners benefit directly from burning better quality coal. Coal-fired boilers represent significant economic assets for their owners and operators. Construction materials used are high value, such as stainless steel for certain ductwork and equipment, and boilers are designed to last for 20-30 years or more. Improving coal quality preserves the value of this long-term investment.[11]

(3) Improve Air Quality

Reducing sulfur in the fuel combusted also will reduce sulfate formation and fine particulate emissions and help to improve visibility by reducing regional haze. The actual quantity of sulfate formed is dependent on the amount of SO_3 that is emitted and on various meteorological and chemical reactions caused by the emissions. Data from U.S. coal plants show that about 1-2% of sulfur oxides are emitted as SO_3. Sulfur trioxide also easily converts to hydro sulfuric acid (H_2SO_4), a potent contributor to acid rain.[12]

Studies of U.S. coals show that washing reduces sulfur content by 10-20% (on a pounds-per-MMBtu basis). Ash reductions of 30-50% were reported for Mexican coals, with a 20-30% reduction in sulfur content. A National Academy of Sciences study reports sulfur reductions for China's coals of up to 20%.[13] A minimum 10% reduction in SO_2 is considered to be a conservative assumption of the emissions-savings potential from coal washing. This minimum 10% reduction in SO_2 for a 600 MW plant, operating at an 80% capacity factor (or 7000 hours per year), would result in a minimum SO_2 reduction of 1,682 metric tons.

(4) Improve Transportation Systems

Coal washing reduces the weight of the raw coal by up to 25%, with the effective heat content, in Btus per gram, increasing. A net reduction in transportation energy demand of about 20% is possible, requiring less fuel to transport the coal from a mine to a power plant, yielding reductions in fine particulate, NO_X, and greenhouse gas emissions.[14] The same study reports that 45% of China's railway capacity goes to transporting coal, and 70 million tons of dirt and rock are moved along with coal each year.

(5) Less Expensive

One joint U.S.-India study showed that washed coal was, on average, about 10% less expensive than that of raw coal, even with a calculated washing fee of RS 130 per ton (about 15 RMB or U.S. $2.40 at exchange rates as of December 2012).[15] This report graphed the heating value of coal after different levels of washing and showed that, for distances greater than 900 kilometers, the delivered price (on a cost per k-cal basis) was lower for washed coal than for raw. The study also concluded that washing produced additional plant benefits (higher heat content per kg of coal, lower ash disposal costs, lower operations and maintenance costs, etc.). Finally, the report compared imported coal with both raw and washed coal (including the benefits to the power plant). This analysis found that washed coal was 10-20% less expensive than that of imported coal.

11 It must be acknowledged, however, that even with higher quality coal, boiler design is still critical to the efficient operation of a power plant. Boiler design life is predicated on adherence to good fluid dynamics and heat transfer principles. Layout of the plant's ductwork and piping aims to minimize turns and bends and have large diameter ducts to keep minimize pressure drops, to maximize the thermal efficiency of the plant, and to avoid extra energy demand just to move flue gases from one point to another. Critical to this are well-mixed flue gases, which depend upon adequate retention time in the combustion chamber to complete chemical reactions, achieve maximum heat transfer, and minimize the formation of air pollutants. Well-mixed flue gases also ensure that duct velocities are uniform from top to bottom and side to side. Doing so helps to assure that flue gas temperatures are as uniform as possible. Flue gas hot spots can cause duct deformation and flue gas cold spots can cause corrosion if the temperatures drop below the acid dew point.

12 Allen (2004).

13 National Research Council (2004).

14 Glomrod (2003).

15 Sharpe (2011).

A recent study of the U.S. "Acid Rain" SO_2 reduction program, which was launched in 1990, supports the notion that improving the quality of coal has significant and quantifiable benefits. The program led to a significant decline in SO_2 emissions, largely achieved through a shift to better quality coal (although installation of emissions control equipment also played a supporting role). Overall, the program achieved annual benefits of $122 billion (chiefly from reduced PM2.5 mortality), compared to annual costs of only $3 billion.[16] The next section will discuss these costs in more detail.

A technical paper completed for the U.S. Electric Power Research Institute (EPRI) confirms the benefits of using higher quality coal. The paper states that "it is safe to say that higher ash content for a particular coal is undesirable at any plant for any reason."[17] This paper analyzed coals with different quantities of ash and then determined the effect of ash content on several boiler performance and operation parameters, including thermal efficiency, quantity of ash landfilled, annual tube failures, unit availability, and the quantity of carbon dioxide emitted. Increasing ash content negatively affected all boiler parameters. Thermal efficiency decreased, annual tube failures increased, the quantity of ash sent to landfills and carbon dioxide emissions increased, and unit availability decreased. Even a one percent improvement in boiler efficiency will have a significant impact on the quantity of coal combustion by a power plant over the course of a year. Improving the generation or "heat" rate of a unit, i.e., reducing the grams of coal to produce one kilowatt-hour of electricity, reduces fuel costs and improves profitability. Later studies on the benefits of improving coal quality have supported the conclusions of the study completed for EPRI.[18]

Costs

Precise data on the costs associated with washing and processing coal are scarce. A review of publicly available information emphasizes the benefits to coal producers from washed coal, i.e., they can fetch a higher price for their product.[19]

The environmental and private benefits associated with improving coal quality must be compared with the costs, including the environmental costs of washing and processing coal. In certain geographic areas, water resources are constrained, in some cases severely so. Using scarce water resources to improve coal quality may not be advisable in such areas, and it may be better to improve coal quality at the power plant or at some intermediate site between the mine mouth and the plant, where water resources are more plentiful and can be reused.

Also, washing coal creates a need to impound the residual slurry from the washing process itself. Slurry storage ponds give rise to the risk of contamination of local waterways and ground water if the containment ponds leak. This is a serious environmental consideration and requires careful oversight by regulators.

16 U.S. EPA (2013).

17 Anderson & Nowling (2002).

18 Canadian Clean Power Coalition Technical Committee (2011).

19 See for example: http://seekingalpha.com/article/426421-mongolian-mining-corp-a-high-profit-margin-play-with-room-to-grow an article about how Mongolia's coal producers are enjoying a higher price per ton for selling washed coal to China.

IV. Effects of Current System in China and Recommendations for China

China's use of low quality coal results in several impacts that increase environmental damage, add unnecessary expense, and decrease the operating life of power plants. The goals of the 9th Five Year Plan to increase the percentage of coal washed have yet to be realized. At least four major effects can be identified from the current system China uses to transport and burn coal in power plants:

- The high ash and sulfur content decreases the effective operating life of power plants, increases the costs to dispose of fly ash, increases emissions of fine particulate and sulfur oxides, and, where this practice occurs, increases the risks to the plant of exposure to future regulatory actions related to the hazardous materials collected and disposed of on-site.
- Higher ash content burdens China's transport network, adding to or creating rail network congestion, and causing more diesel fuel to be burned by trains to carry coal from mining areas to power plants.
- Uncovered rail cars leak coal and coal dust, creating public health and environmental impacts to areas along China's rail network.
- Because China's rail network is congested, diesel trucks are used to transport coal between mining areas and power plants. These trucks burn high sulfur fuel and are not subject to the same emissions standards as light duty trucks and cars. As a result, diesel truck transport of coal is increasing the $PM_{2.5}$ contribution in certain urban areas.

V. Points of Regulation

Because not all costs associated with poor quality coal are borne by the plant owners, and because many plant owners have already invested in plants that can effectively use low quality coal,[20] it is advisable for the Chinese government to take certain actions to encourage the increased use of higher quality coals.

There are several ways in which quality control requirements can be specified. Contractual arrangements between the seller of the coal and the purchaser are the primary means by which commercial quality control is established. One example of contractual standards for coal quality comes from the New York Mercantile Exchange ("NYMEX"). Under standard NYMEX rules, there are a number of coal quality specifications:

(A) Coal delivered under this contract shall meet the following quality specifications on an as received basis, (as-received does not refer to subsections (6) and (7)):

(1) **Btu:** Minimum 12,000 btu/lb., gross calorific value, with an analysis tolerance of 250 btu/lb below (A.S.T.M. D1989)

(2) **Ash:** Maximum 13.50%, with no analysis tolerance (A.S.T.M. D3174 or D5142)

(3) **Sulfur:** Maximum 1.00%, with an analysis tolerance of 0.050% above (A.S.T.M. D4239)

(4) **Moisture:** Maximum 10.00%, with no analysis tolerance (A.S.T.M. D3302 or D5142)

(5) **Volatile Matter:** Minimum 30.00%, with no analysis tolerance (A.S.T.M. D5142 or D3175)

(6) **Grindability:** Minimum 41 Hardgrove Index (HGI) with three-point analysis tolerance below. (A.S.T.M. D409)

(7) **Sizing:** Three inches topsize, nominal, with maximum fifty five per cent passing one quarter inch square wire cloth sieve to be determined basis the primary cutter of the mechanical sampling system. (A.S.T.M. D4749)[21]

Under these kinds of contractual arrangements, quality standards are enforced by the parties to the contract, with recourse to the appropriate judicial body in cases of disputes over performance.[22]

A second type of quality control can take place through air pollution permitting. Permits impose different types of restrictions on the specific permitted sources, with site-specific parameters. Restrictions may be placed on the heating value range of coal (minimum and maximum), its sulfur and ash content, and its throughput (tons of coal combusted per hour) and on record keeping and reporting (including sampling and emissions testing requirements). Typical entities in need of permitting are power generators and large industrial facilities that use coal in their operations.

An example of a permitting program is the U.S. Environmental Protection Agency's ("EPA's") New Source Review ("NSR") program.[23] NSR applies when a company, such as the future operator of a coal-fired generator, intends to build a new plant or modify an existing plant to such a degree that certain emissions will increase by a large amount. NSR permits are construction permits, and they require that a company minimize specified emissions either by changing the proposed industrial process or by installing air pollution control equipment.

Another type of permitting program that the EPA operates falls under Title V of the Clean Air Act as it was amended in 1990.[24] Title V permits are operating

20 Steinfeld, et al. (2008).

21 CME Group (2012).

22 Contracts generally specify the method of resolving conflicts, as well as the adjudicatory body and jurisdiction.

23 A description of the New Source Review program can be found on the EPA's website at http://www.epa.gov/nsr/, accessed on 12/16/12.

24 See EPA website for Title V information at http://www.epa.gov/air/caa/title5.html.

permits that govern the activity of sources once they are in operation. They cap a facility's allowable emissions of certain pollutants, such as CO_2, SO_X, mercury, and NO_X.

EPA is the body responsible for enforcing the NSR program, and regulated entities are required to comply with a strict regime of data collection and reporting to EPA.

Finally, there are general quality-control measures that can be applied across a region or across an industry (as opposed to permits, which are site-specific). Regulations can take a number of forms, such as "command and control," whereby a regulator sets emissions targets for pollutants and penalizes entities that exceed those levels; incentives, whereby a regulator sets targets and rewards entities that achieve those targets; and market mechanisms, such as cap-and-trade regimes.

Perhaps the most well-known global example of emissions control policies is the European Union's Emissions Trading Scheme ("ETS") for the regulation of CO_2 emissions.[25] The ETS began in 2005. The European Commission is the entity that enforces the ETS. The program places a limit (a cap) on the total amount of particular greenhouse gases that can be emitted from industrial operations and power generators. Companies each receive permission to emit up to a specified amount per compliance period (this permission takes the form of an allowance per unit of emissions).[26] Allowances can be bought and sold, depending upon each emitter's strategy for achieving compliance with the pollution limits. At the end of a compliance period, each regulated entity must submit allowances to cover its emissions during that period. If an entity emits more than it has allowances to cover, then it is fined. Emissions levels can be gradually reduced by limiting the number of allowances issued.

25 See the European Commission's website on its Emissions Trading System at http://ec.europa.eu/clima/policies/ets/index_en.htm.

26 A common criticism of the ETS is that emission allowances were given out freely to emitters. An alternative, preferred methodology is to sell the allowances and then reinvest those funds into energy efficiency and renewable energy programs, thereby further reducing emissions levels. See Cowart (2008).

VI. Recommendations

China can improve upon the quality of the coal burned. Doing so can help to improve the economics of the power plant and reduce the environmental damages that are currently occurring. Following are several recommendations that China can consider to improve the quality of coal combusted in power plants:

- Conduct research in conjunction with a cognizant university, China's coal institutes, and the China Electricity Council to:
  - Determine the potential in China to improve the quality of coal through a cost-benefit analysis and planning process (i.e., how much ash and sulfur can be removed, what would be its costs, to what levels could coal's heating value be increased, what quantities of water would be required?)
  - Develop the appropriate policy mechanisms to recover any costs associated with improving the quality of coal, and where those costs are best allocated.
- Include coal quality specifications in EIAs and licenses for coal-fired power plants. This will permit the power plants to contract with the coal companies for the type and quality of the coal to be burned. The specifications should include: the types of coal to be burned, the acceptable ranges of heating value, sulfur and ash, and require the received coal to be tested.
- For coal washing, require facilities to recycle and reuse water used for processing.
- In areas with water constraints, or where drinking water or ground water supplies might be used to wash coal, instead improve the quality of coal in these areas through dry additives and processes that do not require water.
- Work with MEP to reduce the sulfur content of fuel burned in diesel trucks. The recent "Joint Prevention, Joint Control" for air quality plan, with commitments by MEP, NDRC and the Ministry of Finance, announced accelerated targets to improve China's fuel quality. Reducing the sulfur content will also allow these trucks to be fitted with modern devices to reduce fine particulate matter.

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