4. Improve Coal Quality[1]

1. Profile

Power plant boilers are designed to accommodate a range of types of coal but, within this range, variations in coal properties can affect performance and efficiency. A boiler designed to burn a high rank bituminous coal is going to perform quite differently if lower rank sub-bituminous coal is introduced, and properties such as high ash or sulfur content can impair not only the thermal performance of the boiler, but also associated duct work and virtually all boiler auxiliary systems, including sootblowing, forced and induced draft systems, steam temperature control, bottom and fly ash removal, pulverizers, and primary air, secondary air, burners, and combustion controls.[2] Air permit conditions for new or modified boilers specify fuel type and quality, and require fuel sampling in order to bind the range of potential emissions that are associated with variations in these parameters. Off-design fuels can affect boiler performance and efficiency.

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

Plant operators understand that there are benefits from specifying coal quality in purchasing contracts, even if higher quality coal is more expensive. Even before the establishment of environmental requirements for coal quality, operators of coal-fired power plants voluntarily established standards and specifications for the fuel they purchased so they would be able to effectively operate their boilers and minimize the amount of time the boilers had to be taken off-line for maintenance. Boilers are typically designed and constructed based on a specification coal or range of specification coals that the purchaser intends to use as its fuel, such as that secured for a long-term purchase agreement with a given mine or group of mines. Once a boiler is constructed and in operation, owner/operators will typically continue to specify fuel coals to be compatible with the design characteristics of their boiler and boiler auxiliaries and any associated regulatory requirements. Alternatively, the owners/operators may make the decision to purchase off-spec fuels that they can live with to provide an economic advantage, assuming there are no regulatory requirements that influence those decisions.

Some coal processing may be required for an as-mined coal to meet the specifications of purchasers.[3] To maintain coal quality within specified ranges and meet boiler performance objectives, coals with different properties can be blended, either by the coal producer or at a power plant. Another option for meeting coal quality specifications is through "beneficiation." Coal beneficiation is the industry's term for any of several processes and treatments that improve coal quality. The most common of these beneficiation processes is "coal washing."

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[1] Adapted from James, C., & Gerhard, J. (2013, February). *International Best Practices Regarding Coal Quality.* Montpelier, VT: The Regulatory Assistance Project. Available at: www.raponline.org/document/download/id/6438

[2] The trend toward increased use of Powder River Basin coals, even in the Eastern United States, has led to newer boilers being designed to operate within broader ranges of fuel types and quality. Tangentially fired boilers can also accommodate a broader range of fuel types and quality. See, for example, the Alstom boiler specification sheet available at: http://www.alstom.com/Global/Power/Resources/Documents/Brochures/pulverised-coal-boiler-tower-type-boilers.pdf.

[3] The Virginia Center for Coal and Energy Research. (2009). *Meeting Projected Coal Production Demands in the USA: Upstream Issues, Challenges, and Strategies.* Prepared for the National Commission on Energy Policy. Chapter 4 (Coal Preparation). Available at: http://www.energy.vt.edu/ncepstudy/outline/Coal_Production_Demands_Chapter4.pdf.

Beneficiation results in a variety of improvements to power plant operations that directly affect the profitability of a coal plant, its emissions and ability to meet environmental requirements, and its ability to avoid future economic risks. In particular, coal washing can dramatically reduce the sulfur and ash content of coal, resulting in a significant reduction in air emissions, a reduction in auxiliary power demand, and a number of other co-benefits.

2. Regulatory Backdrop

Coal quality standards are typically implemented through state or local construction and operating permits and via language in procurement contracts.

There are several ways in which quality control requirements can be specified in a permit. For example, the source's operating permit may specify a maximum ash content and a maximum sulfur content for coal burned in a boiler. These conditions are typically enforced through sampling, recordkeeping, and reporting requirements.

Although air permit limitations are important for regulatory purposes, 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. Under standard New York Mercantile Exchange rules, there are a number of coal quality specifications; for example, the following are specifications for Central Appalachian Coal:

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**[4]: 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)
3. **Moisture**: Maximum 10.00%, with no analysis tolerance (A.S.T.M. D3302 or D5142)
4. **Volatile Matter**: Minimum 30.00%, with no analysis tolerance (A.S.T.M. D5142 or D3175)
5. **Grindability**: Minimum 41 Hardgrove Index (HGI) with three-point analysis tolerance below (A.S.T.M. D409)
6. **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)[5]" [*sic*]

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.[6]

3. State and Local Implementation Experiences

Coal specifications were utilized for the design of water tube boilers in the mid to late 1800s and were in place for some of the early steam electric stations that were in operation prior to 1900. More than a hundred years ago, the United States government adopted coal quality specifications for the coal it purchases.[7] In the years since, quality specifications have become an industry norm and essentially all purchasers of coal, including those who use it to generate electricity, have experience with such specifications.

Coal beneficiation has been a common practice for meeting coal quality specifications across the United States. However, coal beneficiation is most economical and beneficial today when applied to fuel that will be burned in a pulverized boiler. Less coal washing occurs in the United States today than in the 1980s and 1990s owing to:

- increased use of fluidized bed boilers;
- increased availability of coal from the Powder River Basin; Powder River Basin coal has a relatively low ash content of five to six percent, is also lower in sulfur than Appalachian coal, and is mined almost exclusively through longwall or opentop extraction,

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[4] A BTU is the amount of heat required to increase the temperature of a pint of water (which weighs exactly 16 ounces) by one degree Fahrenheit.

[5] CME Group. (2012). NYMEX Rulebook: Chapter 260 – *Central Appalachian Coal Futures.* Available at: http://www.cmegroup.com/rulebook/NYMEX/2/260.pdf.

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

[7] Pope, G. (1910). *Purchase of Coal by the Government under Specifications: with Analyses for Coal Delivered in the Fiscal Year 1908-09.* Government Printing Office. Available at: http://pubs.usgs.gov/bul/0428/report.pdf.

which optimizes the amount of coal that can be removed per unit of labor;

- increased coal prices – boilers (including pulverized coal boilers) were designed and/or modified with more flexibility to operate acceptably with the lower quality, less expensive coals; and
- utilization of new or improved emissions controls that allowed the use of lower quality/lower cost coals while still meeting air emissions requirements.

Thus, it is often possible for coal quality specifications to be met without requiring any coal beneficiation techniques.

Air pollution regulators in virtually all states will be familiar with the practice of limiting the sulfur and ash content of coal in power plant operating permits. This, too, has become an industry norm. But because they generally don't specify *how* sources will meet those limitations, air regulators in some cases may not be familiar with the costs or benefits of coal beneficiation.

4. Greenhouse Gas Emissions Reductions

Historically, the primary reasons for improving coal quality have been to increase the thermal efficiency of coal-fired power plants and to improve overall profit margins. Although air pollution concerns have not been the primary driver, a significant body of research indicates that beneficiation can result in substantial direct and indirect emissions reductions.

By improving thermal efficiency (heat rate), coal washing can directly reduce the carbon dioxide (CO_2) emissions rate of coal-fired boilers. Waymel and Hatt assessed the costs and benefits of improving coal quality for a hypothetical 500-megawatt (MW) coal plant, with a heat rate of 10,000 BTU per kilowatt hour (kWh), burning bituminous coal. Their results indicate that a heat rate improvement to 9890 BTU/kWh, that is, a one-percent increase in boiler efficiency, can be achieved through coal washing.[8] Each one-percent increase in boiler thermal efficiency can in turn decrease CO_2 emissions by two to three percent.[9] These results will vary depending on the specific fuel combusted; plants burning lower quality coals are likely to have more potential to improve thermal efficiency.[10] The Asian Development Bank (ADB) conducted an extensive survey of the Indian coal industry in the 1990s and found that for each 10-percent reduction in ash content, thermal efficiency can be improved by up to six percent, with an average of one to two percent; CO_2 emissions were found to decrease by 2.5 to 2.7 percent on average.[11] The ADB study included coals with high ash content, more representative of US lignite coals, and higher than the typical bituminous and sub-bituminous coals more commonly used in the United States.

In addition to boiler heat rate improvements, coal washing can also reduce auxiliary power demand (i.e., the electricity consumed onsite to power auxiliary equipment such as coal and ash handling equipment, fans, pollution control equipment, and the like). Reducing auxiliary power demand reduces the net emissions rate (pounds of emissions per net megawatt hour (MWh) delivered to the grid) of a power plant. The previously cited ADB survey noted a range of 8 to 12 percent of the gross power output at coal-fired power plants was used for plant auxiliary power requirements and found that auxiliary power demand declined by 10 percent on average with coal washing.[12]

Finally, as coal beneficiation can reduce the weight of raw coal by up to 25 percent, a net reduction in transportation energy demand of about 20 percent is

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[8] Waymel, E., & Hatt, R. (1987). *Improving Coal Quality: An Impact on Plant Performance.* Lexington, KY: Island Creek Corporation. (Estimated publication date based on references in the paper.) Available at: http://www.coalcombustion.com/PDF%20Files/Improving%20Coal%20Quality.pdf.

[9] Supra footnote 3.

[10] The U.S Environmental Protection Agency's (EPA) Technical Support Document (TSD) for 111(d): *GHG Abatement Measures,* describes several techniques to improve boiler efficiency. These techniques are also covered in Chapter 1 of this document (Optimize Plant Operations). The EPA's technical analysis does not quantify the CO_2 emissions impact of each specific technique for improving heat rates, as boiler types and fuels combusted in them vary. Rather, the IPM modeling conducted for the EPA and described in Section 2.6.4 of the EPA's TSD analyzed the combined influence from all heat rate improvement technologies on CO_2 emissions. Available at: http://www2.epa.gov/carbon-pollution-standards/clean-power-plan-proposed-rule-technical-documents.

[11] ADB. (1998). *India: Implementation of Clean Technology through Coal Beneficiation.* Project number 26095, prepared for the ADB by Montan-Consulting GMBH in association with International Economic and Energy Consultants and CMPDI International Consultants, India. Available at: http://www2.adb.org/documents/reports/Consultant/IND/26095/26095-ind-tacr.pdf.

[12] Ibid.

possible, requiring less fuel to transport the coal from a mine to a power plant, and yielding additional reductions in greenhouse gas (GHG) emissions.

5. Co-Benefits

Several qualitative and authoritative studies discuss factors that affect the performance of coal boilers, and the direction of the particular effect (i.e., increasing or decreasing). The Electric Power Research Institute (EPRI) and many utilities have developed proprietary models that can assess how a variable, or variables, will influence a particular plant.[13] These models require interested users to purchase them to determine specifics. However, agencies have conducted more general and broader studies that can be used to assess why coal quality matters, and what variables are the most important to consider. Evaluating the benefits of improving coal quality also required a search of the early literature, as later studies have been both narrower and more in-depth (looking at a particular variable like ash on a particular type of boiler, like a fluidized bed), and often refer back to the 1980s (and earlier) work as references.

The International Energy Agency (IEA) surveyed coal boiler operators in the early 1990s to assess what variables affect boiler performance and efficiency, and the direction of each variable (beneficial or harmful).[14] Sixty power plants in 12 countries were included in the survey. Based on the survey responses, the IEA concluded that coal quality factors account for up to 60 percent of forced outages at power plants. Applying mineral additives containing aluminum can reduce ash fouling and slagging in pulverized coal boilers by up to 78 percent.[15] 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 and 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. The greatest improvements in boiler efficiency and coal quality occurred when the base coal itself was of poor quality, such as lignite coals combusted in the United States and Eastern Europe, and high ash content coals combusted in China and India. In the United States, higher quality bituminous and sub-bituminous coals are more commonly used. And consistent with the Chapter 1 discussion on heat rate improvements, the actual benefits from improved coal quality will vary according to the power plant and its specific operating conditions.

Beneficiation also has benefits for the operation of emissions control devices. About 80 percent 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 devices. 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.

Studies of US coals show that washing reduces sulfur content by 10 to 20 percent (on a lb/MMBTU[16] basis). Ash reductions of 30 to 50 percent were reported for Mexican coals, with a 20- to 30-percent reduction in sulfur content. A National Academy of Sciences study reports sulfur reductions for China's coals of up to 20 percent.[17] A minimum ten-percent reduction in sulfur dioxide (SO_2) is considered to be a conservative assumption of the emissions-savings potential from coal washing. This minimum ten-percent reduction in SO_2 for a 600-MW plant, operating at an 80-percent capacity factor (or 7000 hours per year), would result in a minimum SO_2 annual reduction of 1682 metric tons.

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[13] Examples include EPRI's Coal Quality Impact Model, EBASCO performance models, heat rate models, or least-cost fuel models.

[14] Skorupska, N. (1992). Coal Specifications - *Impact on Plant Performance: An International Perspective.* Presented at Effects of Coal Quality on Power Plants, Third International Conference, EPRI.

[15] Vutharulu, H. (1999). Remediation of Ash Problems in Pulverized Coal-fired Boilers. *Fuel.* 78 (15), 1789–1803.

[16] MBTU stands for one million BTUs, which can also be expressed as one decatherm (10 therms). MBTU is occasionally expressed as MMBTU, which is intended to represent a thousand thousand BTUs.

[17] National Research Council. (2004). *Urbanization, Energy and Air Pollution in China: The Challenges Ahead - Proceedings of a Symposium.* Washington, D.C.: National Academies Press.

As noted above, the Waymel and Hatt study assessed the co-benefits of improving coal quality for a hypothetical 500-MW coal plant, with a heat rate of 10,000 BTU per kWh, burning bituminous coal. In addition to the heat rate improvements noted above, they noted a 45-percent decrease in ash and more than a 50-percent decrease in sulfur. The sulfur emissions rate was estimated to decrease from 4.2 lb/MMBTU to 1.9 lb/MMBTU.[18]

The ADB survey cited above mentions several other environmental co-benefits of coal washing. To begin with, the efficiency of electrostatic precipitators improves from 98 to 99 percent.[19] Land requirements for ash disposal are also reduced. For a 1000-MW coal plant, assuming a plant life of 20 years, the amount of land required for ash disposal is reduced from 400 hectares to 229 hectares. Finally, the amount of water required to move ash from the plant to a land disposal site is reduced by 30 percent. For a typical 1000-MW plant, this translates to 11.99 million m^3 per year consumption, compared to 17.05 million m^3 per year for a plant using unbeneficiated coal.

It is also worth repeating that as coal beneficiation can reduce the weight of raw coal by up to 25 percent, less energy is needed for transportation of the fuel, and additional reductions in fine particulates, nitrogen oxides, and other pollutants can result.[20] In a 2003 study of Chinese coals, Glomrod and Taoyuan calculated that coal cleaning removes 25 percent of the coal weight, resulting in a 20-percent net reduction in transportation demand for each unit of thermal energy.[21]

The full range of co-benefits that can be realized through coal beneficiation are summarized in Table 4-1.

Table 4-1

Types of Co-Benefits Potentially Associated With Coal Beneficiation

Type of Co-Benefit	Provided by This Policy or Technology?
Benefits to Society	
Non-GHG Air Quality Impacts	Yes
NO_x[22]	Yes
SO_2	Yes
PM[23]	Yes
Mercury	Yes
Other	Yes
Water Quantity and Quality Impacts	Yes[24]
Coal Ash Ponds and Coal Combustion Residuals	Yes
Employment Impacts	No
Economic Development	No
Other Economic Considerations	No
Societal Risk and Energy Security	No
Reduction of Effects of Termination of Service	No
Avoidance of Uncollectible Bills for Utilities	No
Benefits to the Utility System	
Avoided Production Capacity Costs	Maybe
Avoided Production Energy Costs	Yes
Avoided Costs of Existing Environmental Regulations	Yes
Avoided Costs of Future Environmental Regulations	Yes
Avoided Transmission Capacity Costs	No
Avoided Distribution Capacity Costs	No
Avoided Line Losses	No
Avoided Reserves	No
Avoided Risk	Yes
Increased Reliability	Yes
Displacement of Renewable Resource Obligation	No
Reduced Credit and Collection Costs	No
Demand-Response-Induced Price Effect	Maybe
Other	

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[18] Waymel & Hatt, supra footnote 8.

[19] In effect, this is a 50-percent improvement in the particulate collection efficiency. A 98-percent efficiency means that, for each 100 tons of particulate mass in the flue gas, two tons would not be captured and would be emitted to the atmosphere. A 99-percent efficiency means that for each 100 tons of particulate mass in the flue gas, one ton would not be captured.

[20] Supra footnote 11. Data on transport savings were calculated for India at Table 4-2 on page 69 of this document.

[21] Glomrod, S., & Taoyuan, W. (2003). *Coal Cleaning: A Viable Strategy for Reduced Carbon Emissions and Improved Environment in China?* Norway and China. Available at: http://www.ssb.no/a/publikasjoner/pdf/DP/dp356.pdf.

[22] Nitrogen oxides.

[23] Particulate matter.

[24] Depending on the coal beneficiation techniques used, water consumption can be a potential concern. Improved thermal efficiency reduces water consumption per MWh of generating output, which must be weighed against any water impacts of the techniques that are used to improve coal quality.

6. Costs and Cost-Effectiveness

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 to 30 years or more. Improving coal quality preserves the value of this long-term investment.[25] However, 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. Actual costs and cost-effectiveness of improved coal quality will vary according to the power plant and its specific operating conditions.

As noted above, the Waymel and Hatt study assessed the costs and benefits of improving coal quality for a hypothetical 500-MW coal plant, with a heat rate of 10,000 BTU per kWh, burning bituminous coal. In addition to the results noted above, they reported that delivered coal costs would increase from $41.50 per ton (for coal with a heating value of 11,900 BTU/lb) to $46.50 per ton for the washed coal (with a heating value of 13,300 BTU/lb), leading to an increase in annual fuel costs of $200,000. However, the plant operator would realize a net annual savings of $710,000 per year, attributable to $450,000 in savings from increased boiler efficiency, $230,000 in savings from reduced ash disposal, and $230,000 from improved coal handling. On a net output basis, fuel costs were forecast to decline slightly, from 17.44 mil/kilowatt (kW) to 17.25 mil/kW.[26] Savings were also expected (but not quantified) from extended boiler and equipment life.

The ADB survey, also cited above, found that by reducing ash content from 41 percent to 34 percent, operation and maintenance costs declined by 20 percent and overall capital investment in the power plant could be reduced 5 percent.[27]

The IEA also published detailed results in conjunction with the above-mentioned survey.[28] Changes in coal quality were evaluated in general, and several case-specific examples were provided. The general trends in coal quality were evaluated for a 1000-MW plant, with a 65-percent capacity factor, a 10,000 BTU/kWh heat rate, a coal heating value of 12,000 BTU/lb, an ash content of 10 percent, and a fuel cost of $35/ton. Changing the quality of the coal burned by increasing the ash content 10 percent, increasing moisture content by 5 percent, and decreasing heating value by 15 percent resulted in a higher heat rate, and a negative cost impact of $4.46 million/year (1986$).

Results of other case studies also reflect significant cost effects from poor quality coal. The Tennessee Valley Authority (TVA) improved coal quality at its Cumberland power plant (two units, each at 1300 MW) over the period from 1977 to 1986. TVA found that its operating and maintenance costs decreased on average by $15 million per year. The largest change in coal quality was decreasing the ash content from 15.2 percent to 9.2 percent.[29] Sulfur content also decreased from 3.5 percent to 2.8 percent, and heating value increased from 10,712 BTU/lb (24.9 MJ/kg) to 11,635 BTU/lb (27.1 MJ/kg).

The Southern Company, which operates several coal-fired plants in the Southeastern United States, also analyzed its operating and maintenance costs. Southern found that increasing the ash content from 15 percent to 20 percent increased waste disposal costs, maintenance costs, and

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[25] 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 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 on 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.

[26] Waymel & Hatt, supra footnote 8.

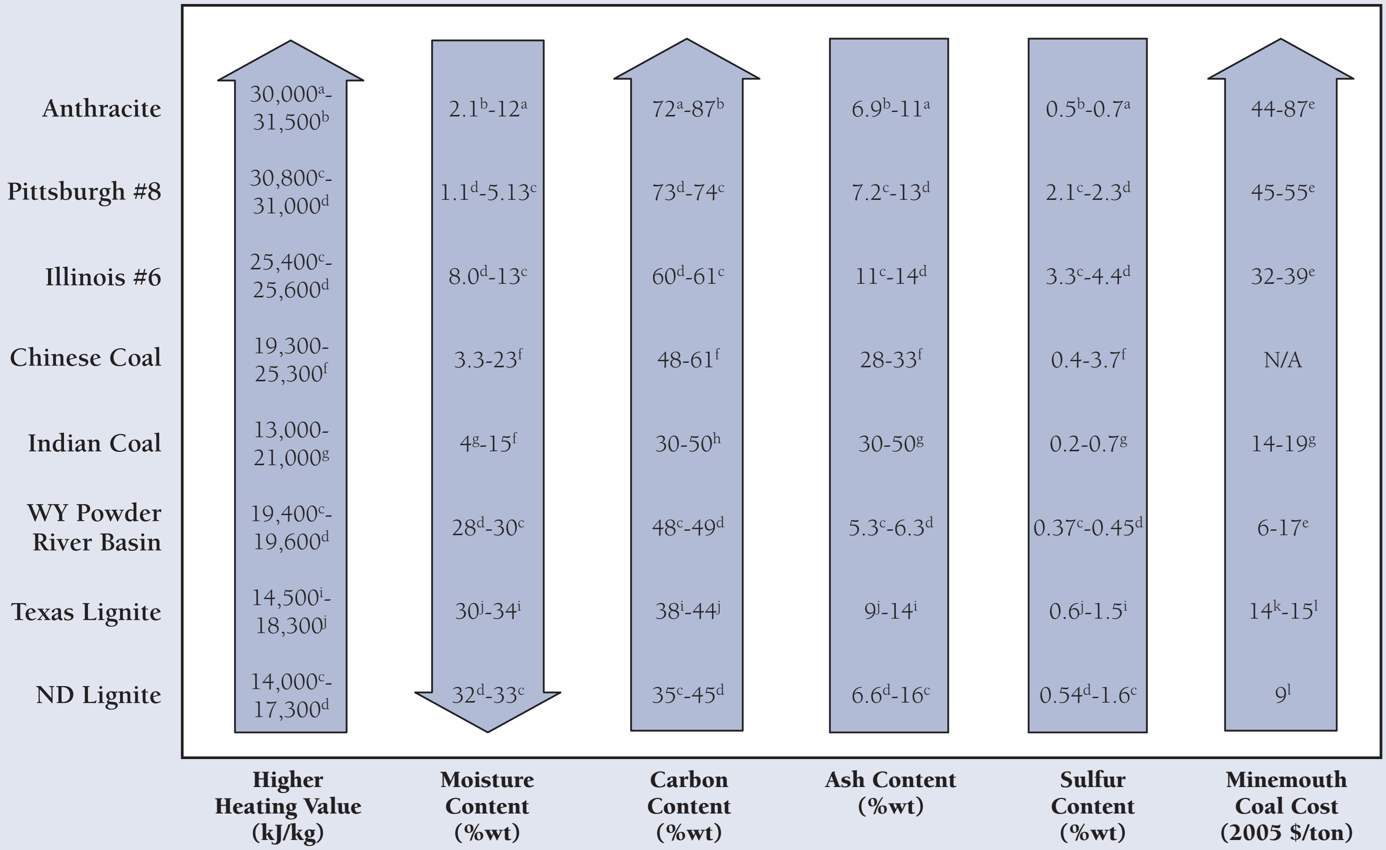
[27] Supra footnote 11.

[28] Skorupska, N. (1993). *Coal Specifications - Impact on Power Station Performance.* London: IEA. IEACR/52.

[29] Ibid, page 75.

Figure 4-1

Coal Characteristics by Coal Type



	Higher Heating Value (kJ/kg)	Moisture Content (%wt)	Carbon Content (%wt)	Ash Content (%wt)	Sulfur Content (%wt)	Minemouth Coal Cost (2005 $/ton)
Anthracite	30,000[a]-31,500[b]	2.1[b]-12[a]	72[a]-87[b]	6.9[b]-11[a]	0.5[b]-0.7[a]	44-87[e]
Pittsburgh #8	30,800[c]-31,000[d]	1.1[d]-5.13[c]	73[d]-74[c]	7.2[c]-13[d]	2.1[c]-2.3[d]	45-55[e]
Illinois #6	25,400[c]-25,600[d]	8.0[d]-13[c]	60[d]-61[c]	11[c]-14[d]	3.3[c]-4.4[d]	32-39[e]
Chinese Coal	19,300-25,300[f]	3.3-23[f]	48-61[f]	28-33[f]	0.4-3.7[f]	N/A
Indian Coal	13,000-21,000[g]	4[g]-15[f]	30-50[h]	30-50[g]	0.2-0.7[g]	14-19[g]
WY Powder River Basin	19,400[c]-19,600[d]	28[d]-30[c]	48[c]-49[d]	5.3[c]-6.3[d]	0.37[c]-0.45[d]	6-17[e]
Texas Lignite	14,500[i]-18,300[j]	30[j]-34[i]	38[i]-44[j]	9[j]-14[i]	0.6[j]-1.5[i]	14[k]-15[l]
ND Lignite	14,000[c]-17,300[d]	32[d]-33[c]	35[c]-45[d]	6.6[d]-16[c]	0.54[d]-1.6[c]	9[l]

a Eberle, J.S., Garcia-Mallol, A.J., Simmerman, AM, "Advanced FW Arch Firing: NOXReduction in Central Power Station," WPS Power Development, Inc. & Foster Wheeler Power Group, Inc., Presented at Pittsburgh Coal Conference, Pittsburgh, PA, Sept. 2002.

b Edward Aul & Associates, lnc., & E.H. Pechan & Associates, Inc., "Emission Factor Documentation for AP-42 Section 1.2 Anthracite Coal Combustion," US EPA, Research Triangle Park, NC, 1993.

c Integrated Environmental Control Model, Carbon Sequestration Edition, IECM-cs 5.02, Carnegie-Mellon University, 2005.

d US Department of Energy, OFE/NETL "Carbon Capture and Sequestration Systems Analysis Guidelines," Washington, D.C, April 2005.

e US Department of Energy, Energy Information Administration, "Coal News and Markets," webpage, downloaded 11/30/05 from http://www.eia.doe.gov/cneaf/coal/page/coalnews/coalmar.html

f Oskarsson, Karin, et al., "A planner's guide for selecting clean-coal technologies for power plants," Washington, DC: The World Bank, 1997.

g International Energy Agency, "Coal in Energy Supply of India," OECD/IEA, Paris, France, 2002.

h Ohio Supercomputer Center, "Anthropogenic Emissions from Energy Activities in India: Generation and Source Characterization" website, downloaded 11/30/05 from http://www.osc.edu/research/pcrm/emissions/coal.shtml.

i San Filipo, John R., "US Geological Survey Open-File Report 99-301," US Geological Survey, Reston, VA, 1999.

j Gray, D., et al., "Polygeneration of SNG, Hydrogen, Power, and Carbon Dioxide from Texas Lignite," NETL, Falls Church, VA, 2004.

k US Department of Energy, Energy Information Administration, "Coal Industry Annual, 2000," Washington, D.C. 2000.

l US Department of Energy, Energy Information Administration, "Average Open Market Sales Price of Coal by State and Coal Rank," 2004, webpage, downloaded 11/30/05 from http://www.eia.doe.gov/cneaf/coal/page/acr/table31.html.

forced outages due to ash.[30]

A review of publicly available information on coal washing often finds an emphasis on the benefits to coal *producers* from washed coal (i.e., they can fetch a higher price for their product). Coal with lower sulfur and ash content is indeed more expensive than coal with higher sulfur and ash content.[31] The Massachusetts Institute of Technology study, "The Future of Coal," includes Figure 4-1, which illustrates the influence of these and other variables on the price of coal.[32]

Table 4-2 below is an example of the coal commodity spot price data available from the EIA. This table illustrates the price differences based on both heating value and sulfur content. Low-sulfur Central Appalachian coal represents the highest price, whereas low-BTU Powder River Basin coal is lowest.

The EIA also summarizes the prices fetched by various coal ranks. Table 4-3 on the following page presents data for 2012. Regardless of the mine location, bituminous coals sold for much higher prices than sub-bituminous coals and lignite. Anthracite is mined in Pennsylvania; its high heating value makes it attractive as a coking or metallurgical coal.

7. Other Considerations

As is the case for many other pollution control options, beneficiation has the potential to increase the utilization of a given power plant. The ADB survey found that for each 10-percent reduction in ash content, the plant use factor (or capacity factor) can increase up to six percent as forced outages and maintenance issues related to tube leaks, the economizer, and associated components are reduced. Thus, the potential exists for the gross annual emissions of a given power plant to increase as a result of beneficiation, despite decreases in the emissions *rates*. Any increases in plant

Table 4-2

Average Weekly Coal Commodity Spot Prices (Per Short Ton)[33]

Week Ended	Central Appalachia 12,500 Btu, 1.2 SO_2	Northern Appalachia 13,000 Btu, <3.0 SO_2	Illinois Basin 11,800 Btu, 5.0 SO_2	Powder River Basin 8,800 Btu, 0.8 SO_2	Uinta Basin 11,700 Btu, 0.8 SO_2
18 January 2013	$68.05	$62.10	$47.90	$10.15	$35.85
25 January 2013	$68.05	$62.10	$47.90	$10.15	$35.85
01 February 2013	$66.50	$62.10	$47.90	$10.15	$35.85
08 February 2013	$66.50	$62.10	$47.90	$10.15	$35.85
15 February 2013	$66.50	$62.10	$47.90	$10.25	$35.85

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[30] Supra footnote 29 at page 75.

[31] Coal is priced both on a dollars per ton and a dollars per MMBtu basis. The price itself is based on several factors, including its rank, how it is mined, and its quality. Coal mined through subsurface means is more expensive than coal mined at the surface (e.g., mountain top removal).

[32] Massachusetts Institute of Technology. (2007). *The Future of Coal - Options for a Carbon Constrained World.* Available at: http://web.mit.edu/coal/.

[33] The historical data file of spot prices is proprietary and cannot be released by EIA. This sample table is printed with permission from SNL Energy (http://www.snl.com/Sectors/Energy/Default.aspx). Note: Coal prices shown are for a relatively high-Btu coal selected in each region, for delivery in the "prompt quarter." The prompt quarter is the quarter following the current quarter. For example, from January through March, the second quarter is the prompt quarter. Starting on April 1, July through September define the prompt quarter.

Table 4-3

Average Sales Price of Coal by State and Coal Rank, 2012 (Dollars Per Short Ton)[34]

Coal-Producing State	Bituminous	Sub-bituminous	Lignite	Anthracite	Total
Alabama	106.57	-	-	-	106.57
Alaska	-	w	-	-	w
Arizona	w	-	-	-	w
Arkansas	w	-	-	-	w
Colorado	w	w	-	-	37.54
Illinois	53.08	-	-	-	53.08
Indiana	52.01	-	-	-	52.01
Kentucky Total	**63.12**	**-**	**-**	**-**	**63.12**
Kentucky (East)	75.62	-	-	-	75.62
Kentucky (West)	48.67	-	-	-	48.67
Louisiana	-	-	w	-	w
Maryland	55.67	-	-	-	55.67
Mississippi	-	-	w	-	w
Missouri	w	-	-	-	w
Montana	w	17.6	w	-	18.11
New Mexico	w	w	-	-	36.74
North Dakota	-	-	17.4	-	17.4
Ohio	47.8	-	-	-	47.8
Oklahoma	59.63	-	-	-	59.63
Pennsylvania Total	**72.57**	**-**	**-**	**80.21**	**72.92**
Pennsylvania (Anthracite)	-	-	-	80.21	80.21
Pennsylvania (Bituminous)	72.57	-	-	-	72.57
Tennessee	73.51	-	-	-	73.51
Texas	-	-	19.09	-	19.09
Utah	34.92	-	-	-	34.92
Virginia	109.4	-	-	-	109.4
West Virginia Total	**81.8**	**-**	**-**	**-**	**81.8**
West Virginia (Northern)	63.34	-	-	-	63.34
West Virginia (Southern)	91.4	-	-	-	91.4
Wyoming	-	14.24	-	-	14.24
US **Total**	**66.04**	**15.34**	**19.6**	**80.21**	**39.95**

- = No data reported.

w = Data withheld to avoid disclosure.

Note: An average sales price is calculated by dividing the total free onboard rail/barge value of the coal sold by the total coal sold. Excludes mines producing less than 25,000 short tons, which are not required to provide data. Excludes silt, culm, refuse bank, slurry dam, and dredge operations. Totals may not equal sum of components because of independent rounding.

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[34] US EIA. (2013). Annual Coal Report 2012. Available at: http://www.eia.gov/coal/annual/pdf/acr.pdf.

use factor could of course allow for decreased generation and emissions from some other power plant. These factors will need to be evaluated in the context of the EPA's Clean Power Plan proposal, where heat rate improvements are the cornerstone of Building Block 1.

Using scarce water resources to improve coal quality may not be justified in some geographic 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 for contamination of local waterways and ground water if the containment ponds leak. This is a serious environmental consideration and requires careful oversight by regulators.

8. For More Information

Interested readers may wish to consult the following reference documents for more information on coal beneficiation:

- ADB. (1998). *India: Implementation of Clean Technology through Coal Beneficiation.* Project number 26095, prepared for the ADB by Montan-Consulting GMBH in association with International Economic and Energy Consultants and CMPDI International Consultants, India. Available at: http://www2.adb.org/documents/reports/Consultant/IND/26095/26095-ind-tacr.pdf.
- Pacyna, J.,Sundseth, K., Pacyna, E. G., Jozewicz, W., Munthe, J., Belhaj, M. & Aström, S. (2010). An Assessment of Costs and Benefits Associated with Mercury Emission Reductions from Major Anthropogenic Sources. *Journal of the Air & Waste Management Association.* 60:3, 302-315, doi: 10.3155/1047-3289.60.3.302. Available at: http://dx.doi.org/10.3155/1047-3289.60.3.302.
- Rubin, E., Chen, C., & Rao, A. B. (2007). Cost and Performance of Fossil Fuel Power Plants with CO_2 Capture and Storage. *Energy Policy.* 35, 4444–4454. Available at: http://www.cmu.edu/epp/iecm/rubin/PDF%20files/2007/2007b%20Rubin%20et%20al,%20Energy%20Policy%20%28Mar%29.pdf
- Skorupska, N. (1993). *Coal Specifications - Impact on Power Station Performance.* London: IEA. IEACR/52.
- Waymel, E., & Hatt, R. (1987). *Improving Coal Quality: An Impact on Plant Performance.* Lexington, KY: Island Creek Corporation. (Estimated publication date based on references in the paper.) Available at: http://www.coalcombustion.com/PDF%20Files/Improving%20Coal%20Quality.pdf.

9. Summary

Coal beneficiation has the potential to provide economic, energy, and environmental benefits for some units depending on unit-specific design. Even small reductions in coal consumption on the order of one to two percent, for the same generating output, improve the profit margin of the power plant, extend the life of pollution controls, reduce the quantity of water and solid waste discharged, and reduce GHG, criteria pollutant, and mercury emissions. Water constraints in certain regions will favor dry beneficiation processes over wet.