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Project Summary

Assessment of Physical Coal Cleaning Practices for Sulfur Removal

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This report gives results of a study of the current level of coal cleaning activity in the U.S. in 1983, the U.S. Department of Energy's (DOE's) Energy Information Administration (EIA) expanded coal data collection activities to include information on the extent and type of coal preparation conducted in each coal-producing region. The additional information included data on raw coal input to coal cleaning plants, clean coal output, quality characteristics of the prepared coal, and end-use markets of both raw and prepared coal. These data, combined with other EIA data, provide information on the extent and type of coal cleaning activity in each major coal-producing state or region. The impact on coal preparation of differences in mining methods and requirements of the various end-use markets also is discussed. Estimates were developed of SO_2 emission reduction by current mechanical cleaning plants based on clean coal quality characteristics reported to EIA and bed/county raw coal quality estimated from the EIA/U.S. Bureau of Mines (USBM) analytical file. Estimates also were developed of the potential for improving current SO_2 reduction. The current level of SO_2 reduction by mechanical cleaning is estimated at about 5 million metric tons per year. An estimated 2 to 3 million metric tons of additional emission reduction could be achieved through additional coal cleaning activity, at an average cost of about \$150 to \$200 per ton of SO_2.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Overview

Coal preparation removes ash, sulfur, moisture, and other impurities from raw coal. Coal preparation processes vary among regions because mining methods, geological conditions, and end-use market requirements differ by geographic area. In this study, the extent to which coal producers in different regions of the U.S. currently clean their coal was estimated and the potential SO_2 reduction that can be achieved through increased cleaning was determined. Estimates of the potential for increasing SO_2 reduction were derived on the basis of a consideration of commercially-proven, conventional cleaning technology (i.e., physical coal cleaning) only; chemical coal cleaning is not considered in this study.

Coal Preparation Techniques

All coal, including the final product shipped to end-use markets, contains impurities. Some impurities are introduced from the area around the coal seam during extraction; others are within the seam itself. The raw coal's physical characteristics, and the intensity of the preparation it undergoes, determine the quality of the final product. The two basic cleaning procedures used in preparation plants are crushing and screening, and mechanical cleaning ("washing").

The simplest cleaning procedure is crushing and screening. In crushing and screening, the raw coal is pulverized into fragments small enough to pass through a screen, separating the coal from the harder non-coal rock particles that are more difficult to crush. Crushing and screening, however, tends not to remove the smaller foreign particles or impurities within the coal seam. Smaller particles and internal impurities respond only to mechanical cleaning, a more expensive and involved process that begins with crushing and screening and ends with separation and dewatering. Separation uses the specific gravity differences between coal and other particles to filter out impurities. However, coal is filtered out along with the impurities during mechanical cleaning. As the amount of refuse material removed approaches 100% the amount of coal lost increases and mechanical cleaning becomes economically unattractive beyond a certain level of purity. Thus, the decision to mechanically clean (as opposed to simply crushing and screening) involves an economic trade-off between the quality and the quantity of the end product.

Typically, preparation plants are classified according to four preparation levels (the same scheme used throughout this report): level 1 consists of crushing and screening only; level 2 uses a single mechanical cleaning circuit); level 3 consist of two separate mechanical cleaning circuits, one for coarse and one for mid-sized coal the fine coal may or may not be passed through the mid-sized circuit); and level 4 consist of three (sometimes four) mechanical cleaning circuits -- one for coarse, one for mid-sized, and one for fine coal.

Data Sources

The results of this study for current coal preparation activities are based primarily on analysis of data derived from two (EIA) survey forms: the 1983 EIA-7A and the 1983 EIA-7A (Supplement) "Coal Production Report." The EIA-7A forms are sent annually to mines that produce, process, or prepare 9,070 or more metric tons (10,000 or more short tons) of coal per year. The EIA-7A form requests data on the:

- Type of mining operation (underground, surface, preparation plant, etc.).
- Production by coal bed and coal rank. Breakdown of production by market type (captive, openstocks, etc.) and the value free-on-board (FOB) mine.
- Respective percentages of prepared coal (for mines that include preparation plants) from surface and from underground mines.

The EIA-7A Supplement is a biennial survey of coal mines that produce, process, and prepare 90,700 or more metric tons (100,000 or more short tons) per year. The EIA-7A Supplement form requests data on:

- Tonnage shipped without preparation.
- Tonnage crushed and screened only.
- Tonnage mechanically cleaned
- Tonnage shipped to each end-use market (electric utilities, coke plants, exports, etc.).

Information from each form is combined to produce the EIA-7A coal data base, a computer file maintained and updated annually by EIA.

Coal data also are available from the Federal Energy Regulatory Commission (FERC) Form 423 computer file (maintained by EIA), "Cost and Quality of Fuels for Electric Utility Plants." The file includes information on the quality of coal delivered to electric powerplants and, for most plants, the name(s) and location(s) of the mine(s) from which they purchased the coal. The U.S. Bureau of Mines/EIA analytical computer file (also maintained by EIA) supplements the EIA-7A and FERC-423 forms by providing information on raw coal quality by seam and county for each producing state.

The conclusions drawn in this report concerning the potential SO_2 reduction from additional preparation of both the cleaned and uncleaned portions of current production are based on an extensive analysis of currently available data on coal washability and demonstrated coal reserves. The coal washability data were obtained from the U.S. DOE's washability data base* and several U.S. Bureau of Mines Reports of Investigation. These data were combined into a single data base representing the major producing coal seams in the U.S.

The 1971 U.S. Demonstrated Coal Reserve Base (DRB) (maintained as a computer file by EIA) was the principal source of information on coal reserves at the bed/county level. This data base is the only source of coal reserve data disaggregated by coal seam (bed) and location (county). However, because substantial changes in quantities have been assigned to the DRB since 1971, it was necessary to adjust the 1971 figures to reflect the most recent updates. The updating was accomplished using the 1983 DRB (containing reserves only at the state level) together with the more disaggregated data base to derive the best possible estimates of reserves by bed and county.

After the demonstrated coal reserves were distributed by bed and county, the reserves were disaggregated further by quality within each bed/county combination, using a coal quality data base assembled from the USBM/EIA analytical file and other sources. Overall, more than 33,000 coal quality samples were obtained and merged into the new reserve data base. The result was a set of data that identified both coal quantity and quality at the lowest possible level of aggregation.

The study divides the U. S. into five coal-producing regions: Central Appalachia, Southern Appalachia, Northern Appalachia, the Midwest, and the West. The division was made to capture existing differences in mining methods, geologic conditions, in-seam coal quality, and end-use markets -- factors that affect the type and degree of coal-cleaning activities.

Regional Analysis

In 1983, over 50% of U.S. raw coal production was cleaned. Of underground coal production, 70% was mechanically cleaned, and 23% of surface coal production was mechanically cleaned.

The percentage of underground-mined coal mechanically cleaned is high because virtually all production of metallurgical-grade coal comes from underground mines. Also, more use of highly mechanized mining techniques, such as continuous and longwall mining, has reduced the average particle size of the run-of-mine product, thereby making the output less responsive to crushing and screening alone. Lastly, increased emphasis on quality on the part of end-users has had a direct impact on the amount of coal being mechanically cleaned.

* This data base was originally developed by the USBM but is now maintained and updated by the U.S. DOE's Pittsburgh Energy Technology Center. The data base is available on computer tape.

Central Appalachia

The Central Appalachia region consists of eastern Kentucky, Tennessee, Virginia, and West Virginia. In 1983, Central Appalachian mining operators mechanically cleaned 73% of their production and crushed and screened an additional 20%. As for the Nation as a whole, the use of mechanical cleaning in Central Appalachia is highly correlated with mining method. For the region as a whole, over 96 percent of the more than 100 million metric tons (110 million short tons) of raw coal output from underground mines was at least crushed and screened before being sold. However, 21% of surface production, 7.6 million metric tons (8.4 million short tons), was sold without any form of preparation. Virtually all of the "no-preparation" coal was sold to electric utilities.

Nonetheless, mechanical cleaning is important in Central Appalachia; the region contains 158 mechanical cleaning plants, more than half the U.S. total. During the period of study (1983), Central Appalachia sold most of its output to domestic electric utility companies. The second leading customer was the export market, both in terms of metallurgical- and steam-grade products.

Some 88 of Central Appalachia's mechanical cleaning plants are in West Virginia; more of that state's output is mechanically cleaned than that of any other Central Appalachian state except Tennessee (by volume a relatively minor coal producer) (Table 1). This reflects West Virginia's importance as a source of metallurgical coal for both foreign and domestic use.

Data for 1983 show that plants in Central Appalachia prepared 146.6 million metric tons (161.2 million short tons) of their 200.9 million metric tons (221.5 million short tons) of coal. The region's mechanical cleaning plants showed an overall clean-coal yield (salable product as a percentage of input to preparation plants) of 64 %. The clean coal yield for individual Central Appalachian states are: eastern Kentucky, 62%; Tennessee, 57 %; Virginia, 59%; and West Virginia, 65 %.

Southern Appalachia

The Southern Appalachia region consists of Alabama and Georgia; however, since Georgia is not a major coal producer, data are available only for Alabama. The state's coal, 79% of which was mechanically cleaned, is relatively low in sulfur. Alabama contains about 30 mechanical cleaning plants that have stepped up coal preparation considerably in recent years. Of the 20.8 million metric tons (22.9 million short tons) of raw input to preparation plants, the final salable yield was 65 percent, or 13.6 million metric tons (15 million short tons). Like those in Central Appalachia, Alabama plants sold most of their coal to the domestic utility industry, and mechanically cleaned most of that coal.

Northern Appalachia

The Northern Appalachia region consists of Pennsylvania, Ohio, and Maryland. The plants in the region mechanically cleaned 70% of the region's coal and crushed and screened 22% (Table 2). In 1983, the region contained over 85 mechanical cleaning plants, about 20% of the U.S. total. As the largest coal producer in the region and the only state with any significant metallurgical coal reserves, Pennsylvania contains most of these plants.

Plants in Ohio, however, have dramatically increased mechanical cleaning in recent years (from 47% in 1978 to 82% of total production in 1983) so that Ohio coal, relatively high in impurities, can compete in today's quality-conscious market. Although more Ohio coal is washed now, a third of Ohio's mechanical cleaning plants are single-circuit; that is, coal fed into the plants undergoes the lowest level of mechanical preparation.

(The highest number of cleaning circuits in mechanical cleaning plants currently in operation is four).

Clean-coal yields in Northern Appalachia exceed considerably those in Central Appalachia. The difference in yields for the two regions partly reflects the fact that Northern Appalachia coal seams tend to be thicker (1.63 versus 1.37 m based on 1983 EIA-7A data), thus reducing the amount of dilution material added to the coal during the mining process. Also, much of the coal cleaning in Central Appalachia is for metallurgical purposes, and thus entails a generally more intensive process than the preparation of steam coal. Preparation reduced the region's total output from 103 to 82.9 million metric tons (113.5 to 91.4 million short tons), a loss of about 20%. Yields from mechanical cleaning were 76, 70, and 71% for Maryland, Ohio, and Pennsylvania, respectively.

The Midwest

Illinois, Indiana, and western Kentucky constitute the Midwest region. Some 95 percent of the region's coal was either mechanically cleaned or crushed and screened (Table 3). Illinois producers mechanically clean about 93% of their raw coal output, and Indiana, whose coal is almost all surface-mined, mechanically cleans over 70% of its coal. Preparation reduced the region's 133 million metric tons (146.6 million short tons) of raw coal to 104 million metric tons (114.6 million raw tons). The Midwest's overall mechanical cleaning yield was 74%, significantly higher than yields for the coal-producing areas of Appalachia (64%, 65% and 70% for Central, Southern, and Northern Appalachia, respectively). Much of this difference can be attributed to the fact that very little metallurgical coal is mined and prepared in the Midwest. Yield figures for Midwestern preparation plants, therefore, do not reflect the cleaning losses associated with the intense preparation of this product type.

As indicated above, most of the production from this region is sold as a steam product to electric utilities. In Illinois and Indiana, 86% of the total salable output was sent to the utility market. In western Kentucky, 92% of production went to electric utilities. Of this production, 91%, 72%, and 65% was mechanically cleaned for Illinois, Indiana, and western Kentucky, respectively. These percentages reflect differences in in-place reserve quality as well as mining conditions and methods within each state.

The West

Coal washing in the Western coal-producing states, except for the interior states,* is not very extensive. The coal mined in this region is primarily a sub-bituminous product, none of which is mechanically cleaned. Bituminous coal, for use by electric utilities, is mined in Colorado, Utah, and, to a much lesser extent, New Mexico. Utility coal mined in these states is inherently high Btu, low-sulfur, and low-ash and does not require extensive cleaning. Only 6% of the utility coal mined in Colorado in 1983 was mechanically cleaned. In Utah, the figure was about 13% of utility coal production, and in New Mexico, less than l% of the bituminous steam coal was cleaned. In contrast, Missouri produces bituminous coal exclusively, and the utility coal mined in the state is high in sulfur. Approximately 51% of Missouri's utility coal production was cleaned in 1983. Although very little coal produced in the West is mechanically cleaned, over 80%

*The interior states are Arkansas, Iowa, Kansas, Missouri, and Oklahoma.

Table 1. *Central Appalachian Coal Preparation (1983)*[a]

Area	Quantity Produced (million raw metric tons)	Percentage Mechanically Cleaned	Percentage Crushed and Screened	Percentage Not Prepared
Eastern Kentucky	50.7	57	27	16
Tennessee	4.2	80	20	0
Virginia	25.0	77	16	7
West Virginia	121.0	79	19	2
Total	200.9	74	20	6

[a]All values include only mines producing more than 90,700 metric (100,000 short) tons of coal per year and reporting on Form EIA-7A Supplement.

Table 2. *Northern Appalachian Coal Preparation (1983)*[a]

Area	Quantity Produced (million raw metric tons)	Percentage Mechanically Cleaned	Percentage Crushed and Screened	Percentage Not Prepared
Maryland	5.39	58	26	16
Ohio	33.39	82	14	4
Pennsylvania	64.35	65	25	10
Total	103.13	70	22	8

[a]All values include only mines producing more than 90,7000 metric (100,000 short) tons of coal per year and reporting on Form EIA-7A Supplement.

Table 3. *Midwestern Coal Preparation (1983)*[a]

Area	Quantity Produced (million raw metric tons)	Percentage Mechanically Cleaned	Percentage Crushed and Screened	Percentage Not Prepared
Illinois	63.0	93	6	1
Indiana	33.7	78	17	5
Western Kentucky	36.5	72	18	10
Total	133.2	83	12	5

[a]All values include only mines producing more than 90,700 metric (100,000 short) tons of coal per year and reporting on Form EIA-7A Supplement.

of all production (both bituminous and sub-bituminous) is crushed and screened.

Current SO_2 Reduction

The method used to determine current SO_2 reduction levels was structured to take advantage of the 1983 EIA-7A Supplement data. In addition to providing information on the quantity of coal mechanically cleaned, this data base also includes quality information on coal shipped to each end-use sector. By obtaining raw sulfur inputs on a bed/county basis from the EIA/USBM analytical file, estimates of SO_2 reduction obtained through mechanical cleaning could be derived.

The use of the average bed/county SO_2 content as a proxy for the actual SO_2 content of the raw feed* to the plant is the primary cause of uncertainty in the estimation procedure. The data used represent information on coal in place and coal being mined at the time the samples are taken. This could result in an estimate at the bed/county level substantially different from the coal currently mined. Consequently, any inferences drawn from the analysis must be viewed against the potential uncertainty caused by inherent limitations of the raw data.

The problem of uncertainty is addressed separately from the analysis. A method was developed whereby estimates of uncertainty at different levels in the analysis could be combined meaningfully to develop an overall estimate of the probable error. The uncertainty analysis is discussed in more detail in the full report.

The procedure used to develop the SO_2 reduction estimates is described in the full report. Table 4 presents the results obtained through the application of the procedure.** As the data indicate, Appalachian operators cleaned more coal than their Midwestern and Western counterparts combined; of approximately 245 million metric tons (270 million short tons) of as-shipped coal produced by Appalachian operations in 1983, approximately 156 million metric tons (172 million short tons), or 64%, was mechanically cleaned. The coal that was processed by the region's plants contained a total of 8.0 million metric tons (8.8 million short tons) of SO_2; of this 2.9 million metric tons (3.2 million short tons) (36%) was removed from the coal through cleaning. Nearly all of this 2.9 million metric tons (3.2 million short tons) of SO_2 was removed from coal that was mined and processed in the northern part of the region (i.e., Pennsylvania, Ohio, and West Virginia); in fact, Northern Appalachian plants accounted for 88% of the total SO_2 reduction. This is in part because Northern Appalachian coal is generally higher in sulfur content than is the coal in Southern Appalachian reserves; more SO_2 can be removed from Northern Appalachian coal because more SO_2 is present in the coal. In fact, more SO_2 was removed from Ohio, Pennsylvania, and West Virginia coal than was present in the raw coal processed by Southern Appalachian operators.

In Northern Appalachian states (particularly Pennsylvania), good SO_2 reduction results are being achieved through cleaning; thus, Northern Appalachia may represent an area in which increased mechanical cleaning could significantly increase the SO_2 removed*. In general, the same is not the case for Central and Southern Appalachia because the sulfur content of Central and Southern Appalachian coal is quite low; at least in Virginia and Alabama, the coal is not amenable to sulfur reduction through washing. Within Southern Appalachia, only the unwashed coal of eastern Kentucky contains a relatively large quantity of SO_2 that is potentially removable through cleaning.

Although Midwestern operators cleaned less coal than those in Appalachia in absolute terms--82.5 versus 156 million metric tons (82.5 versus 172 million short tons) for Appalachia -- in relative terms, it cleaned a larger percentage of its as-shipped production (76, versus 64% for Appalachia). The coal that was processed by the region's plants contained 7.5 million metric tons (8.3 million short tons) of SO_2; of this total, 2.5 million metric tons (2.8 million short tons), or about 34 percent, was removed through cleaning. These sulfur and sulfur-reduction quantities are not much lower than the corresponding quantities for Appalachia, despite the fact that in Appalachia nearly twice as much coal was cleaned as in the Midwest. This indicates that Midwestern coal is much higher in sulfur than Appalachian coal, a fact that has clearly forced Midwestern operators to rely more heavily on mechanical cleaning than do their Appalachian counterparts. In fact, of operators in all the mining regions, only those in the Midwest are cleaning as large a percentage of their surface production as their underground production; thus, it appears that sulfur, rather than ash, reduction may be the primary objective of Midwestern preparation plant operators.

In addition to presenting SO_2 reduction estimates for the major Appalachian and Midwestern coal-producing states, Table 4 also provides estimates for Western states for which usable EIA-7A data were available. Four Western states are included in the table; one of these is characterized by high-sulfur reserves (Missouri), and three are characterized by low-sulfur coal (Colorado, New Mexico, and Utah). Because of the low absolute tonnage of bituminous coal production and/or processing in these states, relatively little SO_2 reduction is achieved through coal cleaning.

Potential Reductions

The method used to determine potential SO_2 reduction from physical coal cleaning is based on assigning average washability characteristics to coal reserves on a bed/county basis. This approach allows calculating a range of SO_2 reduction estimates for various coal preparation options. Within each option (corresponding to a given level of preparation), separation gravities could be chosen to yield optimum SO_2 reduction levels for preselected, economically acceptable heat content yields (95%, 90%, etc.). Thus for each preparation option, a range of SO_2 reduction estimates corresponding to selected heat content yield values could be developed.

To implement this methodology, a considerable amount of effort was expended to identify and gather available data on coal washability and to construct a data base that could be mapped against demonstrated coal reserves, providing an enumeration, as complete as possible, at the bed/county level. The data sources used to complete this task were discussed above.

Another critical component of this effort was selecting a model to assist in determining SO_2 reduction and costs associated with preparation options. For this project the Skea and Rubin coal preparation model was chosen as the basic analysis tool. While the basic framework of the model was left intact, several modifications were made to the

*That is, the SO_2 equivalent of the sulfur content of the raw feed, assuming that all of the sulfur in the feed would be released as SO_2 upon consumption. The convention of referring to the SO_2 equivalent of the sulfur content of coal as the "SO_2 content" of the coal has been adopted herein for convenience. Unless otherwise noted, all estimates of the SO_2 content of coal are based on the assumption that all of the sulfur in the coal would be released as SO_2.

**Results for Maryland are not included in this table. In 1983, only one cleaning plant was operating in Maryland, and data for this plant were not usable.

*Note that, throughout this report, coal cleaning is considered in isolation from other SO_2 reduction technologies, such as flue gas desulfurization. Therefore the statement that significant increases in SO_2 reduction can be achieved by cleaning Northern Appalachian coal is based on the assumption that no SO_2 is currently being removed from this coal by other means.

Table 4. *Current SO_2 Reduction Estimates (Based on 1983 Data)*

Region and State	*Quantity of Coal Cleaned[a] (thousand clean metric tons)*	*Quantity of SO_2 in Raw Coal[a] (thousand metric tons)*		
		Input to Mechanical Cleaning Plants	*Removed Through Mechanical Cleaning*	*Remaining in Clean Coal*
Appalachia [b]				
Ohio	*19,317*	*2,175*	*741*	*1,434*
Pennsylvania	*29,689*	*1,838*	*827*	*1,011*
West Virginia	*62,745*	*2,875*	*943*	*1,932*
Alabama	*13,377*	*397*	*55*	*342*
Eastern Kentucky	*18,067*	*431*	*159*	*272*
Tennessee	*1,919*	*81*	*58*	*23*
Virginia	*11,186*	*243*	*45*	*198*
Total	*156,300*	*8,040*	*2,828*	*5,212*
Midwest				
Illinois	*43,448*	*3,877*	*1,463*	*2,414*
Indiana	*19,588*	*1,466*	*204*	*1,262*
Western Kentucky	*19,599*	*2,163*	*848*	*1,315*
Total	*82,635*	*7,506*	*2,515*	*4,991*
West				
Colorado	*1,434*	*27*	*10*	*17*
Missouri	*2,362*	*363*	*130*	*233*
New Mexico	*145*	*3*	*1*	*2*
Utah	*1,367*	*24*	*12*	*13*
Total	*5,308*	*417*	*153*	*265*
Grand Total	*244,243*	*15,963*	*5,486*	*10,468*

[a]Includes only coal produced and SO_2 removed by operators that mined over 90,700 metric (100,000 short) tons in 1983.

[b]Maryland results not included (see text).

costing algorithms and other components to fit the specific needs of this study.

Overall, considerable work was expended to come up with potential SO_2 reduction estimates and costs for both the cleaned and uncleaned portions of current production. Because of the detail and complexity of the methodology, a lengthy discussion of the approach is provided in the full report.

As discussed above, the first step in the process was to develop a coal reserve base by bed/county, which contained corresponding average washability data. Using this reserve base, washability curves were prepared for both the cleaned and uncleaned portions of each region's current production. These curves show the SO_2 reduction potential by preparation option and heat content yield, as well as the corresponding cleaning costs in dollars per metric ton (in parentheses). Examples of the curves are shown by Figures 1 and 2.

Using these figures and information on the coal preparation and mining industries within each region, a range of SO_2 reductions and corresponding costs was developed using "light" and "heavy" coal cleaning scenarios.

Each scenario is defined by a preparation level and a heat content yield. In defining the scenarios, economic as well as technical considerations were taken into account. The definition of light and heavy cleaning thus varies from state to state, reflecting regional variability in the washability of coal. Also, the scenario definitions vary within each state for the cleaned and uncleaned portion of the state's production. For the cleaned production, both the light and the heavy cleaning options represent additional or more intensive cleaning, over and above the cleaning to which the coal has already been subjected. Mine operators already cleaning their coal can attain highly intensive levels of cleaning at a lower additional cost than other operators, simply by expanding their existing cleaning plants and/or modifying the plants' operating characteristics. For this reason, the definitions of light and heavy cleaning reflect a more intensive degree of preparation than for the uncleaned coal. Significant additional SO_2 reduction through further cleaning of the uncleaned production, beyond heavy cleaning, is thus technically feasible in many states, although the resulting costs would be high if not prohibitive. The cleaning scenarios within each state are defined in Table 5.

Using available information, it was estimated that approximately 19 million metric tons (21 million short tons) of SO_2 is contained in the raw coal mined in the coal-producing states east of the Mississippi River. These states contain most of the bituminous coal reserves that traditionally are cleaned. It is estimated that slightly over 5 million metric tons

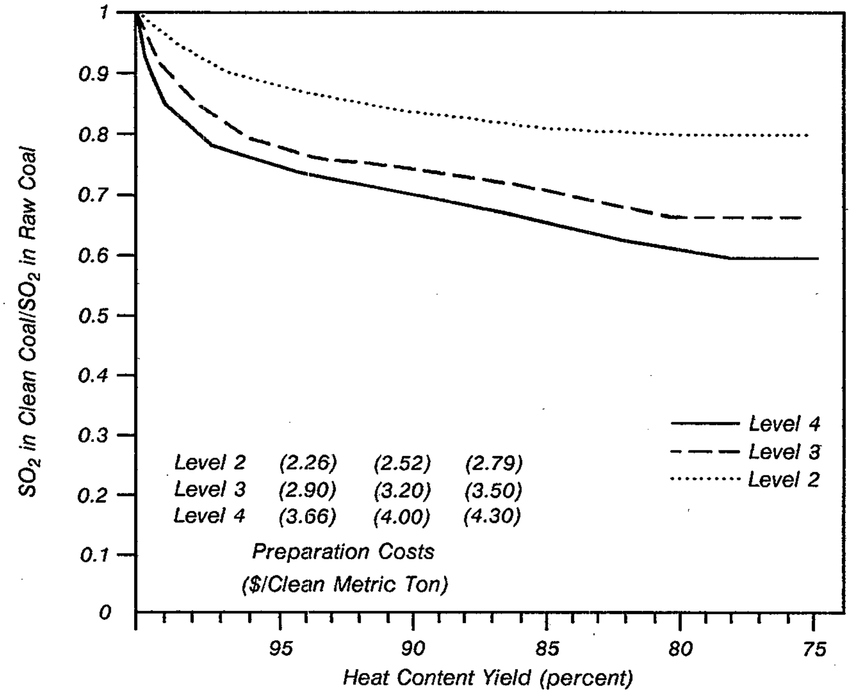

Figure 1. *Clean coal content versus heat content yield and preparation costs for Illinois' 1983 uncleaned production.*

(5.5 million short tons) of SO_2 currently is being removed by existing coal preparation plants and cleaning procedures. Under a "light cleaning" scenario in which all production is subjected to some form of moderate preparation, an additional 1.7 million metric tons (1.9 million short tons) of SO_2 can be removed. A "heavy cleaning" of all production results in an additional 3.1 million metric tons (3.4 million short tons) of SO_2 being removed.

In addition to the quantity of SO_2 that can be removed via coal cleaning, a corresponding cost was calculated. The model estimates the capital and operating costs (in 1986 dollars) of the cleaning process using equations that relate costs to the clean plant output (in tons/hour), weight yield, and other relevant operating and financial parameters. The economic assumptions used in developing the cost estimates are shown in Table 6. Note that the cost estimates include only the costs of the cleaning process itself; neither the *reductions* in coal transportation and power plant operating costs resulting from cleaning, nor the value of the coal lost to the refuse, are included in the estimates. Under the light cleaning scenario the estimated cost for the East as a whole is about $206 per metric ton ($187 per short ton) of SO_2 removal. The cost for heavy cleaning is about $151 per metric ton ($137 per short ton). These figures do not necessarily suggest that heavy cleaning is always the better option. The "better" option can only be determined by corresponding examinations of costs on a dollar per ton of coal cleaned basis and heat content losses. However, the results of this study do suggest that substantial amounts of SO_2 can be removed through coal cleaning at costs that appear to be less than current post-combustion technologies. Table 7 summarizes the current and potential SO_2 reduction estimates developed during this study.

Recommendations

The principal output of this effort is a comprehensive data base that characterizes U.S. coal reserves by their sulfur reduction potential through physical coal cleaning. For the first time, data on the quantity, quality, washability, and minability of coal reserves on a bed/county basis have been combined into a single comprehensive data base. There are many possible applications of the data base; e.g., it may be linked with a policy model such as the Advanced Utility Simulation Model to enhance the model's current capabilities by providing a detailed structural representation of coal preparation. With this representation in place, more accurate and defensible analyses of the tradeoffs among control technologies can be developed.

A second application of the data base is the direct analysis of specific target areas. The current study was limited to the development of SO_2 reduction estimates at the regional and national levels. However, since the data are on a bed/county basis, many different levels of aggregation are possible; e,g., one concern often raised when examining impacts of proposed acid rain legislation are their effects on the mining regions of the Midwest. The data base can be used to focus on very specific areas and conduct detailed impact/trade-off analyses.In Illinois one could look at the supply distribution pattern from the Herrin #5 and #6 seams; identify specific tonnages, coal quality, and delivered prices to utilities purchasing these coals; and then examine the specific washability of these coals and the costs associated with

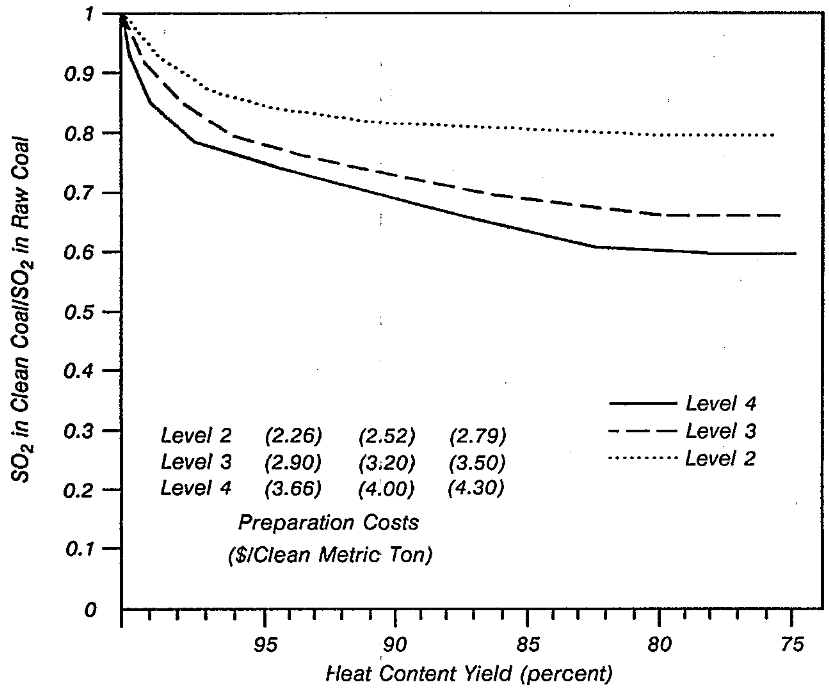

Figure 2. *Clean coal content versus heat content yield and preparation costs for Illinois' clean production.*

bringing them in-line with alternative control technologies.

A question often raised when examining coal supply issues is the quantity, availability and price of low-sulfur eastern bituminous coal. The answer to this question, for the most part, has been given in terms of in-place coal reserves' meeting specific pre-preparation quality characteristics. With the data base it is possible to identify the amount of coal that can be cleaned to a specified level, and the associated costs. Obviously, many similar questions can be addressed. The fact that the data base was constructed at the bed/county level makes it flexible and easy to use for addressing many varying coal supply/demand issues.

Some words of caution are in order. Throughout this study every effort was made to obtain the most complete and reliable washability data available. To that end it is believed that the study was successful. However, while the data base was constructed on a bed/county basis, it does not cover all beds and all counties where mining is prevalent. Data gaps do exist, some more pronounced than others.

Also, as discussed above, the definitions of light and heavy cleaning are based on economic as well as technical considerations, and reflect a less intensive degree of cleaning for the uncleaned portion of current production than for the cleaned portion.*Therefore, significant increases in SO_2 reduction, beyond those estimated for the heavy cleaning scenario, are technically feasible in some regions.

*The definitions of light and heavy cleaning for uncleaned coal were selected based on an analysis of the regional SO_2 reduction curves (see, for example, Figure 1), and do not necessarily correspond to current degrees of cleaning for cleaned coal.

Table 5. Definitions of Cleaning Scenarios

Area/State[a]	Light Cleaning: Preparation Level	Light Cleaning: Heat Content Yield	Heavy Cleaning: Preparation Level	Heavy Cleaning: Heat Content Yield
West Virginia				
Uncleaned	3	95	3	90
Cleaned	4	88	4	85
Eastern Kentucky				
Uncleaned	2	95	2	90
Clean	4	89	4	86
Virginia				
Uncleaned	2	97	3	96
Cleaned	N/A[b]	N/A[b]	N/A[b]	N/A[b]
Alabama				
Uncleaned	2	95	3	85
Cleaned	4	90	4	85
Pennsylvania				
Uncleaned	3	95	4	90
Cleaned	N/A[c]	N/A[c]	4	85
Ohio				
Uncleaned	2	95	3	90
Cleaned	4	89	4	85
Illinois				
Uncleaned	2	95	3	90
Cleaned	4	90	4	85
Indiana				
Uncleaned	2	95	3	90
Cleaned	3	95	4	85
Western Kentucky				
Uncleaned	2	95	3	90
Cleaned	4	87	4	85

[a]The analysis of the potential for removing SO_2 through cleaning was limited to major coal-producing states east of the Mississippi River. Available data for major coal-producing states are too limited to support the development of SO_2 reduction estimates, and SO_2 reduction is not a major concern for western coal (which is already low in SO_2).

[b]N/A = not applicable. The available washability data for Virginia are too limited to support the development of SO_2 reduction estimates for the state's cleaned production.

[c]N/A = not applicable. Pennsylvania's cleaned production is already being subjected to an intensive degree of cleaning; therefore any additional cleaning must be heavy rather than light.

Table 6. *Economic Assumptions for All Model Runs (Potential Reduction Scenarios)*

Annual plant operation	*3325 hours per year*
Plant output	*454 dry metric tons (500 dry tons) per hour*
Economic life of plant	*20 years*
Nominal interest rate	*10 percent*
Rate of inflation	*5 percent*
Index updating 1978 base year costs to mid-1986 dollars (mid-1978 = 1)	*1.484*

Table 7. *Current and Potential SO_2 Reduction Estimates and Preparation Cost Estimates*

Region and State	Total 1983 Raw Production (thousand raw metric tons)	Total SO_2[a] in Raw Coal (thousand raw metric tons)	Quantity of SO_2 (thousand metric tons): Currently[b]	Potentially: Light[c]	Potentially: Heavy[c]	Preparation Costs ($/ton SO_2 removal): Light	Heavy
Appalachia							
Ohio	33,400	2,594	741	126	282	204.84	119.66
Pennsylvania	64,400	2,845	827	312	486	167.03	172.58
W. Virginia	121,000	4,066	943	286	519	309.17	194.53
Alabama	26,300	766	55	80	182	309.06	180.47
E. Kentucky	50,700	1,209	159	145	240	306.17	238.84
Virginia	25,000	386	45	16	21	464.91	455.13
Total	320,800	11,866	2,770	965	1,730	251.71	183.99
Midwest							
Illinois	63,000	4,134	1,463	142	367	277.59	141.61
Indiana	33,700	1,986	204	322	610	74.48	84.76
W. Kentucky	36,500	2,967	848	229	385	151.23	114.96
Total	133,200	9,087	2,515	693	1,362	141.46	108.79
Grand Total[b]	454,000	20,953	5,285	1,58	3,092	205.63	150.79

[a]Includes cleaned and uncleaned.

[b]Tennessee, Colorado, Missouri, New Mexico, Maryland, and Utah costs are not included because potential SO_2 reduction estimates were not developed for these states (see Table 5, especially footnote a.)

[c]Light and heavy cleaning vary by region, and are defined in Table 5.

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The complete report, entitled "Assessment of Physical Coal Cleaning Practices for Sulfur Removal," (Order No. PB 90-250 143/AS; Cost: $23.00, subject to change) will be available only from:

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