United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

Research and Development

EPA-600/S7-81-086 Sept. 1981

EPA

Project Summary

Coal Resources and Sulfur Emissions Regulations: A Summary of Eight Eastern and Midwestern States

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Increasing demand for electric power and the national mandate to become less dependent on expensive imported petroleum will result in the increased use of coal for power generation. Accompanying the changes in fuel mix will be revisions to environmental regulations and legislation and legislation affecting the use of coal. This report analyzes coal resources, current coal use, and the effectiveness of SO_2 control strategies for use by coal users, regulators, and administrators in future coal-related decisions.

The report focuses on an analysis of eight major eastern and midwestern coal-producing states: Alabama, Illinois, Indiana, Kentucky, Ohio, Pennsylvania, Virginia, and West Virginia. Each state analysis includes a general overview of the coal industry, an overview of coal properties, a description of major coal seams, an evaluation of the quality of coal available to meet various SO_2 emissions regulations, and information regarding the sulfur content of coals used by utilities in 1979. The report focuses primarily on physical coal cleaning (PCC) and the use of low-sulfur coal as viable emission control strategies. Flue gas desulfurization (FGD) is discussed to a lesser extent.

Data on coal resources, coal properties, coal production, and coal deliveries to utilities were compiled from several sources and organized into computer data bases. The Coal Assessment Processor (CAP) model was developed to operate on these data bases to determine the quantity of coal that would be available in each state to meet various SO_2 emission regulations using one or a combination of alternative SO_2 control technologies. With this information, decision makers can examine the situation from state to state to identify the appropriate strategies for controlling SO_2 emissions from coal combustion.

This Project Summary was developed by EPA's Industrial Environmental 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).

Introduction

In the next several years, an increasing amount of coal will be used for electric power generation in the U.S. This is in response to both an increased demand for electric power and the national mandate to become less dependent on expensive imported petroleum. Accompanying the changes in fuel mix are revisions to environmental regulations and legislation affecting the use of coal.

These regulatory considerations include a growing realization that accelerated coal use may make it more difficult to meet State Implementation Plans (SIPs), to meet Prevention of Significant Deterioration (PSD) requirements while still permitting growth, to find sufficient offsets in nonattainment areas, and to find cost-effective ways to control emissions for small boilers. There is also an emerging awareness of the acid rain/acid deposition problem and its potential impact, and of the fact that fuel sulfur variability and temporal variations in the efficiency of flue gas scrubbers are significant considerations in determining whether any given source will exceed air quality standards.

To respond to these events, regulators and administrators must have extensive information on coal resources, current coal use, SO_2 control technologies, and alternative SO_2 emission regulatory strategies. The overall purpose of this study was to supply regulators and administrators with information on current coal use and on the effectiveness and costs of SO_2 control technologies for the eight major eastern and midwestern coal producing states: Alabama, Illinois, Indiana, Kentucky, Ohio, Pennsylvania, Virginia, and West Virginia. An analysis of each state includes a general overview of the coal industry, an overview of coal properties, a description of major coal seams, an evaluation of the quantity of coal available to meet various SO_2 emission regulations, and information regarding the sulfur content of coals used by utilities in 1979. The report focuses primarily on physical coal cleaning (PCC) as a method of controlling SO_2 emissions. Limited comparative data are presented on chemical coal cleaning (CCC) and flue gas desulfurization (FGD).

Methodology

Each state analysis is organized to supply the following information:

- A general overview of the state's coal industry, including the location of coal fields, coal production and employment for major counties, and current coal washing practices.
- An overview of the properties of the coal in the state, with emphasis on coal sulfur content.
- A description of the major coal seams in the state.
- The quantity of coal able to meet various SO_2 emission ceilings, floors, and percentage removal standards using PCC and FGD.
- The extent of coal movements between states and the coal blending strategies used by the state's major utility plants to comply with the SIP SO_2 standard.

The information presented in this report was compiled from a number of existing sources (as documented in the references) and from simulations using the Coal Assessment Processor (CAP) model. The CAP model was developed under EPA's Coal Cleaning Program to determine the quantity of coal available to meet various SO_2 emission control technologies. Five coal data bases and a washability data base were compiled to interface with the model. The coal data bases include reserves data, 1976 production data, 1985 planned production data, and utility delivery data for 1977/1978 and 1979. The washability data give theoretical sulfur and ash reductions for over 500 coals. The SO_2 control technologies simulated by the CAP model include various PCC and CCC processes, FGD, fluidized-bed combustion (FBC), low- and medium-Btu gasification, and PCC + FGD. Performance models for each of these control technologies determine potential SO_2 reduction and energy penalties. Only PCC, CCC, and FGD were considered in this study.

Coal Data Bases

Reserves Data Base

The coal reserves data base contains 52,986 records, each specifying coal location, quantity, and properties. Coal quantities were derived from 3,167 resource records representing the demonstrated coal reserve base as summarized in Bureau of Mines (BOM) Reports IC 8680 and IC 8693.[1,2] Coal properties and locations from nearly 269,000 sample analyses recorded in the "historical coals file" archived by the BOM in Denver, CO, were matched geographically with the 3,167 resource records to produce the 52,986-record reserves data base. Coal properties currently specified in the reserves data base include heating value, sulfur content, ash content (on a moisture-free basis), and moisture content. Sulfur content is divided into pyritic and organic sulfur in proportion to their ratio in the washability data base. Other coal properties available from the BOM "historical coals file," but not included in the reserves data base, are: (1) proximate analysis, (2) ultimate analysis, (3) ash softening temperature, (4) free swelling index, (5) Hardgrove grindability index, and (6) preparation code (i.e., washed or not washed). Figure 1 shows information which is summarized on the reserve, production, and delivery data bases for each state.

1976 Production Data Base

The data base for 1976 production contains 3,074 records, each including coal location, quantity, and properties. Information on the location and quantity of coal produced in 1976 was obtained primarily from annual state coal production reports, a 1979 Ohio River Basin Energy Study (ORBES) report,[3] and various Keystone manuals.[4,5] Coal properties were assigned to the 1976 production sources using the BOM "historical coals file." As a result, emission histograms for 1976 production data are similar to those for the reserves data.

1985 Planned Production Data Base

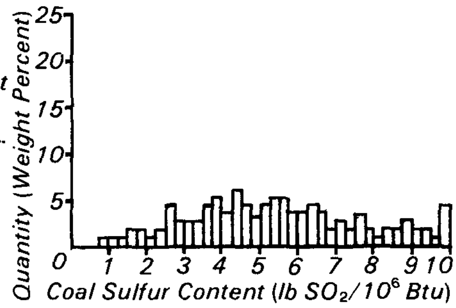
The data base for production planned for 1985 was developed from individual mine-expansion plans reported by the National Coal Association (NCA)[6] and the Department of Energy's Western Coal Development Monitoring System (WCD).[7] The NCA data were combined with the 1976 production data for the eastern states and the WCD data were combined with the 1976 production data for the western states to form the 4,328-record data base for projected 1985 production. Like the reserves and 1976 production data bases, this data base uses BOM "historical coals file" coal properties. The 1985 emission histogram is essentially an expansion of the 1976 emission histogram.

Deliveries-to-Utilities Data Base

The deliveries-to-utilities data base includes information on the quantity, cost, and properties (sulfur, ash, heating value) of all coal delivered to utilities from September 1977 to September 1978 and from January through December 1979, as reported to the Department of Energy on EIA Form 423. The Form 423 data for September 1977 to December 1978 were obtained from NCA, while the January through December 1979 data were obtained from *Coal Outlook*. Unlike the other data bases, this one does not take coal properties from the BOM "historical coals file," since the data are available

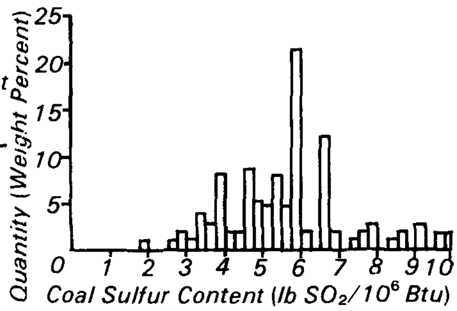
Reserves: 21,055 million tons, 509 quadrillion Btu

	Heating Value (Btu/lb)	Sulfur Content (%)	Ash Content (%)
Mean	12,780	3.45	11.78
Std. Dev.	907	1.40	5.39
Minimum	8,571	0.50	2.20
Maximum	14,256	9.40	37.40



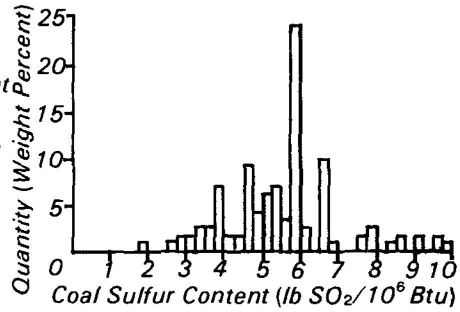
1976 Production: 45.80 million tons, 1.11 quadrillion Btu

	Heating Value (Btu/lb)	Sulfur Content (%)	Ash Content (%)
Mean	12,921	3.62	11.01
Std. Dev.	489	1.02	2.16
Minimum	9,750	0.60	5.20
Maximum	14,230	8.70	23.40



Projected 1985 Production: 54.54 million tons, 1.34 quadrillion Btu

	Heating Value (Btu/lb)	Sulfur Content (%)	Ash Content (%)
Mean	12,937	3.62	10.95
Std. Dev.	481	1.00	2.03
Minimum	9,750	0.60	5.20
Maximum	14,230	8.70	23.40



1979 Deliveries to Utilities: 38.31 million tons, 0.86 quadrillion Btu

	Heating Value (Btu/lb)	Sulfur Content (%)	Ash Content (%)
Mean	11.183	3.48	15.00
Std. Dev.	838	0.95	4.12
Minimum	8,564	0.67	3.00
Maximum	14,436	6.58	25.10

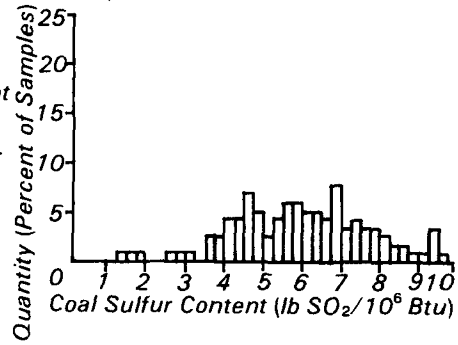


Figure 1. *Ohio coal properties fact sheet.*

from Form 423. In addition to coal quantities and properties, this data base identifies coals that were physically cleaned before delivery in 1979. This feature allows the CAP model to simulate cleaning only for coals not cleaned prior to delivery. The reserve and production histograms of coal sulfur content are not identical with those of coal delivered to utilities. The delivery histograms exclude metallurgical coals and some coal delivered to utilities has been cleaned.

Coal Washability

The coal washability data base contains information on the composition and washability characteristics of 587 coal samples as reported by BOM Report RI 8118[8] and later unpublished supplements.

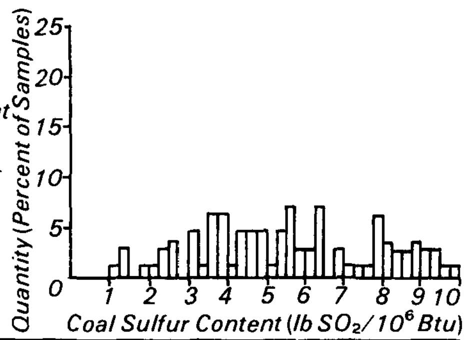
The location of samples in the washability data base is given by state, county, and coal bed. For each sample, the results of laboratory float-sink tests were included for samples crushed to pass through 1.5 in.,* 3.8 in., and 14-mesh screens. The following information was included for the total sample and for products floating at 1.3, 1.4, 1.6, and sometimes 1.9 specific gravity: weight recovery, Btu recovery, heating value, pyritic sulfur percentage, total sulfur percentage, ash percentage, and the theoretical pounds of SO_2 per million Btu.

In the CAP model, each data base coal at the county-seam level was assigned the washability characteristics of one or more of the 587 coal samples. Washability was assigned on a geographical basis in the following order of priority: (1) county bed, (2) state bed, (3) state county, (4) out-of-state bed, and (5) closest out-of-state sample. Coals from Appalachia (Alabama, Georgia, eastern Kentucky, Maryland, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia) and from the eastern Midwest (Illinois, Indiana, and western Kentucky) were represented by 380 and 98 washability samples, respectively, and in most cases county-bed or state-bed matching was possible. For the remaining coal regions, represented by only 109 washability samples, matching is often more tenuous. Figure 2 illustrates the summary of coal washability data given for each state.

(*)Certain nonmetric units are used in this Summary for the reader's convenience Readers more familiar with metric units are asked to use the conversion table provided with this Summary

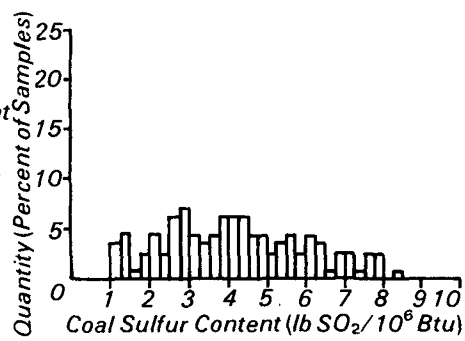
Raw Coal: 90 Samples

	Heating Value (Btu/lb)	Sulfur Content (%)	Ash Content (%)
Mean	12,494	3.55	13.61
Std. Dev.	930	1.39	5.56
Minimum	8,571	0.67	3.57
Maximum	14,256	6.55	37.43



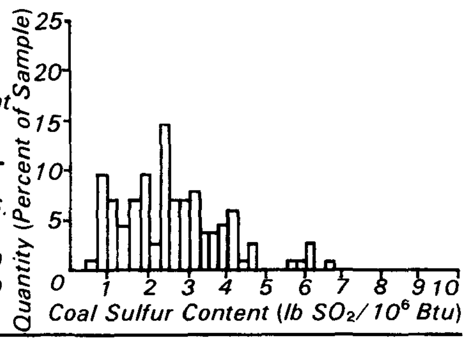
PCC I: 1-1/2 in., 1.6 sp. gr., 90 Samples

	Heating Value (Btu/lb)	Sulfur Content (%)	Ash Content (%)
Mean	13,212	2.77	8.65
Std. Dev.	586	1.16	3.08
Minimum	11,689	0.66	3.10
Maximum	14.325	5.46	17.50



PCC II: 3/8 in., 1.3 sp. gr., 90 Samples

	Heating Value (Btu/lb)	Sulfur Content (%)	Ash Content (%)
Mean	13,952	1.81	3.56.
Std. Dev.	329	0.89	1.01
Minimum	12,871	0.51	1.50
Maximum	14,578	4.26	8.50



Emission Reduction vs. Energy Recovery:

	Emission Reduction (%)		Btu Recovery (%)	
	PCC I	PCC II	PCC I	PCC II
Mean	25.9	53.4	95.2	45.7
Std. Dev.	12.7	13.7	2.9	22.2
Minimum	8.0	16.0	82.4	5.4
Maximum	63.0	81.0	99.6	90.0

Figure 2. *Ohio coal washability data sheet.*

SO_2 Emission Control Technologies

Physical Coal Cleaning

The PCC processes that can be simulated by the CAP model include any combination of top size (i.e., 1.5 in., 3/8-in., 14 mesh) and specific gravity (i.e., 1.3, 1.4, 1.6). For these state analyses, only two combinations were chosen: 1.5 in. top size, 1.6 specific gravity; and 3/8-in. top size, 1.3 specific gravity. The first combination is called PCC I; and the second, PCC II. The PCC I simulation corresponds better to moderate cleaning by commercial processes. The PCC II simulation slightly overestimates SO_2 emission reductions from most existing plants, but can be regarded as the SO_2 reduction which can be achieved by advanced PCC processes.

Flue Gas Desulfurization

The performance of FGD systems is simulated in the CAP model by assuming the use of wet lime/limestone systems having a 90 percent SO_2 removal efficiency (30-day averaging time). Partial scrubbing is assumed in cases where the emission limit can be met by removing less than 90 percent of the SO_2, thereby allowing part or all of the flue gas reheat to be achieved by mixing the scrubbed gas with the bypassed unscrubbed gas. Energy penalties assigned to FGD systems vary between 5 percent, where all of the flue gas is scrubbed, and 1 percent, where all of the reheat is provided by the bypassed gas.

SO_2 Emissions Regulations

The CAP model can evaluate the effect of different SO_2 emission requirements on actual emissions. The emission requirements include emission ceilings, required percentage SO_2 removal, emission floors, and minimum required percentage SO_2 removal. For example, as shown in Figure 3, the CAP model can determine the amount of Ohio coal that can meet a given emission limit. Figure 4 illustrates the effect that SO_2 reduction requirements and SO_2 emission limits will have on the availability of cleaned compliance from Ohio. Or, as provided in Table 1, the amount of SO_2 reduction and costs of cleaning for Ohio coals can be calculated by the CAP model. Similar figures and tables are presented in the report for the eight states studied.

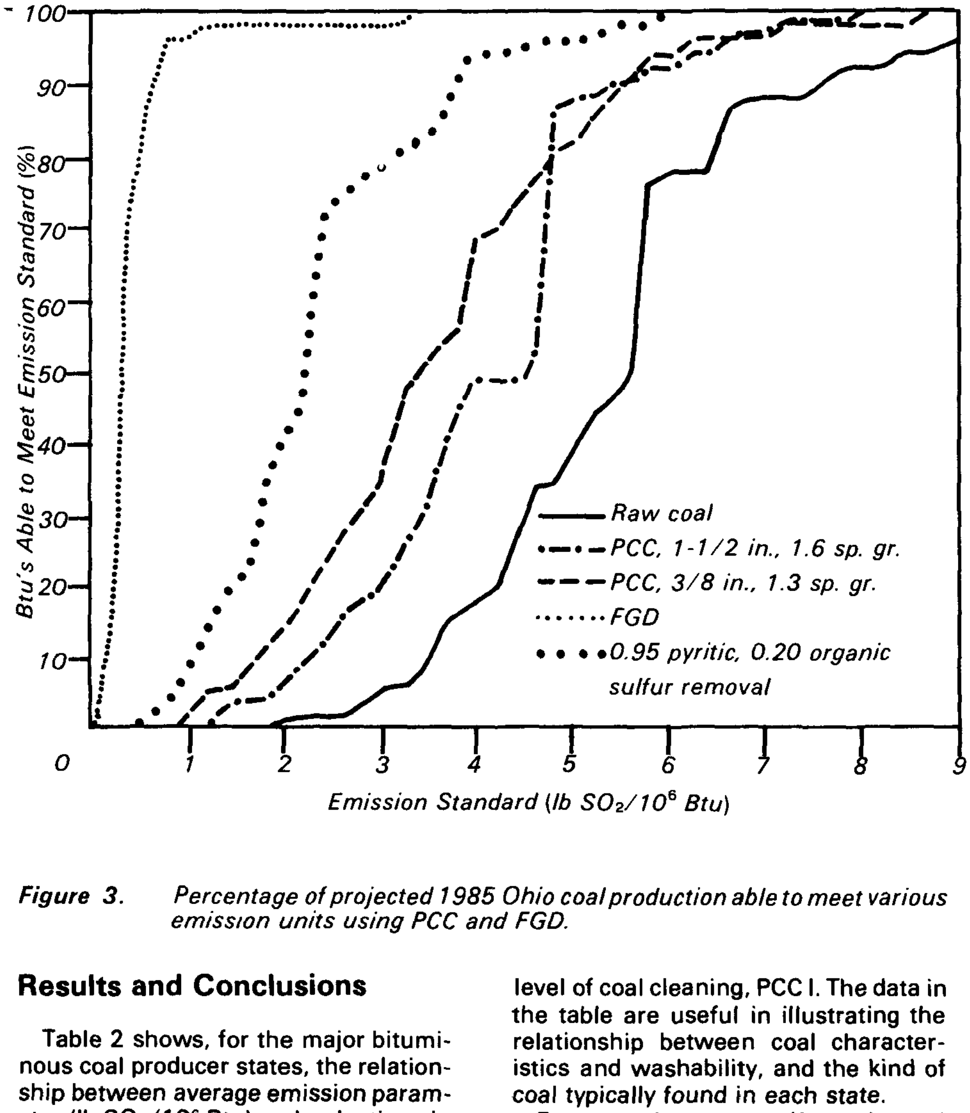


Figure 3. *Percentage of projected 1985 Ohio coal production able to meet various emission units using PCC and FGD.*

Results and Conclusions

Table 2 shows, for the major bituminous coal producer states, the relationship between average emission parameter (lb $SO_2/10^6$ Btu) and reductions in SO_2 emissions, using the moderate level of coal cleaning, PCC I. The data in the table are useful in illustrating the relationship between coal characteristics and washability, and the kind of coal typically found in each state.

For example, western Kentucky coal has a high average emission parameter of 6.7 lb $SO_2/10^6$ Btu, but moderate cleaning of the coal can provide a 31.5 percent reduction in SO_2 emissions. Virginia coal illustrates the other extreme. The average emission parameter is low (1.1 lb $SO_2/10^6$ Btu), and the percent emission reduction also is low (7.6 percent). Pennsylvania coal shows a third pattern: it has a moderate emission parameter (3.9 lb $SO_2/10^6$ Btu) and a high average percent emission reduction (33.2 percent). This is partially explained by the relatively high ratio of pyritic sulfur to total sulfur in Pennsylvania coal. Table 3 shows the cleaning practice for coal delivered to utilities in 1979. It also shows the SO_2 emission reduction that is already provided by coal cleaning.

The SO_2 reduction that could have been achieved, if all coal delivered to utilities in 1979 had been cleaned at moderate levels, is summarized in Table 4. It shows, for example, that about 1.7 million more tons of SO_2 could have been removed in 1979 by cleaning all the utility coal from Pennsylvania, Ohio, and western Kentucky, and that moderate SO_2 reductions could have been achieved by washing other northern Appalachian and eastern Midwest coals.

Typically, a coal user will purchase washed coal if he perceives an economic advantage to doing so. As shown in Table 4, the estimated levelized cost of cleaning utility coal ranges from $5 to $10 per ton. The weighted average delivered cost of raw coal from the eight states shown in Table 4 amounted to about $30 per ton ($60 per ton levelized) in 1979. Cleaning all the coals would have increased this cost by only 10-20

Table 1. *Potential SO_2 Emission Reductions and Costs Due to Selective Washing of Ohio Coals Delivered to Utilities in 1979*

Coals to Be Washed*	Quantity to Be Washed (10^3 Tons)	Total SO_2 Emissions after Selective Washing (10^3 Tons)	SO_2 Emission Reduction Achieved by Selective Washing (10^3 Tons)	(%)	Levelized Cost of Washing (10^6 1979$)	Cost-Effectiveness ($/Ton SO_2)
No coals	0	2,479	0	0	0	—
Coals with SO_2 contents above floor of:						
7 lb/10^6 Btu	12,353	2,101	378	15	137	360
6 lb/10^6 Btu	20,225	1.964	515	21	201	390
5 lb/10^6 Btu	27,063	1,832	647	26	273	420
4 lb/10^6 Btu	31,986	1,757	722	29	302	420
All coals	34,527	1,735	744	30	322	430

*Excluding the 3,787,000 tons of coal actually washed in 1979.

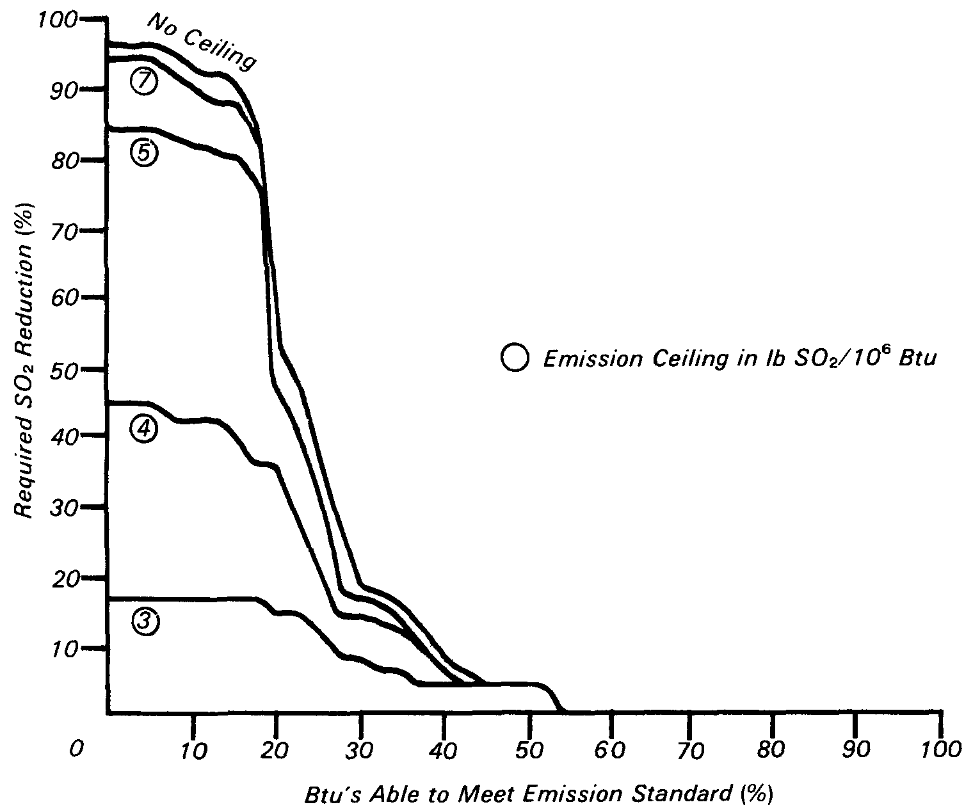


Figure 4. *Percentage of projected 1985 Ohio coal production able to meet various SO_2 emission standards defined by an emission ceiling and percentage SO_2 reduction using PCC at 1-1/2 in., 1.6 sp. gr.*

percent—a low price compared with that of other SO_2 control strategies. Another measure of the cost of pollution control is the cost-effectiveness of the process, which is calculated as the cost per ton of SO_2 removed. Clearly, PCC is more cost-effective for western Kentucky coals than for southern West Virginia coals ($310/ton versus $4,100/ton of SO_2 removed). Fortunately, coal cleaning is most cost-effective with those coals that have the greatest potential SO_2 reduction.

In considering air pollution control strategies, it is important to keep in mind the local coal market and its impact on local employment. Each state analysis in this report includes employment and production data for 1977. The labor requirements in the different states vary depending primarily on coal mining methods. The most labor intensive mining occurs in West Virginia, Alabama, Pennsylvania, and Virginia because of the heavy reliance on underground mining. Accordingly, regulations affecting coal production could affect workers in these states more than those in other, less labor intensive, areas.

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1. Thompson, Robert D., and York, Harold F. *The Reserve Base of U.S. Coals by Sulfur Content*, Vol. 1, *The Eastern States*. Bureau of Mines Information Circular IC 8680. Wash-

Table 2. *Average Emission Parameters and Emission Reductions in Coal from Eight States*

Region and State	*Number of Washability Samples*	*Average Emission Parameter (lb $SO_2/10^6$ Btu)*	*Average Emission Reduction Using PCC I* (%)*
Northern Appalachia			
Pennsylvania	170	3.9	33.2
Ohio	90	5.7	25.9
Northern West Virginia	30	4.8	28.6
Southern Appalachia			
Southern West Virginia	16	1.4	10.1
Virginia	8	1.1	7.6
Eastern Kentucky	13	2.2	15.9
Eastern Midwest			
Western Kentucky	37	6.7	31.5
Indiana	21	5.9	26.4
Illinois	40	6.5	29.3
Alabama			
Alabama	10	1.9	10.8

**PCC I is equivalent to coal crushed to 1-1/2 in. top size and separated at 1.60 specific gravity.*

Table 3. *Current (1979) SO_2 Reduction Achieved by Cleaning Utility Coal from Eight States*

Region and State in Which Coal Was Mined	Coal Delivered to Utilities in 1979 (10^3 Tons)	Utility Coal Cleaned in 1979 (Percent)	SO_2 Content of Coal: As Mined (10^3 Tons)	SO_2 Content of Coal: As Delivered (10^3 Tons)	Average SO_2 Reduction by Coal Cleaning in 1979 (Percent)
Northern Appalachia					
Pennsylvania	47,400	30	2,100	1,860	12
Ohio	38,300	11	2,750	2,670	3
Northern West Virginia	31,300	23	1,760	1,690	4
Southern Appalachia					
Southern West Virginia	17,500	9	300	290	1
Virginia	13,400	7	280	270	1
Eastern Kentucky	68,600	22	1,630	1,570	4
Eastern Midwest					
Western Kentucky	38,100	34	2,880	2,600	10
Indiana	25,300	52	1,620	1,410	13
Illinois	49,500	72	3,570	2,780	22
Alabama					
Alabama	14,600	32	460	440	5
Eight-State Total	344,000	33	17,340	15,570	10

Table 4. *Additional SO_2 Reduction That Could Have Been Achieved if All the 1979 Utility Coal from Eight States Had Been Cleaned*

Region and State in Which Coal Was Mined	Additional SO_2 Reduction* by Washing All Coal (10^3 Tons)	Additional SO_2 Reduction* by Washing All Coal (Percent)	Levelized Cost of Cleaning the Additional Coals ($/Ton**)	Levelized Cost of Cleaning the Additional Coals (Mills/kWh***)	Cost-Effectiveness of Coal Cleaning ($/Ton SO_2 Removed)
Northern Appalachia					
Pennsylvania	470	25	9.10	4.0	670
Ohio	740	28	9.30	4.4	430
Northern West Virginia	280	16	8.00	3.5	720
Southern Appalachia					
Southern West Virginia	30	11	7.90	3.4	4,100
Virginia	30	10	8.30	3.5	3,700
Eastern Kentucky	260	16	10.00	4.4	2,200
Eastern Midwest					
Western Kentucky	530	21	6.50	3.1	310
Indiana	180	13	4.60	2.2	310
Illinois	230	8	6.60	3.3	430
Alabama					
Alabama	70	17	8.60	3.8	1,200
Eight-State Total	2,850	18	8.40	3.8	710

**Over current practice (see Table 3).*

***Of raw coal.*

****For a generating unit with a heat rate of 10,000 Btu/kWh.*

ington, D.C.: U.S. Bureau of Mines, 1975.

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Conversion Factors

ton = 0.907 metric tons

lb = 0.436 kg

Btu = 1055.6 Joule

Btu/lb = 2326 Joule/kg

in. = 2.54 cm

°C = 5/9 x (°F-32)

lb/in.^{2} = 0.07 kg/cm^2

lb SO_2/10^6 Btu = 430 ng SO_2/Joule

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The complete report, entitled "Coal Resources and Sulfur Emissions Regulations: A Summary of Eight Eastern and Midwestern States," (Order No. PB 81-240 319; Cost: $11.00, subject to change) will be available only from:
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