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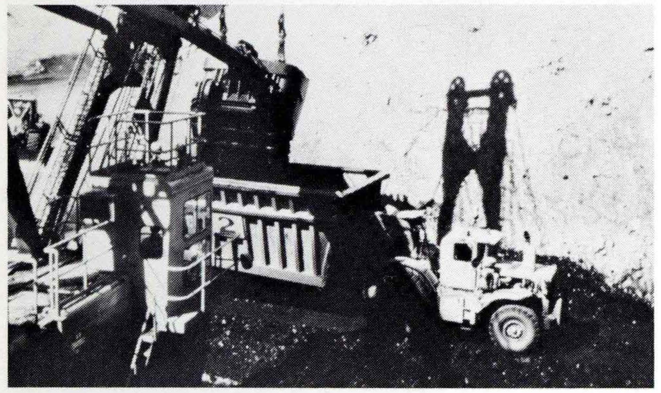

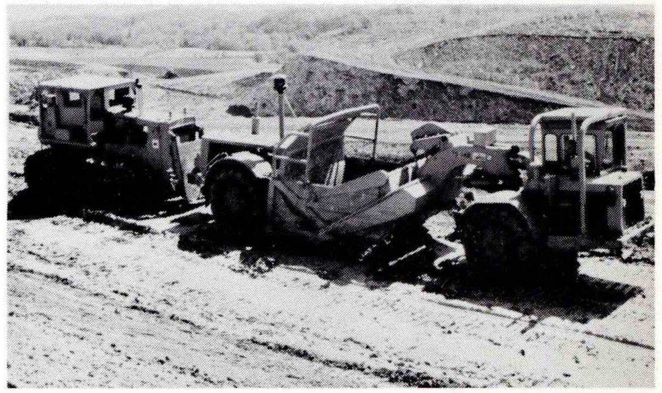

CARD Report 68

AGRICULTURAL AND RURAL DEVELOPMENT

THE CENTER FOR
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AN ANALYSIS OF THE NATIONAL COAL ECONOMY AND A MARGINAL PRODUCING REGION, 1976-1990

By

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PREFACE

In 1974, the Iowa Legislature appropriated $3 million to Iowa State University for the Energy and Mineral Resources Research Institute to conduct a coal research program. One of the goals of this program was to provide an economic analysis of the mining, restoration, refining, transportation, and use of Iowa coal.

This report presents the initial results of a study to evaluate the economic feasibility of a major coal producing industry in Iowa. Further analyses are being conducted to evaluate the impact of technological advancements and changing market forces on the potential development of the Iowa coal industry. The results of these analyses will be forthcoming in additional publications.

A number of individuals contributed to the completion of this study. Numerous personnel from the United States Bureau of Mines provided input data. Iowa State University scientists Arnold Paulsen, Larry Whiting, Tom Wheelock, Robert Hansen, John Lemish, Robert Shearer, Donald Biggs, Lyle Sendlein, and Ray Fisher provided review comments. In traditional fashion, the authors assume full responsibility for the results and conclusions derived therefrom.

The Authors

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I. INTRODUCTION

The Project Independence Report proposes the national policy of expanding the domestic energy supply to achieve energy independence by 1980 [8]. However, natural gas and petroleum reserves are being rapidly depleted, and research indicates that new energy sources such as synthetic fuels, and solar and geothermal power will not make significant contributions to the energy supply before 1985. This leaves nuclear power and coal as the only viable short-run solutions. Because of environmentalist opposition to nuclear power plant development, coal is widely discussed as an increasingly important energy source. Consequently, important policy decisions affecting the U.S. coal industry and its development are now being made.

This report describes an analytical model capable of evaluating the future structure and characteristics of the U.S. coal industry. Of the many policy issues that could be analyzed with the model, the following two have been chosen:

1) The economic consequences for the coal industry (including shifts in the regional location of production) of imposing alternative sulfur dioxide emission standards on coal-burning facilities.

2) The economic feasibility of encouraging a region that has historically had coal resources of marginal economic value to develop those reserves. (The case of Iowa will be examined in detail.)

Chapter II provides a description of the model and data sources. The competitive positions of major coal producing regions are evaluated in Chapter III. This chapter also includes an analysis of the effects of changing sulfur dioxide emission standards. Chapter IV evaluates the potential of a marginal producing region (Iowa) to develop into a major coal producing region. Concluding remarks and suggestions for further study are in Chapter V. Finally, a detailed summary of the data, model results, and the programming tableau are included in the appendices.

II. THE ANALYTICAL MODEL

A multiperiod interregional competition model was specified to evaluate the behavior of the various components of the U.S. coal industry under alternative assumptions concerning costs, sulfur dioxide emission standards, capital availability, and the demand for coal.[1] The objective of the analysis was to find the most efficient, and hence least costly, method of supplying the nation's coal needs. The model includes mining coal in the 21 regions listed in Table 1 and supplying the demand for coal in the 18 demand regions also listed in Table 1. Four time periods were specified: 1976-77, 1978-80, 1981-85, and 1986-90. A large-scale linear programming model was constructed to use in the empirical analysis. The following discussion summarizes the basic relationships included in the model and the data sources.[2]

Mining

The amount of coal mined in any supply region is limited by the available mining capacity (the number and size of operating mines), the coal reserves in the region, and the availability of equipment needed to open new mines and thus expand the mining capacity.

Specifically, the mining capacity restrictions are as follows:

$$(1) \quad \sum_{q=1}^{3} M_{i,m,q,t} \leq MC_{i,m,t}$$

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[1] Interregional competition models have been widely used in agricultural and industrial applications [3,7,11,16,17,20]. However, their use in the energy and coal industries is relatively new [1,2,8].

[2] A more complete description of the input data and programming tableau is provided in Appendices A and B.

Table 1. Supply and Demand Regions Used in the Model.

Supply Regions	Demand Regions[a]
1. Alabama-Georgia	1. Minnesota, Wisconsin, North Dakota, South Dakota
2. Arkansas-Missouri	2. Western Missouri
3. Colorado	3. Illinois, Indiana
4. Illinois	4. Michigan
5. Indiana	5. Washington, Oregon, California, Arizona, New Mexico, Colorado, Utah, Nevada, Idaho, Montana, Wyoming
6. Iowa	6. New York, New Jersey, Massachusetts, Connecticut, Vermont, Delaware, Maryland, Maine, New Hampshire, Rhode Island
7. Eastern Kentucky	7. Florida, Georgia
8. Western Kentucky	8. Virginia, West Virginia, North Carolina, South Carolina
9. Maryland	9. Kentucky, Tennessee, Alabama, Mississippi
10. North and South Dakota	10. Texas, Oklahoma, Arkansas, Louisiana, Kansas, Nebraska
11. Montana	11. Pennsylvania, Ohio
12. New Mexico	12. Eastern Missouri
13. Ohio	13. Central Iowa
14. Oklahoma-Texas	14. Western Iowa
15. Pennsylvania	15. North Central Iowa
16. Tennessee	16. Southeast Iowa
17. Utah	17. Northeast Iowa
18. Virginia	18. East Central Iowa
19. Washington-Oregon	
20. West Virginia	
21. Wyoming	

[a] Iowa is represented by six demand regions to allow for a more detailed evaluation of the competitive position of the Iowa supply region in Chapter IV.

where M represents the tons of coal mined and MC is the mining capacity in tons. The t subscript denotes the time period while the i subscript indicates the supply region. The subscript m designates thin and thick seam surface or underground mining.[3] Finally, as many as three quality levels (based on sulfur content and heating value) of coal were allowed in each region. The quality levels are designated by the subscript q. The underground and surface mining capacities for each region were projected from data in [22]. It was assumed for all regions that mining thin seams required 25 percent more mining capacity investment than did mining thick seams.

The mining capacity in any region was allowed to be augmented by constructing new mines:

$$(2) \quad MC_{i,m,t} = \phi_t \; MC_{i,m,t-1} + K_{i,m} \; N_{i,m,t}$$

where N is the number of new mines constructed and K is the capacity, in tons per time period, of a new mine. The K values were estimated based on representative mine sizes shown in [22]. Both new and existing mines were assumed to have a useful life of 20 years. Five percent of existing mine capacity was depreciated each year (ϕ_t). This adjustment is made in the right-hand side vector for each time period. All new mine capacity was assumed to be available for the entire planning horizon

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[3] Four mining options were allowed in each region--mining thin-seam strippable reserves, mining thick-seam strippable reserves, mining thin-seam underground reserves, and mining thick-seam underground reserves. For simplicity, these options are not explicitly included in the mathematical representation of the model in this section. They are included, however, in the discussion of the programming tableau in Appendix B. Seam thickness for each mining option in each region is indicated in Appendix Tables A-4 through A-24.

of the model. The investment cost for new mines was adjusted to reflect the proportion of the useful life that expires before 1990. For example, a new mine with a total investment cost of $15 million if purchased in 1980 has an investment cost in the model of $7.5 million discounted to present value.

Equipment availability constraints were included to restrict the number of mines built before 1981 as follows:

$$(3)\quad N_{i,m,t} \leq N^*_{i,m,t}$$

where N* is the planned expansion as reported in [5]. The N* variables were specified as upper limits to reflect the inability of the industry to expand more rapidly than current plans because of the limited capacity of the capital goods market, the decision lags--caused in part by uncertainty concerning government regulations--in responding to economic incentives for expansion of the industry, and the normal delays in getting new mines "on stream." The planned expansion data restricts the opening of new mines until 1981. For the 1981-85 and 1986-90 periods, no limits on the development of new mines are included in the model.

Finally, the total coal mined over time must not exceed the available reserves:

$$(4)\quad \sum_{t=1}^{4} M_{i,m,q,t} \leq R_{i,m,q}$$

The reserves, denoted by R, were estimated from [18,24,25]. Reserves and demand (and consequently production) were not separated into steam or metallurgical grades for this analysis. Anthracite deposits were not included in reserve quotations.

Processing

Coal washing was allowed as the only means of upgrading the quality of run-of-mine coal in each region. Letting P represent the tons of coal which are washed and P′ represent the tons of coal which are transported to market without processing, we have:

$$(5)\quad P'_{i,q,t} + \omega_{i,q}\, P_{i,q,t} \leq \sum_{m=1}^{2} M_{i,m,q,t}$$

$\omega_{i,q}$ is the inverse of the fractional weight recovery. All washability statistics were obtained from [4].

Transportation

The tonnage of coal of each quality level shipped from each production region to all demand points was restricted to be no more than the amount available as follows:

$$(6)\quad \sum_{j=1}^{18} T_{i,j,q,t} \leq P'_{i,q,t} + P_{i,q,t}$$

$T_{i,j,q,t}$ represents the tons of coal of quality level q shipped from supply region i to demand region j in time period t. There can be as many as six quality levels of coal transported from each region--the original three levels and the three levels that result after processing.

Demand

The coal demand in each region is specified in heating units rather than tons to account for differences in the heating value of coals from different regions. Letting $D_{j,t}$ be the demand for coal in region j in period t and $\psi_{i,q}$ be the heating value per ton of coal of quality q from region i, we have:

$$(7)\quad \sum_{i=1}^{21} \sum_{q=1}^{6} \psi_{i,q}\, T_{i,j,q,t} \geq D_{j,t}$$

The 1976-77 annualized regional coal demands used in the analysis were specified as equal to the 1973 consumption levels shown in Table A-25. The 1978-80, 1981-85, and 1986-90 annual consumptions in each region showed 5 percent, 15 percent, and 25 percent increases, respectively, over the 1973 level. The model requires that the demand be stated in heating value terms rather than by weight. The average heating value of all coal burned in 1973 was determined from [22] and used as the conversion factor.[4]

Blending of coal to meet sulfur dioxide standards was allowed in each region. Letting $Y_{i,q}$ be the pounds of sulfur dioxide per million Btu contained in coal from region i of quality q and $Y^*_{j,t}$ be the maximum allowable emissions (measured as pounds of sulfur dioxide per million Btu) for mixtures burned in region j in time t, we have:

$$(8)\quad \sum_{i=1}^{21} \sum_{q=1}^{6} [Y_{i,q}\, \psi_{i,q}\, T_{i,j,q,t} \,/\, D_{j,t}] \leq Y^*_{j,t}$$

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[4] This exogenous specification of demand does not allow price to have an influence on the quantity of coal consumed. Recent studies of the price elasticity of demand for coal indicate that as prices increase, consumption will decline [1]. Thus, projections of coal demand which ignore the price effects will overstate future consumption. Including price explicitly in the model would require sacrifices in detail in other parts of the analysis. Consequently, the price impact on quantity of coal consumed is included implicitly through parameterization of demand levels in the sensitivity analysis reported later.

It should be noted that (8) is linear if $D_{j,t}$ is specified exogenously.

Objective Function

The objective of the analysis is to minimize the present value of the cost of supplying the national coal demand in all time periods subject to constraints (1) through (8). This can be stated mathematically as:

$$(9)\quad \text{Minimize } Z = \sum_{i=1}^{21} \sum_{m=1}^{2} \sum_{q=1}^{3} \sum_{t=1}^{4} \alpha_t\, \beta_{i,m,q,t}\, M_{i,m,q,t} + \sum_{i=1}^{21} \sum_{m=1}^{2} \sum_{t=1}^{4} \alpha_t\, \sigma_{i,m,t}\, N_{i,m,t} + \sum_{i=1}^{21} \sum_{q=1}^{3} \sum_{t=1}^{4} \alpha_t\, \pi_{i,q,t}\, P_{i,q,t} + \sum_{i=1}^{21} \sum_{j=1}^{18} \sum_{q=1}^{6} \sum_{t=1}^{4} \alpha_t\, \tau_{i,j,q,t}\, T_{i,j,q,t}$$

The α_t values represent costs discounted at 5.845 percent per year for each corresponding activity.[5] Data on mining costs ($\beta_{i,m,q,t}$) and new mine investment costs ($\sigma_{i,m,t}$) were obtained from [13,14,21,23] and by using a model developed by Otte and Boehlje [19]. Processing costs ($\pi_{i,q,t}$) were assumed to be $1.00 per ton in all regions. Transportation costs ($\tau_{i,j,q,t}$) were based on [10] and equations supplied by the U.S. Bureau of Mines relating costs to distance hauled.

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[5] The purpose of discounting future financial streams is to reflect the fact that individuals and society display a positive time preference for money. This positive time preference is based upon the future earnings potential of money received today and the risk of reduced value of money received in the future, due primarily to inflation. However, the costs of mining, processing, and transportation included in the multiperiod interregional competition model are held constant over all periods, thus abstracting from the problem of an appropriate rate of inflation. Consequently, to maintain consistency, the risk premium for inflation also is excluded from the discount rate. However, costs must still be discounted for the pure time preference for money. This pure time preference was calculated as a geometric weighted average of annual treasury bill rates [9].

Solution

The model was solved using four different sulfur standard scenarios. The first set of sulfur standards was the regional standards shown in Appendix Table A-26. The second, third, and fourth sets of standards were 1.2 pounds (the Federal standard), 3.0 pounds, and 5.0 pounds of sulfur dioxide per million Btu, respectively, for all time periods in all regions.

III. IMPLICATIONS FOR THE NATIONAL COAL INDUSTRY

The least-cost production and distribution pattern for the U.S. coal industry will be discussed in two parts. First, the model results using the regional sulfur standards (i.e., those in Table A-26) will be reviewed. These sulfur standards reflect a reasonable compromise between current regulations and the proposed 1.2 pounds of sulfur dioxide per million Btu Federal standard. However, because there is considerable uncertainty as to which sulfur standards will finally apply, the second part of this discussion will analyze the implications of alternative sulfur dioxide emission standards.

Analysis of the Regional Sulfur Standards

A summary of the regional coal production and the transportation of coal between U.S. production and consumption regions in the short run and long run with the regional sulfur standards is provided in Figures 1 through 4. Figures 1 and 2 summarize data for the 1976-77 and 1978-80 time periods. Long-run national trends unrestricted by limits in the capital markets are more clearly shown by the results of the 1981-85 and 1986-90 periods (Figures 3 and 4) when the industry approaches its unrestricted competitive equilibrium.

The demand for Montana, Wyoming, and New Mexico coal is strong in the 1976-80 periods. However, when capital constraints are eliminated after 1980, the Montana and New Mexico supplies are not utilized, and all of the demand for western coal is supplied by Utah and Wyoming supplies. In addition, significant expansion occurs in the eastern coal producing regions of Alabama-Georgia, Indiana, Eastern Kentucky, Ohio,

Figure 1. Coal Shipments 1976-77 (million tons per time period).

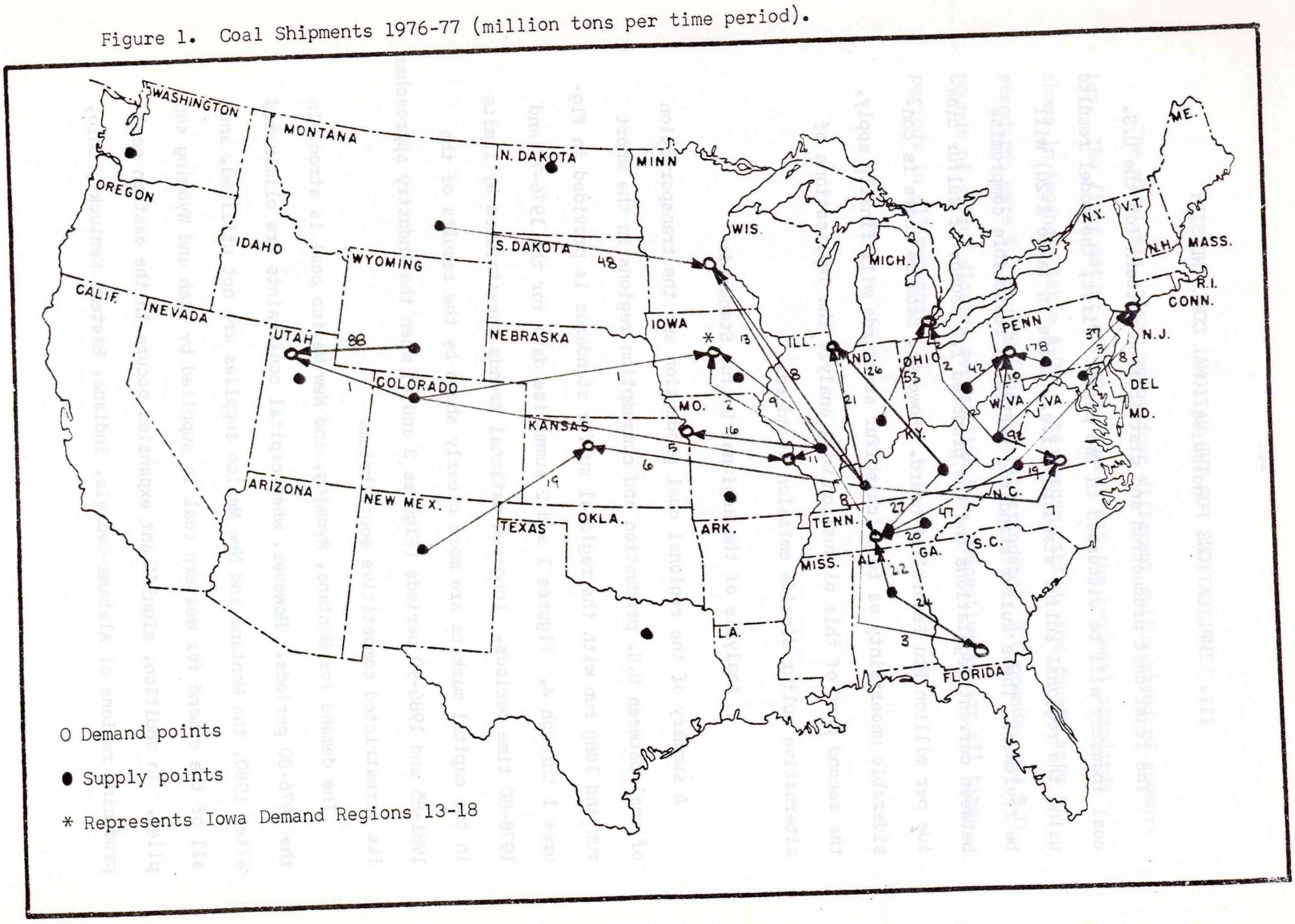


Figure 2. Coal Shipments 1978-80 (million tons per time period).

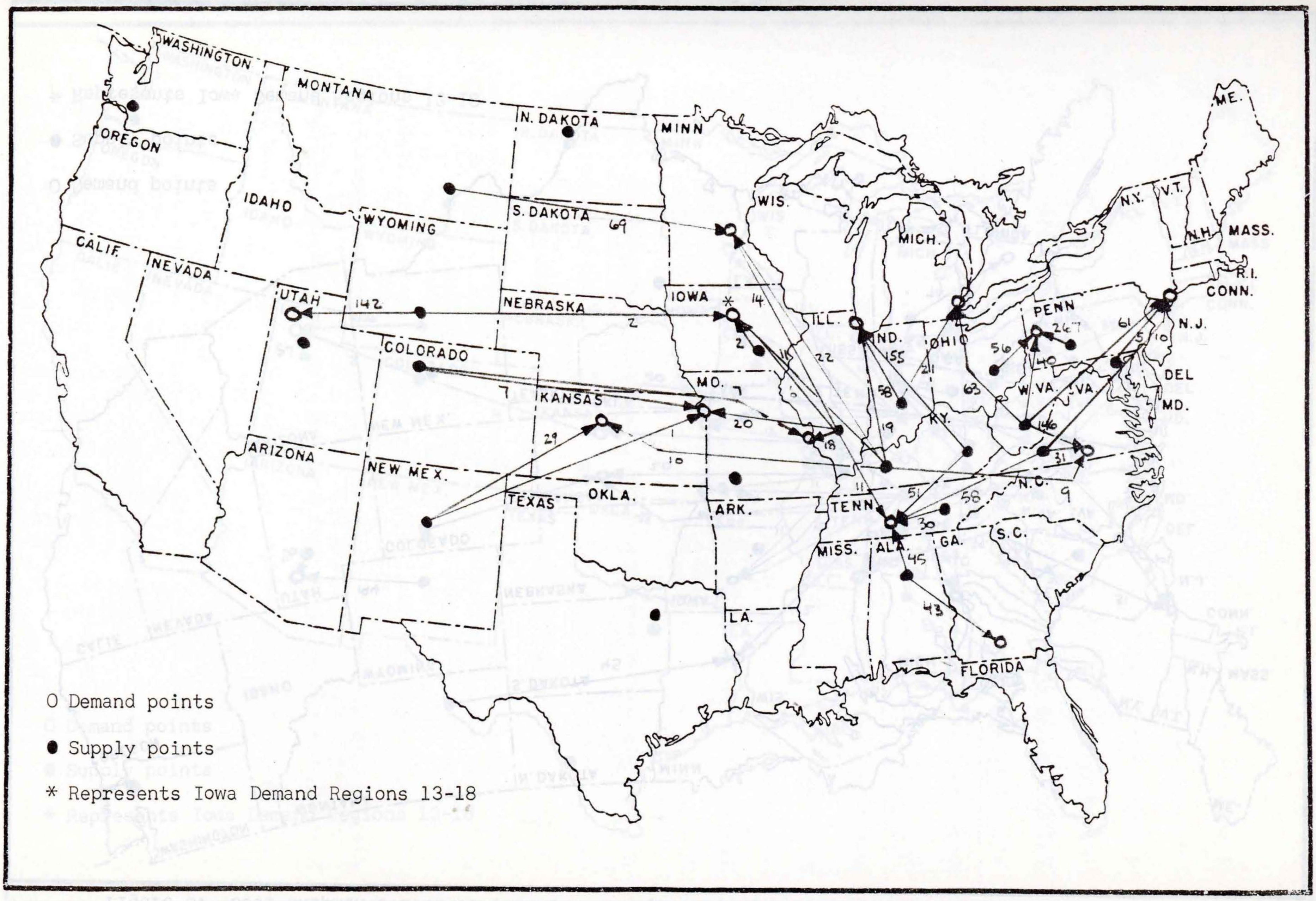


Figure 3. Coal Shipments 1981-85 (million tons per time period).

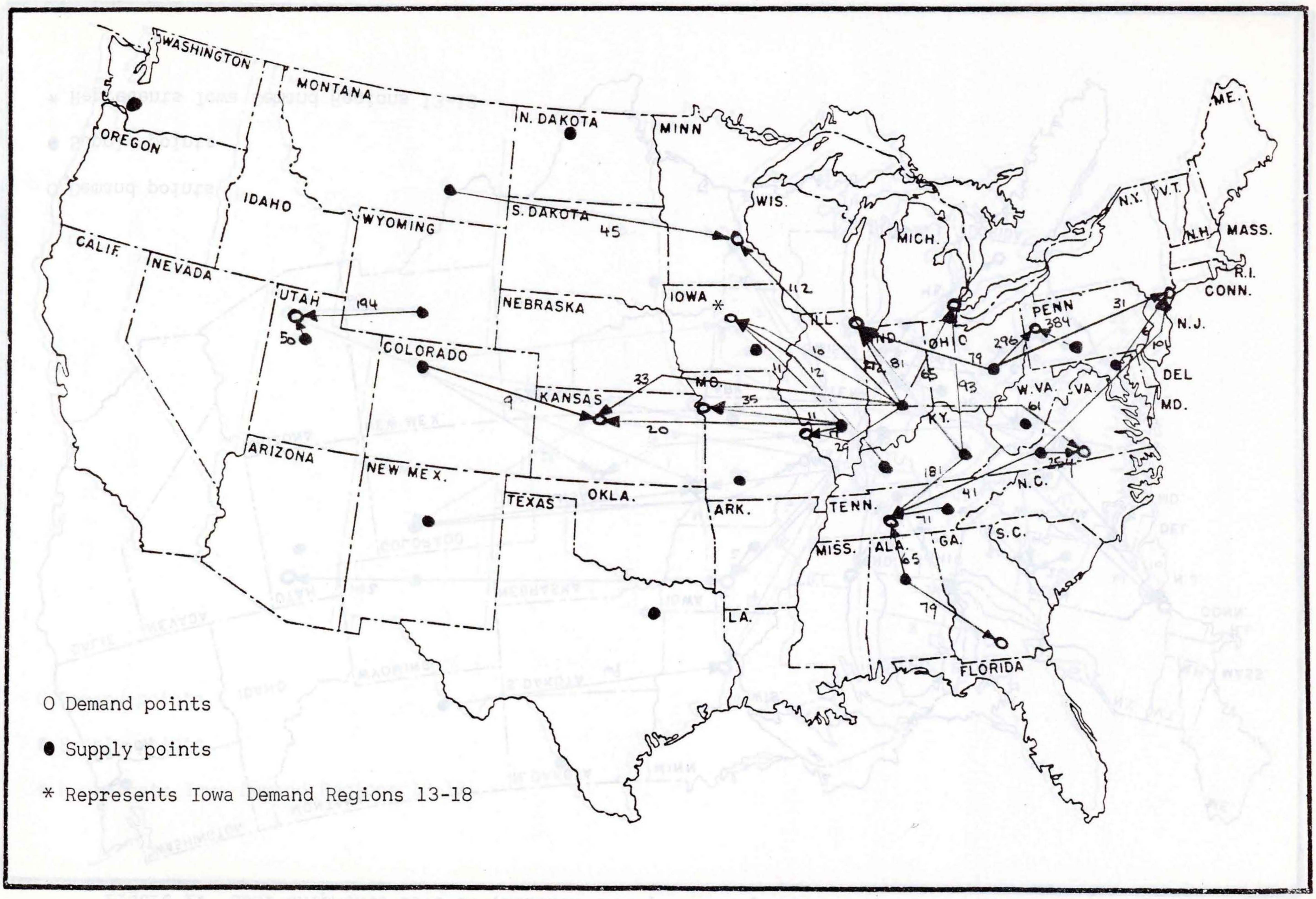
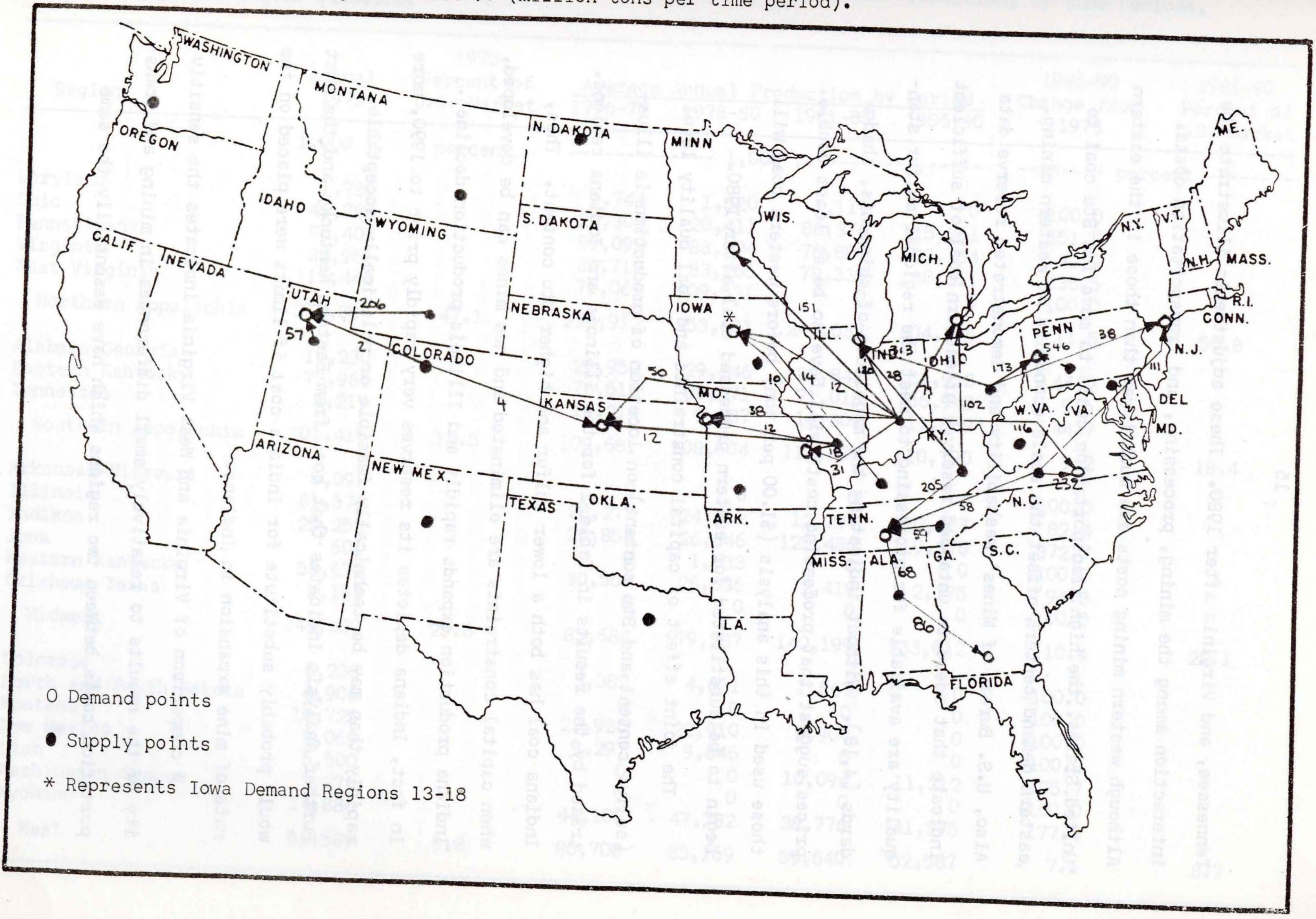


Figure 4. Coal Shipments 1986-90 (million tons per time period).



Tennessee, and Virginia after 1980. These adjustments illustrate the interaction among the mining, processing, and transportation costs. Although western mining costs are much lower than those in the eastern United States, the high transportation costs to move low Btu coal to eastern demand centers offset the scale economies of western mining. Also, U.S. Bureau of Mines' washability and demonstrated reserve data indicate that adequate untapped reserves of eastern coal of sufficient quality are available for processing to meet the regional sulfur standards [4,18]. Without indicating the magnitude of shipments, shadow prices suggest that processing costs will have to be at least double those used in this analysis ($1.00 per ton) before western coal will begin to be substituted for eastern processed coal after 1980.

The joint effect of capital constraints and coal quality level (sulfur content and Btu content) on location of production is illustrated by the results in Table 2 for the Illinois and Indiana regions. Indiana coal has both a lower sulfur and higher Btu content. Thus, when capital constraints are eliminated and new mines can be developed, Indiana production expands rapidly and Illinois production declines. In fact, Indiana depletes its reserves very rapidly prior to 1990, more rapidly than may be technically feasible or politically acceptable. Further analysis indicates that coal from Eastern Kentucky and the West would probably substitute for Indiana coal if limits were placed on the rate of mine expansion in Indiana.

A comparison of Virginia and West Virginia indicates the sensitivity of the results to relatively small differences in mining and transportation costs between two regions which have essentially the same

Table 2. Average Annual Regional Coal Production and Change from 1973 Actual Production, by Time Periods, Regional Sulfur Standard.

Region	Actual 1973	1973 Percent of U.S. Market	Average Annual Production by Period 1976-77	1978-80	1981-85	1986-90	1986-90 Change from 1973	1986-90 Percent of U.S. Market
	1,000 T.	percent	1,000 T.				percent	
Maryland	1,789		1,744	1,520	1,119	0	-100.0	
Ohio	45,783		23,303	20,411	86,376	115,261	151.8	
Pennsylvania	76,403		89,092	88,904	76,809	109,154	42.9	
Virginia	33,961		36,712	33,265	79,335	80,311	136.5	
West Virginia	115,448		73,061	109,531	0	0	-100.0	
Northern Appalachia	273,384	47.1	223,912	253,631	243,639	304,725	11.5	50.8
Alabama-Georgia	19,230		22,950	29,646	28,842	31,953	66.2	
Eastern Kentucky	73,966		76,516	68,871	71,018	66,948	- 9.5	
Tennessee	8,219		10,214	9,987	14,309	11,889	44.7	
Southern Appalachia	101,415	17.5	109,681	108,504	114,169	110,790	9.2	18.4
Arkansas-Missouri	5,092		0	0	0	0	-100.0	
Illinois	61,572		28,277	24,652	12,294	10,867	- 82.4	
Indiana	25,253		26,854	26,646	125,486	119,370	372.7	
Iowa	601		0	1,533	0	0	-100.0	
Western Kentucky	53,679		30,554	26,636	2,419	2,775	- 94.8	
Oklahoma-Texas	2,183		0	0	0	0	-100.0	
Midwest	148,380	25.6	85,684	79,287	140,199	133,012	- 10.4	22.1
Colorado	6,233		3,382	4,631	1,867	0	-100.0	
North and South Dakota	6,906		0	0	0	0	-100.0	
Montana	10,725		23,930	22,910	8,904	0	-100.0	
New Mexico	9,069		9,297	9,846	0	0	-100.0	
Utah	5,500		0	0	10,094	11,312	105.7	
Washington-Oregon	3,270		0	0	0	0	-100.0	
Wyoming	14,886		44,100	47,782	38,776	41,275	177.3	
West	56,589	9.8	80,708	85,169	59,640	52,587	- 7.1	8.7

quality coal and are shipping to the same consumption points. When long-run adjustments can be made (i.e., after 1980), coal production in Virginia increases by 100-135 percent and West Virginia production is reduced to almost zero. These dramatic shifts occur partly because of the specification of the supply and demand points in the model. The choice of demand points or destinations in the populous areas of the eastern United States resulted in consistently higher transportation costs to deliver West Virginia coal, compared to coal from surrounding production regions. Shadow prices suggest that a relative change in total delivered costs (mining, processing, and transportation) of only $0.04 per ton in favor of West Virginia would bring that region into the long-run solution.[6]

Mining equipment availability

To produce the quantity of coal suggested by the model in the 1981-90 period, a substantial number of new mines must be developed. A total of 890 strip mines, each producing 70,000 tons of coal per year, are opened in Virginia during the 1981-90 period. Eastern Kentucky opens 238 strip mines with an average capacity of 200,000 tons per year during this period while 150 strip mines with an average annual capacity of 750,000 tons are opened in Ohio. In Indiana, 105 strip mines with average annual capacity of 1 million tons per mine are opened during 1981-90 and 204 strip mines with an average capacity of 100,000 tons per year are opened in Pennsylvania. This large number of new mine openings will most certainly place severe pressures on the capital-short, mining equipment manufacturers. The implications for land use and reclamation problems and conflicts in these areas are also apparent. Only 50 underground mines with an average capacity of 930,000 tons per year are opened in the United States during this period--suggesting that equipment shortages will not be as severe with respect to underground mines.

Transportation "bottlenecks"

The results of the national production and distribution analysis indicate that substantial concentration of production in regions with high quality reserves will occur after the mining capital availability constraints are relaxed in 1981. This concentration of production could in turn present serious coal transportation problems. Because transportation constraints were not explicitly included in the model, the feasibility of transporting coal from the major production regions to demand centers must be examined. In most cases, the production from one region was distributed to numerous demand points, thus not requiring large shipments over single routes. However, all of the Montana production is shipped to the North Central demand region. This results in a flow from Montana to the North Central region that is five times the 1973 coal movement. In addition, 53 percent of Virginia's significantly increased production goes into the Virginia-Carolina consumption area;

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[6] When evaluating results such as the West Virginia to Virginia shift, it must be recognized that from a national viewpoint it may (and often does) make good sense to abandon operating mines in one region and build more efficient new mines in other regions. From an individual mine operator's point of view, however, abandoning an operating mine may not seem at all attractive and he may continue to operate the mine for the balance of its useful life. This effect will dampen the dramatic adjustments that occur in this model when the capital constraints are lifted in 1981.

however, the most serious transportation bottleneck would appear to be in Ohio. Although Ohio ships coal to three production regions in the 1986-90 period, 60 percent of its shipments go to the Illinois-Indiana demand region. This results in a 63 million-ton-per-year flow from Ohio to Illinois-Indiana, as opposed to near zero shipments between these regions in 1973. Thus, the concentration of coal production in fewer regions will certainly aggravate already difficult transportation problems, and major adjustments will be required in the U.S. transportation industry to satisfy the nation's future energy demand from coal at the lowest cost.

Analysis of Alternative Sulfur Standards

The results of the empirical analysis and the implications for various components of the coal industry under several alternative sulfur standards will now be discussed and compared with the results generated by the regional standards. The three alternative standards to be analyzed are uniform 1.2, 3.0, and 5.0 pounds of sulfur dioxide per million Btu, respectively.

Cost of delivered coal

The objective function gives the discounted total cost of meeting the national coal demand for the 1976-90 period. Therefore, one indicator of the potential increase in the costs to the coal industry and to society in general of meeting increasingly strict emission standards is the change in the value of the objective function as the sulfur standards are changed. The values of the objective function, when expressed in cents per million Btu, were 27.4 cents, 27.8 cents, 29.3 cents, and 30.9 cents for the 5.0 pound, 3.0 pound, regional, and 1.2 pound sulfur standard, respectively. These figures are not of the magnitude one might expect for delivered market prices since they contain no allowance for profit, and they are in present value terms. However, an interesting observation can be drawn from the direction and relative magnitudes of the cost changes. Going from the 5.0 pound to the 3.0 pound sulfur standards involved a 1.2 percent cost increase while changing from the 3.0 pound to the regional standard involved an additional 5.5 percent cost increase. A further change from the regional standard to the 1.2 pound standard results in an additional cost increase of 4.5 percent. Thus, reducing sulfur emissions by 60 percent from 3.0 to 1.2 pounds would require a cost increase of 11.4 percent.[7] The results indicate that as sulfur standards become more strict, the cost of obtaining energy from coal increases at an increasing rate.

Mining methods

The purpose of strict emission standards is the improvement of air quality. A significant additional effect of the standards which also has environmental implications is their effect on how coal will be mined (surface versus underground). The percentages of the total coal demand for all time periods supplied from strip mines were 86 percent, 81 percent, 73 percent, and 68 percent for the 5.0 pound, 3.0 pound, regional, and 1.2 pound sulfur standards, respectively. Thus, more stringent sulfur standards seem to discourage strip mining and favor underground

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[7] An additional solution using a uniform 1.5 pound standard indicates that a 50 percent reduction of emissions (from 3.0 pounds to 1.5 pounds) could be obtained for only a 6.5 percent cost increase.

mining. This effect is due mainly to a relatively higher concentration of low sulfur coal in the nation's underground reserves [18].

Competitive positions of producing regions

Tables 2, 3, 4, and 5 outline changes in coal production by regions and time periods for the regional, 5.0 pound, 3.0 pound, and 1.2 pound sulfur standards, compared to 1973 actual regional production. The long-run equilibrium generally shows a concentration of western coal production in Utah (also Wyoming with the regional and 1.2 pound standards and Montana with the 1.2 pound standard) and a concentration of eastern production in Ohio and Virginia (also Eastern Kentucky and Pennsylvania with the regional and 1.2 pound standards, Indiana with the 5.0 pound and regional standards, and Illinois and Western Kentucky with the 5.0 pound standard).

As one might expect from the small changes in the objective function values, there was little difference in the competitive positions of the various regions between the 3.0 pound and 5.0 pound sulfur standards. However, production in Eastern Kentucky, Pennsylvania, Tennessee, and Wyoming was significantly higher with the 3.0 pound standard, compared to the 5.0 pound standard. In contrast, the competitive positions of Western Kentucky and Ohio were significantly improved as the sulfur standards were relaxed from 3.0 to 5.0 pounds.

The effect of increasingly strict sulfur emission standards is illustrated by changes in the production of low and high quality coal in Kentucky. Under the relaxed 5.0 pound sulfur standard, Western Kentucky shows a 33 percent increase in production from 1973 to 1990.

Table 3. Average Annual Regional Coal Production and Change from 1973 Actual Production, by Time Periods, 5.0 Pound Sulfur Standard.

Region	Actual 1973	1973 Percent of U.S. Market	Average Annual Production by Period 1976-77	1978-80	1981-85	1986-90	1986-90 Change from 1973	1986-90 Percent of U.S. Market
	1,000 T.	percent	----------	1,000 T.	----------		---- percent	--------
Maryland	1,789		1,744	1,520	0	0	-100.0	
Ohio	45,783		23,303	20,411	160,763	169,986	271.3	
Pennsylvania	76,403		89,092	79,842	15,593	17,203	- 77.5	
Virginia	33,961		33,112	28,867	62,026	67,995	100.2	
West Virginia	115,448		58,128	105,860	0	0	-100.0	
Northern Appalachia	273,384	47.1	205,379	236,499	238,381	255,184	- 6.7	41.2
Alabama-Georgia	19,230		19,163	16,759	16,057	11,250	- 41.5	
Eastern Kentucky	73,966		76,516	68,871	6,054	0	-100.0	
Tennessee	8,219		8,614	8,387	4,380	3,234	- 60.7	
Southern Appalachia	101,415	17.5	104,294	94,017	26,491	14,483	- 85.7	2.3
Arkansas-Missouri	5,092		4,962	4,327	0	0	-100.0	
Illinois	61,572		32,277	30,652	34,986	88,202	43.3	
Indiana	25,253		27,623	26,646	165,227	143,214	467.1	
Iowa	601		307	511	0	0	-100.0	
Western Kentucky	53,679		30,554	36,755	41,174	71,318	32.9	
Oklahoma-Texas	2,183		4,182	5,671	0	0	-100.0	
Midwest	148,380	25.6	99,905	104,381	241,387	302,735	104.0	48.9
Colorado	6,233		4,170	4,200	1,867	1,149	- 81.6	
North and South Dakota	6,906		0	0	0	0	-100.0	
Montana	10,725		25,456	24,115	0	0	-100.0	
New Mexico	9,069		11,294	9,846	0	0	-100.0	
Utah	5,500		0	0	8,536	43,864	697.5	
Washington-Oregon	3,270		0	0	0	0	-100.0	
Wyoming	14,886		44,100	30,292	42,408	1,778	88.1	
West	56,589	9.8	85,020	87,075	52,811	46,791	- 17.3	7.6

Table 4. Average Annual Regional Coal Production and Change from 1973 Actual Production, by Time Periods, 3.0 Pound Sulfur Standard.

Region	Actual 1973	1973 Percent of U.S. Market	Average Annual Production by Period 1976-77	1978-80	1981-85	1986-90	1986-90 Change from 1973	1986-90 Percent of U.S. Market
	1,000 T.	percent	-------------	1,000 T.	-------------		-------- percent	--------
Maryland	1,789		1,744	1,520	1,119	689	- 61.5	
Ohio	45,783		23,303	20,411	90,295	133,214	191.0	
Pennsylvania	76,403		89,092	79,842	64,561	44,474	- 41.8	
Virginia	33,961		33,112	28,867	68,311	75,179	121.4	
West Virginia	115,448		52,648	109,531	0	0	-100.0	
Northern Appalachia	273,384	47.1	199,898	240,170	224,287	253,556	- 7.3	41.6
Alabama-Georgia	19,230		22,950	20,546	16,700	18,181	- 5.5	
Eastern Kentucky	73,966		76,516	68,871	27,718	19,365	- 73.8	
Tennessee	8,219		8,821	8,593	6,898	17,906	117.9	
Southern Appalachia	101,415	17.5	108,288	98,011	51,316	55,452	- 45.3	9.1
Arkansas-Missouri	5,092		4,962	4,327	0	0	-100.0	
Illinois	61,572		32,277	30,652	32,157	91,031	47.8	
Indiana	25,253		27,623	26,466	165,227	143,214	467.1	
Iowa	601		239	408	0	0	-100.0	
Western Kentucky	53,679		30,554	27,836	21,509	14,140	- 73.7	
Oklahoma-Texas	2,183		7,076	3,007	0	0	-100.0	
Midwest	148,380	25.6	102,730	92,696	218,953	248,386	67.4	40.7
Colorado	6,233		6,077	5,298	1,867	1,149	- 81.6	
North and South Dakota	6,906		0	0	0	0	-100.0	
Montana	10,725		25,456	24,257	0	0	-100.0	
New Mexico	9,069		11,294	9,846	0	0	-100.0	
Utah	5,500		0	0	8,536	43,864	697.5	
Washington-Oregon	3,270		0	0	0	0	-100.0	
Wyoming	14,886		44,100	53,115	50,253	7,529	- 49.4	
West	56,589	9.8	86,926	92,547	60,656	52,542	- 7.2	8.6

Table 5. Average Annual Regional Coal Production and Change from 1973 Actual Production, by Time Periods, 1.2 Pound Sulfur Standard.

Region	Actual 1973	1973 Percent of U.S. Market	Average Annual Production by Period 1976-77	1978-80	1981-85	1986-90	1986-90 Change from 1973	1986-90 Percent of U.S. Market
	1,000 T.	percent	-------------	1,000 T.	-------------		-------- percent	--------
Maryland	1,789		1,744	1,520	0	0	-100.0	
Ohio	45,783		23,303	20,411	57,562	55,835	22.0	
Pennsylvania	76,403		89,092	88,904	100,421	109,178	42.9	
Virginia	33,961		36,712	36,067	79,166	89,805	164.4	
West Virginia	115,448		113,311	109,531	0	0	-100.0	
Northern Appalachia	273,384	47.1	264,162	256,433	237,149	254,818	- 6.8	41.6
Alabama-Georgia	19,230		22,950	29,646	40,673	45,783	138.1	
Eastern Kentucky	73,966		76,516	68,871	141,794	166,887	125.6	
Tennessee	8,219		10,215	9,987	14,309	11,889	44.7	
Southern Appalachia	101,415	17.5	109,681	108,504	196,776	224,559	121.4	36.6
Arkansas-Missouri	5,092		0	0	0	0	-100.0	
Illinois	61,572		7,946	12,175	0	0	-100.0	
Indiana	25,253		26,854	25,795	20,902	14,786	- 41.4	
Iowa	601		0	0	0	0	-100.0	
Western Kentucky	53,679		487	0	0	0	-100.0	
Oklahoma-Texas	2,183		0	0	0	0	-100.0	
Midwest	148,380	25.6	35,287	37,970	20,902	14,786	- 90.0	2.4
Colorado	6,233		6,877	12,098	7,867	8,226	32.0	
North and South Dakota	6,906		0	0	0	0	-100.0	
Montana	10,725		25,456	37,089	34,945	36,347	238.9	
New Mexico	9,069		15,860	14,413	0	0	-100.0	
Utah	5,500		0	0	10,094	10,972	99.5	
Washington-Oregon	3,270		0	0	0	0	-100.0	
Wyoming	14,886		44,100	70,590	58,295	63,399	325.9	
West	56,589	9.8	92,293	134,190	111,200	118,943	110.2	19.4

However, the more strict regional and 1.2 pound standards make it too costly to use Western Kentucky low quality coal, even for blending. On the other hand, Eastern Kentucky's more expensive, higher quality coal plays a major role in meeting the national coal demand under the regional and 1.2 pound standards but is an insignificant source under the 5.0 pound standard.

In some regions, production decreased significantly in later periods not because of costs alone, but because their most accessible and highest quality reserves were exhausted. This occurred in Alabama-Georgia, Ohio, and Pennsylvania for all four sets of sulfur standards, and in Indiana for all but the 1.2 pound standard. Higher quality Illinois and Utah reserves and lower quality Pennsylvania and Virginia reserves were also exhausted for the 3.0 and 5.0 pound standards, and higher quality Tennessee and Virginia reserves were exhausted for the 3.0 pound, regional, and 1.2 pound sulfur standards.

Although numerous shifts occurred among the various production regions as sulfur dioxide standards and capital availability assumptions were changed, several of these shifts were only reallocations between neighboring regions that may have been caused in part by the decisions made concerning the aggregation and delineation of the regions in the model. To facilitate an understanding of the implications of these adjustments for major production areas and the development of national policy, the 21 regions were aggregated into four areas--Northern Appalachia, Southern Appalachia, the Midwest, and the West. The changes in long-run production and share of total U.S. output for these areas are also summarized in Tables 2, 3, 4, and 5 for the regional, 5.0 pound, 3.0 pound, and 1.2 pound sulfur standards, respectively. Note that the results with the regional standard show little change in the percent of total U.S. consumption supplied from the four major areas in the 1986-90 period, compared to 1973. However, significant adjustments do occur between regions in each area to exploit the highest quality coal in that area.

The national implications of different sulfur dioxide standards are readily apparent in the comparison of the results of Tables 2, 3, 4, and 5. As sulfur dioxide standards become more restrictive, those areas with lower sulfur content coal and competitive costs increase their share of the U.S. market dramatically. Thus, with a change from the 5.0 pound to the regional sulfur standard, the share of U.S. 1986-90 consumption supplied by the Midwest declines from 48.9 to 22.1 percent. In this region, production declines in absolute as well as relative (market share) terms. A further tightening of sulfur dioxide standards to 1.2 pounds rapidly accelerates this trend, as the Midwest share is reduced to only 2.4 percent of U.S. 1986-90 consumption. In contrast, 1986-90 production increases dramatically in Southern Appalachia, from 2.3 to 18.4 to 36.6 percent of total U.S. consumption as sulfur dioxide standards become more restrictive. Note that the share of U.S. output obtained from the West does not change significantly until sulfur dioxide standards are lowered to 1.2 pounds. Southern Appalachia and Western coal substitutes for the lower quality Midwestern coal as sulfur dioxide standards become more restrictive. Thus, the 5.0 pound standard would allow the Midwest to replace Northern Appalachia as the major coal producing area in 1986-90. In contrast, the

1.2 pound standard would double the shares of both Southern Appalachia and the West, mainly at the expense of the Midwest.

Coal processing capacity

The model as presently specified assumes unlimited processing capacity in each of the regions. Thus, to evaluate the potential problems that may be encountered in processing, the amount of coal processed as indicated by the model results will be compared to regional processing capacity in 1973. This comparison seems relevant only for the periods 1976-77 and 1978-80 since after 1980, it is likely that sulfur-reducing techniques other than washing (gasification or stack gas scrubbing) will become widely accepted. However, the short-run ability of the coal industry to meet processing demands is of importance since there are no immediate substitutes for coal washing.

The average annual amount of coal processed under the regional and 1.2 pound sulfur standards for the seven production regions where significant processing occurs is compared with the 1973 actual processing figures for these regions in Table 6. There would appear to be little problem in meeting the 1976-77 processing demands since the seven regions process only marginally more than the amount processed in 1973. It seems that in the short run, the availability of processing equipment will not be a serious problem under the regional and 1.2 pound sulfur standards.

Very little coal is processed using the 3.0 pound sulfur standard; Illinois is the only region listed in Table 6 that processes any coal during 1976-77 and 1978-80, and the amounts processed in this region are

Table 6. Average Annual Coal Processing in Selected Regions for 1976-80.

Region	1973[a]	Regional Sulfur Standard		1.2 Pound Sulfur Standard	
		1976-77	1978-80	1976-77	1978-80
	1,000 Tons				
Illinois	48,091	16,274	10,658	6,734	10,318
Indiana	19,699	14,796	19,188	26,229	25,044
Eastern Kentucky	22,264	0	0	22,814	0
Western Kentucky	20,005	15,620	15,388	0	0
New Mexico	494	0	0	4,229	2,116
Ohio	14,588	21,184	18,556	0	781
West Virginia	75,672	19,931	48,443	100,276	96,930

[a] 1973 actual production of cleaned coal taken from [22].

less than the 1973 rate. No coal is processed in any region during 1976-80 when the model was solved using the 5.0 pound sulfur standard. Reserves of sufficiently low sulfur content were available to meet the 5.0 pounds of sulfur dioxide per million Btu standard without incurring the processing cost. Therefore, the availability of processing equipment appears to be a matter of little concern in the short run for these more lenient sulfur standards.

Finally, if washing is still the predominant sulfur reduction method in 1981-90, serious equipment availability problems may occur with the regional and 1.2 pound standards. With the regional standard, Indiana processes about 70 million tons annually during the 1981-90 period, and Ohio processes over 50 million tons annually during 1981-86 and 105 million tons annually during 1986-90. However, Illinois reduced processing activity to 3.5 million tons annually, and Western Kentucky and West Virginia process no coal in the 1981-90 period.

Less serious processing equipment shortages would occur after 1980 with the 1.2 pound standard. Eastern Kentucky processes about 93 million tons annually during 1981-85 and almost 110 million tons per year through 1986-90. But, Ohio processes only about 40 million tons per year in 1981-90, a significant decrease from its processing activity under the regional standard. Indiana is the only other region which processes any coal after 1980, processing about 14 million tons annually which is below its 1973 processing activity.

Summary

The results indicate that the costs of supplying coal to the demand points increase at a rapidly rising rate as sulfur standard become increasingly more strict. Furthermore, the more strict sulfur standards also result in more coal coming from underground as compared to strip mines--primarily because the underground reserves contain a relatively large proportion of low sulfur coal.

The changes in the sulfur emission standards also influence the regional production of coal and the development of new mines. As the emission standards become more strict, coal mining in the high sulfur areas such as Illinois and Western Kentucky declines while mining activity increases in Alabama-Georgia, Wyoming, Pennsylvania, Tennessee, and Virginia. Limits on the development of new mines prior to 1980 enhance the competitive position of western production regions until that year. But during the 1981-90 period when no limits are placed on new mine development, the eastern production regions of Indiana, Ohio, and Virginia expand dramatically at the expense of the western regions.

Under the restrictive regional sulfur dioxide standards, the 1986-90 percent of total consumption supplied by various producing areas is quite similar to actual 1973 market shares. Further tightening of sulfur dioxide emission standards to 1.2 pounds results in the West supplying more coal to Midwest consumption regions west of the Mississippi River. Southern Appalachia competes more favorably with Midwestern coals in consumption regions east of the Mississippi. If sulfur standards are relaxed to the 5.0 pound level, the Midwest would increase its market share dramatically at the expense of both Northern and Southern Appalachia. Processing capacity does not appear to present any serious problems for the coal industry prior to 1980, but it may be a serious impediment to growth after that year if new technology (gasification or stack gas scrubbing) is not available to efficiently reduce the sulfur content of coal.

With the significant changes in the regional production of coal suggested by this analysis, coal transportation problems will certainly be severe. These transportation problems are aggravated even more by the increasingly strict sulfur standards because a larger quantity of the nation's coal must come from those few production regions with low sulfur reserves. Thus, major adjustments must be made in the transportation industry to satisfy the nation's future energy demand from coal at the lowest cost. These adjustments will require more efficient and higher volumes on the Virginia to Virginia-Carolina, Ohio to Illinois-Indiana, and Montana to North Central states routes particularly.

IV. EVALUATING THE FUTURE PROSPECTS FOR A MARGINAL PRODUCING REGION

The model used in this study can also provide useful insight into the economic prospects of a marginal producing region. In fact, a principal objective of this study was to evaluate the competitive position of the Iowa producing region. The results of the Iowa analysis are presented to indicated the opportunities for a major industry in Iowa and to provide an example of the type of extensive analysis that should be undertaken before any marginal producing region is encouraged to expand.

A Note on Hypothesis Testing

The analysis of this chapter was undertaken to determine whether public intervention in the Iowa coal economy through research and development expenditures could be expected to attract significant private investment in an industry presently characterized by small-scale operations. Thus, the null hypothesis to be tested was that Iowa has the potential to become a major coal producing region. Concluding that this hypothesis was false when in fact it was true (a Type I error), could discourage the development of an industry which could make a significant contribution to the Iowa economy; therefore, the following two-stage strategy was adopted to guard against such a costly error. First, initial input parameters for coal quality, demand, and costs were specified as favorable to the development of an industry in the state. Second, sensitivity analysis was done on these parameters to evaluate the potential development of an industry under more favorable parameter specifications.

The following model parameters were specified for Iowa for the initial analysis:

1) Run-of-mine Iowa coal was assumed to have a heating value of 11,746 Btu per pound and a sulfur content of 7.1 pounds of sulfur dioxide per million Btu (4.3 percent sulfur by weight). By incurring the $1.00 per ton processing costs, the Btu content could be increased to 12,735 and the sulfur reduced to 5.2 pounds sulfur dioxide (3.1 percent by weight). These heating values and sulfur content levels reflect the characteristics of the higher quality coal in Iowa.

2) Iowa was assumed to have about 2.9 billion tons of underground mineable coal [18]. No strippable reserve limit was specified for Iowa.

3) Although all other regions were restricted as to how many new mines they can open before 1980, no such limits of available equipment or manpower were placed on Iowa for either underground or surface mines.

4) The Iowa demand regions were disaggregated, compared to other demand region specifications, to allow for more "localized" coal shipments from the Iowa producing region.

The impact of changes in model parameters on the competitive position of a producing region must be carefully analyzed before policy recommendations are drawn from the model results for three reasons:

1) The method (linear programming) necessarily requires use of a point estimate of each model parameter from a distribution of parameter values.

2) Results may be biased by the necessary process of aggregating several different components (i.e., mines or coal users) into a single component with a single set of parameters.

3) Unexpected changes in technology may occur which may affect the results.

Thus, the sensitivity analysis was structured to evaluate the impact of changes in Iowa mining costs, transportation costs, sulfur dioxide emission standards, capital constraints, demand levels, and processing technology.

Economic Prospects for the Iowa Producing Region

The model solution using the "most likely" set of parameters (the regional sulfur standards) indicated that in the 1976-77 period no coal is mined in Iowa, even though existing mining capacity would have allowed the production of over 1 million tons without incurring additional costs to build new mines. However, the demand increase in 1978-80 in all consuming regions results in enough pressure on the capital-short national coal industry to mine coal in Iowa in this period. All of the existing surface and underground mining capacity is used during the 1978-80 period. A total of 625,000 tons are strip mined during the three-year period (208,000 tons per year), and the underground mines produce 908,000 tons (303,000 tons per year). After 1980 when the mining capital constraints on coal production in the other production regions in the nation are removed, coal production in Iowa is discontinued. The increasing national demand for coal encourages this brief flurry of mining activity in Iowa because more efficient mines cannot be opened elsewhere. As soon as those mines can be opened, Iowa mines can no longer compete and production is discontinued or reduced to an insignificant level. The sensitivity and dependence of Iowa's coal industry on both demand increases and capital shortages in other regions will be analyzed in more detail later.

No Iowa coal is processed in this solution because of the comparatively high cost of Iowa coal after processing, compared to coal from other regions. Even excluding fixed costs, Iowa coal costs $8.54 per ton to mine ($0.36/million Btu). However, the weight recovery in processing Iowa coal is only 71.5 percent, so 1.40 tons of run-of-the-mine coal must be mined to obtain one ton of processed coal. Thus, the cost per ton of processed coal is $11.96 ($8.54 times 1.40), plus the $1.00 processing cost or $12.96 per ton ($0.55/million Btu). This compares to an operating cost of $4.12 per ton ($0.18/million Btu) to mine the higher quality Illinois coal which does not need to be processed to meet Iowa sulfur dioxide emission standards.

Sensitivity Analysis

In this section, each of the parameters critical to the development of a significant coal industry in Iowa is adjusted to determine the change necessary to improve Iowa's competitive position. No implication is suggested that these adjustments are likely to occur, and, in fact, parameter values farther from those used in the initial analysis just discussed are judged to less likely occur.

Changes in strip mining costs

The $8.54 per ton operating cost for Iowa strip mines is one of the major factors that is detrimental to Iowa's competitive position. Therefore, the impact of reducing strip mining costs to $6.54, $4.54, and $2.54 per ton is examined. Mining costs are reduced only in Iowa with costs in other regions held constant. A development in mining technology that will reduce costs in all regions will not necessarily improve Iowa's competitive position; however, mining costs could be reduced significantly if additional deposits of coal, in thicker seams and closer to the surface than currently documented, are discovered.[8] Furthermore, the mining cost reduction caused by such discoveries would improve Iowa's competitive position vis-a-vis other producing regions.

The findings indicate that Iowa coal production would increase significantly if mining costs could be reduced by $2.00 per ton. In the 1976-77 period, 745,000 tons of coal per year are strip mined in Iowa and over 2.9 million tons per year are mined in 1978-80. A significant number of new strip mines are opened during these two periods. The reduced strip mining costs place the Iowa underground mines at a relative cost disadvantage, and underground mine production in Iowa ceases entirely. However, even with the $2.00 reduction in mining costs, Iowa cannot compete after 1985 and both new and existing mines are abandoned as production moves to other regions. With respect to consumption, Iowa coal is blended with coal from other regions, primarily Illinois and Western Kentucky through 1980. Illinois, Indiana, and Western Kentucky supply most of Iowa's consumption requirements during the 1981-90 period.

If strip mining costs in Iowa are reduced by $4.00 per ton, Iowa

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[8] Derivations of mining costs are explained in greater detail in Appendix A. Large mining equipment is currently not applicable in Iowa because of deposit characteristics. Most mines utilize a small dragline or teams of bulldozers, earth scrapers, and front-end loaders. A dozer-scraper-loader system is used in this study for all small mine sizes. More efficient machines and mining plans may have cost reduction potential as well as thicker, shallower deposits.

becomes a competitive producing region in both short- and long-run situations. Mining occurs in all time periods; a substantial number of strip mines (198) are opened before 1980 and continue to produce through 1990. A limited quantity of Iowa coal is processed in the 1976-77 time period (1.3 million tons) and also in 1978-80 (3.2 million tons). The Iowa supply region provides a significant portion of Iowa's coal consumption requirements in each time period and some Iowa coal is exported to the Western, North Central, and South Central regions of the United States. However, blending coal obtained from other regions is still a less expensive way to meet Iowa emission standards than using processed Iowa coal.

The results of the analysis with Iowa mine operating costs at $2.54 per ton show that Iowa mining costs must be reduced by at least $6.00 per ton (approximately 75 percent) for there to be a significant coal processing industry in Iowa. Again, Iowa mines substantial amounts of strippable coal in each time period and is largely self-sufficient with respect to coal consumption. Thus, Iowa processed coal (mined at $2.54 per ton plus $1.00 per ton for processing) is competitive with Illinois, Indiana, and Western Kentucky coal.

Iowa's dependency on the mining equipment shortage

As has been indicated earlier, Iowa's competitive position depends upon costs and conditions in other producing regions--particularly with respect to mining equipment availability and new mine development. To analyze the impact of unlimited equipment availability, the capital and equipment availability restrictions for all regions and all time periods were removed from the model. Resolving the model showed that no coal was mined in any time period in Iowa with no limits on new mine development in other production regions. Iowa's coal demands were supplied by Western Kentucky and Indiana (plus Illinois in all but 1986-90) during all four periods.

To analyze the interrelationships between mining costs and capital availability, the mining cost analysis of the previous section (i.e., reducing operating costs to $6.54, $4.54, and $2.54 per ton) was repeated with no capital constraints in any supply region or time period. As expected, Iowa production was less in all time periods under all levels of mining costs when capital was unlimited elsewhere. However, the reduction in mining activity during the 1976-80 period was significantly greater for each cost level as compared to the corresponding cases when Iowa's competitors face capital shortages. Thus, the ability and speed of adjustment in the capital goods market to supply new mining equipment is a major (possibly the most important) determinant of the fate of the Iowa coal industry.

Changes in Iowa transportation costs

One possible method to improve the competitive position of the marginal producing region is to reduce the cost of transporting coal from that region to the consumption point. To analyze this method, the cost of transporting coal from the Iowa supply region to each of the Iowa markets was reduced by 20, 40, 60, and 80 percent. As with mining costs, transportation costs are reduced only for Iowa routes and the costs of shipping coal between other regions are held constant.

Such a plan might be implemented through a state legislative subsidy of the Iowa transportation facilities.

Reducing Iowa's transportation costs by 20 percent has an immediate positive effect on Iowa's competitive position in the short run. Iowa strip mines produce about 240,000 tons per year during the 1976-77 period, compared to mining no coal in 1976-77 with the higher transportation costs. About 1.6 times as much coal is strip mined during the 1978-80 period (326,000 tons per year) with the 20 percent reduction in transportation costs. However, again no coal is mined in Iowa after 1980--indicating that a 20 percent decrease in transportation costs does not provide a sufficient incentive to attract mining investments to Iowa when there are alternatives available elsewhere.

Reducing transportation costs an additional 20 percent (a 40 percent total reduction) has only a marginal additional impact on Iowa's competitive position. An additional 1.3 million tons are strip mined in the 1978-80 period with annual production increasing to 756,000 tons per year. However, production again drops to zero after 1980. Thus, a subsidy that reduces transportation costs by 20 percent will have almost the same stimulative effect on the Iowa coal industry as one which reduces costs by 40 percent.

With a 60 percent reduction in Iowa transportation costs, the amount of strip mined coal produced in Iowa increases substantially prior to 1980. The amount of coal obtained from underground mines remains at zero in all periods, except 1978-80 when underground mining is at the maximum mineable limit without investing in new underground mines (300,000 tons per year). However, the 60 percent reduction in

transportation costs does not significantly improve Iowa's competitive position as a coal producer after 1980, nor does it cause Iowa processed coal to be competitive in meeting emission standards in Iowa.

The model solution when transportation costs were reduced by 80 percent provides two important insights into the future of the Iowa coal industry. First, it indicates that transportation cost reductions will have to be in the neighborhood of 80 percent for Iowa coal to be competitive after 1980 when the capital restrictions are lifted from the mining industry in competing regions. Secondly, it suggests that even the 80 percent reduction in transportation costs will not make processing Iowa coal an economically attractive proposition. Blending Iowa run-of-the-mine coal with the better grades of Illinois and Indiana coal is a less expensive way to meet emission standards, irrespective of Iowa transportation costs.

Changes in processing technology

A considerable research effort has been directed at discovering a technological breakthrough in processing that would substantially reduce the sulfur content of Iowa coal. To evaluate the potential payoff of this discovery, a solution was generated using the same washability characteristics of Iowa coal as in the base model, except the sulfur content of the coal after processing was 2.0 pounds of sulfur dioxide per million Btu rather than the 5.2 pounds of sulfur dioxide used in the base solution. This would put Iowa processed coal among the better processed coals available in the United States. Note that it is assumed this sulfur reduction from 7.1 to 2.0 pounds of sulfur dioxide can still be obtained at a cost of $1.00 per ton. Even with this improvement in processing technology, no Iowa coal is mined in 1976-77 or after 1980. Iowa mines the same amount of coal in the 1978-80 period as in the base solution and no coal is processed. The Iowa consumption pattern also remains unchanged.

An additional important dimension of the processing technology is the weight loss or fractional weight recovery. A higher fractional weight recovery would decrease the cost per processed ton of coal. Thus, if the weight recovery in processing Iowa coal was 90 percent instead of 71.5 percent, only 1.11 tons of run-of-the-mine coal, instead of 1.40 tons, would need to be mined to obtain one ton of processed coal. The impact of a technological change allowing a fractional weight recovery for Iowa coal of 90 percent can be judged by reviewing the sensitivity analysis for a mining cost reduction of $2.00 since the resulting costs per processed ton are similar.[9]

Thus, if the quality parameters used for Iowa coal are representative, the short-run payoff of an improvement in processing technology would not appear to improve the competitive position of Iowa as a coal producing region. The more serious problem for Iowa coal is its cost rather than its quality. This result is obviously of no small importance in determining research priorities concerning Iowa coal.

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[9] The cost per processed ton of (a) coal with 90 percent fractional weight recovery, and (b) coal mined with $2.00 reduction in mining costs are:

(a) ($8.54 x 1.11) + $1.00 = $10.48
(b) ($6.54 x 1.40) + $1.00 = $10.19

Changes in emission standards

Currently, each state has some control over the level of sulfur dioxide emission standards, subject to Federal regulations and standards. Therefore, it might be argued that Iowa's competitive position and coal self-sufficiency could be improved by relaxing the Iowa sulfur dioxide emission standards. To test this hypothesis, maximum emission standards in Iowa were raised from 6.0 pounds sulfur dioxide per million Btu to 18.0 pounds before 1978 and from 5.0 pounds to 15.0 pounds after 1978. All of the sulfur dioxide emission standards in the other consumption regions were left unchanged.

When the model was solved with the higher emission standards, Iowa's competitive position as a coal producer was not enhanced. The explanation for no impact when Iowa emission standards are relaxed lies in the interrelationships between production regions. Western Kentucky has a substantial quantity of low quality, inexpensive coal that cannot be used in any consumption region with the original sulfur standards. When Iowa relaxes its sulfur standards, this creates a market for the unusable Western Kentucky coal as well as the Iowa coal. The Western Kentucky coal is less expensive to mine and transport to the Iowa user, so Iowa coal is not used.

Iowa's competitive position would possibly be enhanced if the emission standards in all regions were relaxed simultaneously rather than just in Iowa. Relaxing all standards would reduce Iowa's attractiveness as a "dumping ground" for low quality coal from other regions. To analyze the effects of relaxing sulfur standards in all regions, the base model data was modified to reflect an emission standard of 5.0 pounds sulfur dioxide per million Btu for all regions (including Iowa) and all time periods. When all regions have a 5.0 pound standard, Iowa uses all of its mining capacity in the 1976-80 period and 19 new strip mines are opened. There are sufficient alternative uses for the low quality Western Kentucky coal to prevent heavy shipments of it to Iowa. Iowa is a major supplier of the Iowa coal demand in 1976-80 with various other coals being blended with the Iowa coal to meet the 5.0 pound standard. However, there is no processing of Iowa coal in any time period, nor mining activity after 1980.

Although the simultaneous relaxation of emission standards in all regions is legislatively unlikely, a similar effect may occur if gasification or some such process makes the sulfur content of coal in every region a much less critical consideration. If this occurs, the results of the analysis with the 5.0 pound standard suggest a further problem. By the time gasification is commercially available to potentially improve the position of producers of high sulfur coal, factors such as the mining equipment shortage should be sufficiently remedied to put Iowa and other regions with low quality reserves at a significant competitive disadvantage, irrespective of sulfur emission standards.

Changes in the national coal demand

To analyze Iowa's dependence as a coal producer on the growth in demand for coal, two alternatives to the moderate growth in demand of the initial model were specified. The first was no change in demand for the entire 1976-90 period from the 1973 consumption level. The second demand scenario was designed to approximate a doubling of coal use by the year 2000. Both alternative demand scenarios were analyzed with the 5.0 pound emission standard for all regions and time periods.

The results indicate that changing from the moderate growth in demand to the constant demand alternative reduces Iowa strip mine production by approximately 80 percent. In contrast, Iowa production increases dramatically in the 1978-80 period when the coal industry is forced into an "all-out" effort to satisfy the rapid growth in demand. However, even with these increases in demand, Iowa is competitive as a coal production region only as long as there are mining capital and equipment restrictions in other regions. Iowa mines no coal after 1980, even with the most rapid increase in demand. Note that the relaxed sulfur standards (5.0 pounds of sulfur dioxide), which are the most favorable to Iowa coal development, are used in this analysis. Thus, significant increases in the demand for coal can apparently create a short-lived "coal rush" in Iowa, but once equipment availability problems in other regions are remedied, Iowa mines are abandoned and production moves to other lower cost regions.

Summary

The results suggest that dramatic (and probably unlikely) changes must occur before the marginal producing region--Iowa--will play a long-run role as a supplier in the national coal economy. In most scenarios analyzed, increased production occurs in the short run, but only because expansion in mining capacity was specified as being unlimited in Iowa and severely limited in all other regions until 1980. After 1980 when expansion can occur elsewhere, even the new mines are abandoned in Iowa because Iowa consumers can acquire their coal from other regions at a lower cost.

When the 1976-80 restrictions on new mine development in other regions are eliminated, Iowa does not play a major role as a coal supplier in either the long or short run. Thus, the results suggest that at best the fixed costs incurred in developing new mines in Iowa should be recoverable within a five-year period. In the longer run, if operating costs are $8.54 per ton for Iowa mines, Iowa's energy needs from coal can be supplied at the lowest cost by obtaining coal from other lower cost producing regions.

For Iowa to become a competitive producer of coal in the long run, the results of this analysis indicate that the demand within the state must increase dramatically, the operating costs for strip mines must be reduced by approximately 50 percent, state sulfur dioxide emission standards must be maintained rather than adopting more stringent Federal standards, and expansion of new mines must be limited in all other production regions until 1980. Under the above conditions, Iowa could produce a sufficient quantity of coal to satisfy almost 50 percent of its domestic demand as well as ship a limited quantity out of state. A larger quantity would not be consumed domestically because Iowa coal must be blended with lower sulfur content coal from other regions, even to meet the relatively unrestrictive state emission standards.

V. SUMMARY AND CONCLUSIONS

The rapidly rising demand for energy in the United States has encouraged policy makers to consider several new energy sources. However, both industry and government analysts agree that in all likelihood the traditional sources of energy (natural gas, petroleum, coal, and nuclear) will make the most significant impact on the nation's energy supplies in the next decade. Because of massive reserves and fewer environmental problems in comparison to other sources such as nuclear power, coal is projected to play a major role in the intermediate term energy outlook.

This study was undertaken to determine whether the coal mining industry would be able to meet the demands suggested by policy makers as necessary to satisfy the goal of energy independence. Specifically, the analysis was directed at answering questions about how the industry would expand, how expansion would affect the coal processing industry and capital markets, whether a sufficient quantity of low sulfur coal could be mined to meet Federal sulfur dioxide emission standards, what the implications are for the industry of other emission standards, and the implications of increased demand on the coal mining activity in specific regions (including regions previously considered to be marginal producers).

A multiperiod linear programming model was developed to evaluate various futures which may face the national coal industry. Data on coal reserves, coal sulfur content, mining costs and methods, railroad transportation, historical production and consumption, and planned capital expansion were collected and synthesized into budgets suitable for linear programming. Initial results were obtained for a scenario that included regional sulfur emission standards imposed by state legislatures, a demand growth of approximately 30 percent for 1990 compared to 1973 consumption, and capital availability limited (prior to 1980) to the expansion already planned by mining companies. Additional results were obtained for alternative sulfur emission standards ranging from 1.2 pounds to 5.0 pounds of sulfur dioxide per million Btu. Also, a sensitivity analysis was completed on parameters which may have a significant impact on the development of a major coal industry in a marginal-producing region, Iowa.

Major Findings

The analysis indicates that few major adjustments will be needed in the coal industry to operate under the regional sulfur emission standards, even though they are more restrictive than current emission regulations. When U.S. production is aggregated into the four major-producing areas, little change occurs in the market shares of each area in 1990, compared to actual 1973 production. Thus, even with more restrictive sulfur standards in some consumption regions than presently exist, the industry could expand sufficiently to meet the projected 33 percent growth in coal use from 1973 to 1990. In all four of the major production areas, significant interregional reallocations are predicted and some transportation difficulties are foreseen. Much of this reallocation is necessary to utilize the higher quality reserves within each region. Other adjustments occur to exploit those geologic formations

suitable to large scale-low cost mining and to take advantage of geographic locations with low transportation costs. Some of the interregional shifts can be attributed to aggregation bias in the formulation of the model, but this problem does not appear to be serious.

<u>Effect of change in sulfur standards</u>

The Northern Appalachian area is least affected by changes in sulfur standards, producing 41.2, 41.6, 50.8, and 41.6 percent of total U.S. coal consumption in the 1986-90 period under the 5.0 pound, 3.0 pound, regional, and 1.2 pound standards, respectively (this compares to 47.1 percent in 1973). Northern Appalachia can be characterized as having relatively high quality coal (low sulfur and high Btu content), relatively large mine size, substantial surface and underground reserves, and relatively short haul routes to the major demand centers in the industrial Northeast and Midwest.

Southern Appalachia, with generally higher quality coal than even Northern Appalachia, faces locational disadvantages that are reflected in higher transportation costs as compared with either Northern Appalachia or the Midwest. Therefore, when sulfur standards are relaxed and low sulfur coal does not command a premium, the Southern Appalachian area produces far less than its 1973 U.S. market share of 17.5 percent. But, as sulfur standards become more restrictive and Midwestern coal becomes unusable, the Southern Appalachian area dramatically increases production in absolute as well as relative terms. Southern Appalachia produces 2.3, 9.1, 18.4, and 36.6 percent of 1986-90 U.S. consumption under the 5.0 pound, 3.0 pound, regional, and 1.2 pound standards.

The Midwest has the most to lose if the more restrictive Federal sulfur dioxide standards are adopted and enforced by state authorities. Because of the high sulfur content of its coal, the Midwest decreases production dramatically as standards are tightened, producing 48.9, 40.7, 22.1, and 2.4 percent of 1986-90 consumption under 5.0 pound, 3.0 pound, regional, and 1.2 pound standards (the Midwest's market share in 1973 was 25.6 percent). The locational and transport advantages of the Midwest are irrelevant under tight sulfur standards because of the inability to sufficiently reduce the sulfur content of its coals with current processing technology.

The West is an important source of future coal production in the view of many analysts. However, the results of this study are less encouraging for the development of western coal than past reports. Although the West does increase production as sulfur standards are tightened, the long distances (and resulting high transportation costs) coupled with low Btu content discourage the use of the lower sulfur western coals in favor of eastern underground coals. The West produces 7.6, 8.6, 8.7, and 19.4 percent of 1986-90 U.S. consumption under 5.0 pound, 3.0 pound, regional, and 1.2 pound sulfur standards. Even though western production nearly doubles from 9.8 percent of the 1973 market to 19.4 percent of 1990 consumption under the 1.2 pound standard, no western coal is shipped to points east of the Mississippi River.

Not surprisingly, the costs of producing coal increases rapidly as sulfur standards are tightened. Costs increase by 1.2, 5.5, and 4.5 percent as standards are changed from 5.0 pounds to 3.0 pounds, 3.0 pounds to regional standards, and regional standards to 1.2 pounds.

Part of the cost increases are caused by the regional concentration of production and the decline of the Midwest with its geographic advantages as a major producing region, thereby raising the total transportation bill. Also, more coal is processed as sulfur standards become more restrictive, incurring an added cost of $1.00 for every ton processed. However, a major part of the cost increase is caused by the growth in high cost underground mining which accounts for 14.0, 19.2, 26.9, and 31.2 percent of total production at the 5.0 pound, 3.0 pound, regional, and 1.2 pound standards.

The shifts in production within each of the four major-producing areas as sulfur standards are varied should also be recognized. The results indicate that in Northern Appalachia, the major suppliers of coal for all emission standards are Virginia, Ohio, and Pennsylvania. Ohio and Pennsylvania combined produce nearly the same amount of coal under each of the four sulfur standards, but Ohio production declines and Pennsylvania production increases as standards become more restrictive. In the Southern Appalachian area, Alabama-Georgia and Eastern Kentucky are major coal producers in all cases, except with the 5.0 pound standard. Midwestern production is concentrated in Indiana with Illinois producing a large amount under 5.0 pound and 3.0 pound standards and Western Kentucky under the 5.0 pound standard. Western coal production is concentrated in Montana, Utah, and Wyoming.

Most of the interregional shifts are caused by the relative availability of various qualities of coal and the geographic advantages which translate into low transportation costs. The impact of these forces can be illustrated by the adjustments in Indiana production. Indiana has much higher quality coal than its nearest competitors, Illinois and Western Kentucky, and lower transportation costs, except to points west of the Mississippi River and the southeastern United States. Western Kentucky is able to compete with Indiana at the 5.0 pound standard, and Illinois competes at the 5.0 pound and 3.0 pound standards while the remaining Midwestern regions--Iowa, Arkansas-Missouri, and Oklahoma-Texas--are not able to compete at any sulfur standard. Thus, with large mines and low mining costs, advantageous location, and comparatively high quality reserves, Indiana becomes the dominant Midwestern producer. But, even Indiana is dependent on some moderation in sulfur emission standards as 1986-90 production is reduced to only 58.6 percent of 1973 output under the 1.2 pound standard.

Effects of parameter change in Iowa

Sensitivity analyses were programmed to aid in the search for the most critical element preventing a marginal producer (Iowa) from becoming a major coal producing region. The sensitivity trials included changes in mining costs, transportation costs, processing technology, mining equipment availability, demand, and state sulfur emission standards. Iowa mines only a small quantity and for a brief period under the initial conditions of a 30 percent growth in demand, capital limitations prior to 1980, and regional sulfur standards. Reducing transportation costs does encourage greater production in Iowa, but these costs must be reduced by 80 percent before Iowa coal can be produced competitively in the long run. If Iowa mining costs could be reduced from $8.54 per ton to $4.54 per ton, long-run production in substantial amounts occurs. Moderate improvements in processing technology and relaxation of Iowa emission standards will have little effect on the Iowa coal mining industry. In fact, further relaxation of emission standards in Iowa would promote the "dumping" of extremely high sulfur coals from nearby regions. Thus, the results suggest that the development of Iowa coal depends most on the discovery of large veins of low sulfur coal which could be mined at approximately one-half of current costs and burned without processing. Also, the growth of marginal producing regions depends critically on the inability of current major mining regions to expand rapidly enough to meet increased demands for coal.

Validation, Limitations, and Suggestions for Further Study

As with all large-scale programming efforts, definitive data suitable for direct use is a major determinant of the accuracy of the results. Comparison with actual production is the basic method of model validation. Although no benchmark solution was programmed, the 1976-77 demand levels were specified as equal to 1973 demand which allows general comparisons of the model results for this period to actual 1973 consumption. The market shares generated by the model under the 3.0 pound sulfur standard (generally the same as actual 1973 conditions) deviated by only 4 to 8 percent from actual 1973 production for the four major producing areas.

Solutions predicting zero production for a particular region must be interpreted carefully. The model really suggests that these regions do not have a comparative advantage in coal production and expansion should not be encouraged under current conditions, not that all existing mines should be closed. Ever present aggregation bias with respect to the specification of demand and supply regions and the specifications of coal quality parameters must be recognized as factors affecting the results of any national interregional competition model. Also, the exclusion of factors such as transport capacity constraints which may buffer the dramatic swings of some supply regions should be noted.

Subsequent phases of this national coal industry modelling research will focus on additional issues which may affect the future of the U.S. coal industry and the allocation of coal production among the competing regions. Some of these issues are: relative costs of barge and truck modes of transportation; coal transport capacity; differential reclamation policies in various regions; the availability of steam versus metallurgical coal; the effect of disaggregation of demand regions--primarily in the western United States and around major industrial centers in the east; the social cost of and labor union resistance to displacement of miners from one region to another; the future development of the industry beyond 1990 to the year 2000 or 2020; environmental problems of particulate emissions, and ash and residue disposal; and alternative processing technologies such as gasification and stack gas scrubbing. Further work must also confront the issues of reasonable estimates of the future demand for coal and interfuel competition between coal and other alternative energy sources.

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APPENDIX A

DATA AND DATA SOURCES

Transportation

The transportation costs used in the model were calculated from a set of equations for rail rates obtained from David C. Benson of the U.S. Bureau of Mines. These equations are:

$$Y = 1930 + 3.96X \text{ for } X > 300$$

$$Y = 1140 + 12.36X - .00891X^2 \text{ for } X \leq 300$$

where Y is the estimated 1973 cost in dollars per thousand tons for the shipment and X is the distance shipped in miles.

The distances were calculated by first selecting a city of origin for each supply region and a city of destination for each demand region (see Tables A-1 and A-2). The primary criteria for selecting the cities of origin and destination were proximity to major rail lines and volume of coal moving from and to the immediate area surrounding the city. Rail distances between the selected points in each supply region and each demand region were then calculated using [10].

Since the equations yield 1973 costs, it was necessary to adjust the costs upward to more closely reflect the 1975 situation. It was determined that general interstate freight rates have increased by 36.5 percent during the 1973-75 period, and the 1973 costs for each route increased by this amount are the costs used in the model (see Table A-3).

Table A-1. Supply Regions and Cities of Origin.

Region Number	Geographic Area	Origin City
1	Alabama-Georgia	Birmingham, Alabama
2	Arkansas-Missouri	Clinton, Missouri
3	Colorado	Steamboat Springs, Colorado
4	Illinois	Mt. Vernon, Illinois
5	Indiana	Bedford, Indiana
6	Iowa	Oskaloosa, Iowa
7	Eastern Kentucky	Hazard, Kentucky
8	Western Kentucky	Madisonville, Kentucky
9	Maryland	Baltimore, Maryland
10	North & South Dakota	Minot, North Dakota
11	Montana	Forsyth, Montana
12	New Mexico	Albuquerque, New Mexico
13	Ohio	Zanesville, Ohio
14	Oklahoma-Texas	Denison, Texas
15	Pennsylvania	McKeesport, Pennsylvania
16	Tennessee	Knoxville, Tennessee
17	Utah	Provo, Utah
18	Virginia	Pulaski, Virginia
19	Washington-Oregon	Centralia, Washington
20	West Virginia	Beckley, West Virginia
21	Wyoming	Rawlins, Wyoming

Table A-2. Demand Regions and Cities of Destination.

Region Number	Area Included in Region	City of Destination
1	Minnesota, Wisconsin, North Dakota, South Dakota	St. Paul, Minnesota
2	Western Missouri	Kansas City, Missouri
3	Illinois, Indiana	Chicago, Illinois
4	Michigan	Detroit, Michigan
5	Washington, Oregon, California, Arizona, New Mexico, Colorado, Utah, Nevada, Idaho, Montana, Wyoming	Salt Lake City, Utah
6	New York, New Jersey, Massachusetts, Connecticut, Delaware, Maryland, Maine, New Hampshire, Vermont, Rhode Island	New York City, New York
7	Florida, Georgia	Valdosta, Georgia
8	Virginia, West Virginia, North Carolina, South Carolina	Danville, Virginia
9	Kentucky, Tennessee, Alabama, Mississippi	Chattanooga, Tennessee
10	Texas, Oklahoma, Arkansas, Louisiana, Kansas	Salina, Kansas
11	Pennsylvania, Ohio	Pittsburg, Pennsylvania
12	Eastern Missouri	St. Louis, Missouri
13	Central Iowa	Des Moines, Iowa
14	Western Iowa	Sioux City, Iowa
15	North Central Iowa	Mason City, Iowa
16	Southeast Iowa	Burlington, Iowa
17	Northeast Iowa	Dubuque, Iowa
18	East Central Iowa	Davenport, Iowa

Table A-3. Transportation Costs.

Origin	Destination	Distance (miles)	Cost ($/1,000 tons)
1	1	1047	8293.90
1	2	737	6618.23
1	3	651	6153.36
1	4	739	6629.04
1	5	1906	12937.14
1	6	986	7964.17
1	7	331	4423.63
1	8	563	5677.68
1	9	142	3706.60
1	10	858	7272.28
1	11	797	6942.55
1	12	479	5223.63
1	13	819	7061.47
1	14	994	8007.41
1	15	922	7618.22
1	16	682	6320.93
1	17	704	6439.85
1	18	779	6845.25
2	1	545	5580.39
2	2	87	2931.86
2	3	454	5088.50
2	4	721	6531.73
2	5	1293	9623.63
2	6	1299	9656.06
2	7	978	7920.93
2	8	1184	9034.44
2	9	708	6461.47
2	10	261	5131.03
2	11	859	7277.68
2	12	248	4992.18
2	13	306	4288.50
2	14	355	4553.36
2	15	409	4845.25
2	16	257	5088.75
2	17	427	4942.55
2	18	345	4499.31

Table A-3. Transportation Costs. (Continued)

Origin	Destination	Distance (miles)	Cost ($/1,000 tons)
3	1	1100	8580.39
3	2	850	7229.04
3	3	1240	9337.14
3	4	1512	10807.41
3	5	480	5229.04
3	6	2148	14245.24
3	7	1918	13002.00
3	8	1979	13331.73
3	9	1604	11304.71
3	10	650	6147.96
3	11	1708	11866.87
3	12	1128	8731.73
3	13	897	7483.09
3	14	790	6904.71
3	15	933	7677.68
3	16	1036	8234.44
3	17	1054	8331.74
3	18	1070	8418.22
4	1	584	5791.20
4	2	365	4607.42
4	3	266	5183.34
4	4	505	5364.18
4	5	1527	10888.49
4	6	1013	8110.11
4	7	769	6791.20
4	8	762	6753.36
4	9	397	4780.39
4	10	539	5547.96
4	11	573	5731.74
4	12	87	2931.86
4	13	427	4942.55
4	14	621	5991.20
4	15	483	5245.25
4	16	262	5141.54
4	17	350	4526.34
4	18	272	5245.31

Table A-3. Transportation Costs. (Continued)

Origin	Destination	Distance (miles)	Cost ($/1,000 tons)
5	1	646	6126.33
5	2	503	5353.36
5	3	250	5013.81
5	4	386	4720.93
5	5	1665	11634.43
5	6	880	7391.20
5	7	786	6883.09
5	8	652	6158.77
5	9	414	4872.28
5	10	677	6293.90
5	11	441	5018.23
5	12	225	4736.45
5	13	512	5402.01
5	14	706	6450.66
5	15	568	5704.71
5	16	347	4510.12
5	17	439	5007.42
5	18	361	4585.80
6	1	282	5346.65
6	2	217	4644.49
6	3	291	5435.77
6	4	563	5677.68
6	5	1217	9212.81
6	6	1198	9110.11
6	7	1106	8612.82
5	8	1085	8499.30
6	9	772	6807.41
6	10	391	4747.96
6	11	759	6737.14
6	12	296	5484.43
6	13	64	2586.05
5	14	258	5099.36
6	15	146	3760.07
5	16	100	3121.62
6	17	199	4431.87
6	18	134	3598.48

Table A-3. Transportation Costs. (Continued)

Origin	Destination	Distance (miles)	Cost ($/1,000 tons)
7	1	926	7639.84
7	2	787	6888.50
7	3	501	5342.55
7	4	478	5218.23
7	5	1948	13164.16
7	6	970	7877.68
7	7	744	6656.06
7	8	603	5893.90
7	9	394	4764.18
7	10	961	7829.04
7	11	531	5504.71
7	12	509	5385.80
7	13	849	7223.63
7	14	1043	8272.27
7	15	905	7526.33
7	16	684	6331.73
7	17	681	6315.52
7	18	658	6191.20
8	1	709	6466.87
8	2	504	5358.77
8	3	341	4477.69
8	4	530	5499.31
8	5	1666	11639.84
8	6	1031	8207.41
8	7	632	6050.66
8	8	748	6677.68
8	9	260	5120.50
8	10	678	6299.31
8	11	592	5834.44
8	12	226	4747.84
8	13	548	5596.61
8	14	742	6645.25
8	15	604	5899.31
8	16	383	4704.71
8	17	475	5202.01
8	18	397	4780.39

Table A-3. Transportation Costs. (Continued)

Origin	Destination	Distance (miles)	Cost ($/1,000 tons)
9	1	1193	9083.09
9	2	1198	9110.11
9	3	796	6937.14
9	4	624	6007.41
9	5	2310	15120.92
9	6	187	4285.75
9	7	813	7029.03
9	8	267	5193.73
9	9	665	6229.04
9	10	1372	10050.65
9	11	328	4407.42
9	12	920	7607.41
9	13	1154	8872.28
9	14	1331	9829.03
9	15	1147	8834.44
9	16	1021	8153.36
9	17	1001	8045.25
9	18	953	7785.79
10	1	474	5196.61
10	2	824	7088.50
10	3	870	7337.14
10	4	1142	8807.41
10	5	1081	8477.68
10	6	1778	12245.25
10	7	1620	11391.19
10	8	1430	10364.16
10	9	1468	10569.57
10	10	862	7293.90
10	11	1339	9872.27
10	12	1048	8299.30
10	13	733	6596.61
10	14	537	5537.15
10	15	641	6099.31
10	16	898	7488.49
10	17	708	6461.47
10	18	824	7088.50

Table A-3. Transportation Costs. (Continued)

Origin	Destination	Distance (miles)	Cost ($/1,000 tons)
11	1	748	6677.68
11	2	998	8029.04
11	3	1144	8818.22
11	4	1416	10288.49
11	5	771	6802.00
11	6	2052	13726.32
11	7	2026	13585.78
11	8	1936	13099.30
11	9	1693	11785.79
11	10	1036	8234.44
11	11	1612	11347.95
11	12	1217	9212.81
11	13	872	7347.95
11	14	711	6477.68
11	15	815	7039.85
11	16	1037	8239.85
11	17	972	7888.49
11	18	998	8029.04
12	1	1363	10002.00
12	2	887	7429.04
12	3	1338	9866.87
12	4	1610	11337.14
12	5	985	7958.76
12	6	2216	14612.81
12	7	1638	11488.49
12	8	1923	13029.03
12	9	1448	10461.46
12	10	687	6347.96
12	11	1776	12234.43
12	12	1190	9066.87
12	13	1108	8623.63
12	14	1053	8326.33
12	15	1196	9099.30
12	16	1289	9602.00
12	17	1317	9753.35
12	18	1323	9785.79

Table A-3. Transportation Costs. (Continued)

Origin	Destination	Distance (miles)	Cost ($/1,000 tons)
13	1	769	6791.20
13	2	746	6666.87
13	3	373	4650.66
13	4	239	4893.65
13	5	1908	12947.95
13	6	589	5818.22
13	7	896	7477.68
13	8	527	5483.09
13	9	546	5585.80
13	10	920	7607.41
13	11	150	3813.16
13	12	468	5164.18
13	13	698	6407.41
13	14	892	7456.06
13	15	774	6818.23
13	16	533	5515.52
13	17	553	5623.63
13	18	530	5499.31
14	1	878	7380.39
14	2	398	4785.80
14	3	849	7223.63
14	4	1059	8358.76
14	5	1402	10212.81
14	6	1571	11126.32
14	7	947	7753.36
14	8	1207	9158.76
14	9	774	6818.23
14	10	423	4920.93
14	11	848	7218.22
14	12	570	5715.52
14	13	619	5980.39
14	14	686	6342.55
14	15	742	6645.25
14	16	632	6050.66
14	17	786	6883.09
14	18	714	6493.90

Table A-3. Transportation Costs. (Continued)

Origin	Destination	Distance (miles)	Cost ($/1,000 tons)
15	1	880	7391.20
15	2	904	7520.93
15	3	483	5245.25
15	4	311	4315.53
15	5	1997	13429.03
15	6	434	4980.39
15	7	1060	8364.17
15	8	521	5450.66
15	9	700	6418.23
15	10	1078	8461.46
15	11	15	1806.43
15	12	626	6018.22
15	13	841	7180.39
15	14	1037	8239.85
15	15	828	7110.12
15	16	688	6353.36
15	17	663	6218.22
15	18	640	6093.90
16	1	970	7877.68
16	2	818	7056.06
16	3	574	5737.14
16	4	551	5612.82
16	5	2001	13450.65
16	6	732	6591.20
16	7	436	4991.20
16	8	367	4618.23
16	9	120	3405.53
16	10	992	7996.60
16	11	609	5926.33
16	12	540	5553.36
16	13	880	7391.20
16	14	1071	8423.63
16	15	933	7677.68
16	16	712	6483.09
16	17	754	6710.12
16	18	726	6558.76

Table A-3. Transportation Costs. (Continued)

Origin	Destination	Distance (miles)	Cost ($/1,000 tons)
17	1	1410	10256.06
17	2	1160	8904.71
17	3	1550	11012.82
17	4	1822	12483.08
17	5	46	2306.45
17	6	2458	15920.92
17	7	2228	14677.68
17	8	2289	15007.40
17	9	1914	12980.38
17	10	960	7823.63
17	11	2018	13542.54
17	12	1438	10407.41
17	13	1207	9158.76
17	14	1100	8580.39
17	15	1243	9353.36
17	16	1346	9910.11
17	17	1364	10007.41
17	18	1380	10093.89
18	1	1082	8483.09
18	2	1021	8153.36
18	3	686	6342.55
18	4	575	5742.55
18	5	2183	14434.43
18	6	502	5347.96
18	7	660	6202.01
18	8	143	3720.01
18	9	335	4445.26
18	10	1195	9093.90
18	11	584	5791.20
18	12	743	6650.66
18	13	998	8029.04
18	14	1192	9077.68
18	15	1031	8207.41
18	16	833	7137.14
18	17	866	7315.52
18	18	843	7191.20

Table A-3. Transportation Costs. (Continued)

Origin	Destination	Distance (miles)	Cost ($/1,000 tons)
19	1	1796	12342.54
19	2	2005	13472.27
19	3	2192	14483.08
19	4	2464	15953.35
19	5	975	7904.71
19	6	3100	19391.18
19	7	3073	19245.24
19	8	2984	18764.15
19	9	2740	17445.24
19	10	1887	12834.43
19	11	2661	17018.21
19	12	2264	14872.27
19	13	1995	13418.22
19	14	1904	12926.33
19	15	2047	13699.30
19	16	2150	14256.05
19	17	2168	14353.35
19	18	2184	14439.84
20	1	968	7866.87
20	2	907	7537.14
20	3	572	5726.33
20	4	461	5126.34
20	5	2069	13818.21
20	6	604	5899.31
20	7	771	6802.00
20	8	245	4959.55
20	9	483	5245.25
20	10	1081	8477.68
20	11	388	4731.74
20	12	629	6034.45
20	13	884	7412.82
20	14	1078	8461.46
20	15	917	7591.20
20	16	719	6520.93
20	17	752	6699.30
20	18	729	6574.98

Table A-3. Transportation Costs. (Continued)

Origin	Destination	Distance (miles)	Cost ($/1,000 tons)
21	1	1028	8191.20
21	2	875	7364.17
21	3	1168	8947.95
21	4	1440	10418.22
21	5	346	4504.71
21	6	2076	13856.05
21	7	1903	12920.92
21	8	1943	13137.13
21	9	1570	11120.92
21	10	703	6434.44
21	11	1636	11477.68
21	12	1094	8547.95
21	13	825	7093.90
21	14	720	6526.33
21	15	863	7299.30
21	16	966	7856.06
21	17	984	7953.36
21	18	1000	8039.85

Coal Reserves and Washability

The coal reserves for each supply region were divided into strippable and underground mineable reserves. Each of these two categories was further subdivided into two seam thicknesses. Finally, the reserves were also identified by one, two, or three quality categories. Sulfur levels and heating values were the primary quality determinants.

Coal reserves are generally divided into several quality levels and an "unknown" category in published sources. It was assumed that the unknown coal was distributed among the indicated quality levels in the same proportion as the known coal.

Once the coal reserves in each region were divided into broad quality groups (e.g., 1.2% - 2.1% sulfur content by weight), a washability sample that was judged to be representative of that quality group was chosen from [4], and all of the coal in the group was assumed to have the characteristics of that washability sample. Some regions had coal that was of sufficiently high quality to be used under fairly strict Environmental Protection Agency guidelines without washing. No washability results were identified for these samples.

The coal reserve data and the data sources are displayed in Tables A-4 through A-24.

Table A-4. Reserve and Washability Data for Region 1, Alabama-Georgia.

	Quality I	Quality II	Quality III
Underground Reserves, > 42" Seam	253.90[a]	490.49	18.78
Underground Reserves, 28"-42" Seam	399.81	586.69	65.71
Strippable Reserves, -- Seam	--	--	--
Strippable Reserves, < 43" Seam	46.18	98.49	12.13
Btu/lb.	14,788	14,066	13,014
Lbs. SO_2/million Btu	0.8	1.7	5.8
<u>Processed at Specific Gravity of 1.40</u>			
Btu/lb.	--	14,213	14,078
Lb. SO_2/million Btu	--	1.5	3.8
Percent weight recovery	--	96.1	70.5

[a] All reserves are in million tons.

Sources: Underground reserves by qualities [18].
Underground seam thicknesses [24, p. 41].
Strippable reserves by qualities [18].
Strippable seam thicknesses [25, p. 71].
Washability data taken from [4].
Location of washability samples:
I. --
II. Marion County (Alabama), Black Creek Bed
III. Walker County (Alabama), Clements Bed

<u>Special Note</u>: These reserve figures do not include lignite coal.

Table A-5. Reserve and Washability Data for Region 2, Arkansas-Missouri.

	Quality I	Quality II	Quality III
Underground Reserves, 36" Seam	6,379.60[a]	--	--
Underground Reserves, -- Seam	--	--	--
Strippable Reserves, -- Seam	--	--	--
Strippable Reserves, 24" Seam	3,644.90	--	--
Btu/lb.	11,155	--	--
Lbs. SO_2/million Btu	7.5	--	--
<u>Processed at Specific Gravity of 1.60</u>			
Btu/lb.	12,741	--	--
Lb. SO_2/million Btu	5.8	--	--
Percent weight recovery	81.4	--	--

---

[a] All reserves are in million tons.

Sources: Underground reserves by qualities [18].
Underground seam thicknesses [personal discussions with Charles Robertson, Missouri Geological Survey].
Strippable reserves by qualities [18].
Strippable seam thicknesses [25, p. 76].
Washability data taken from [4].
Location of washability samples:

I. Macon County (Missouri), Bevier Bed
II. --
III. --

Table A-6. Reserve and Washability Data for Region 3, Colorado.

	Quality I	Quality II	Quality III
Underground Reserves, -- Seam	--	--	--
Underground Reserves, 6' Seam	13,999.20[a]	--	--
Strippable Reserves, 12' Seam	--	870.00	--
Strippable Reserves, -- Seam	--	--	--
Btu/lb.	13,380	11,952	--
Lbs. SO_2/million Btu	0.6	0.7	--
<u>Processed at Specific Gravity of --</u>			
Btu/lb.	--	--	--
Lb. SO_2/million Btu	--	--	--
Percent weight recovery	--	--	--

---

[a] All reserves are in million tons.

<u>Sources</u>: Underground reserves by qualities [18].
Underground seam thicknesses [personal discussions with Dr. Bater, Colorado School of Mines].
Strippable reserves by qualities [18].
Strippable seam thicknesses [25, p. 78].
Washability data taken from [4].
Location of washability samples:

I. --
II. --
III. --

Table A-9. Reserve and Washability Data for Region 6, Iowa.

	Quality I	Quality II	Quality III
Underground Reserves, -- Seam	--	--	--
Underground Reserves, 28"-42" Seam	2,884.90[a]	--	--
Strippable Reserves, -- Seam	--	--	--
Strippable Reserves, 36" Seam	*	--	--
Btu/lb.	11,746	--	--
Lbs. SO_2/million Btu	7.1	--	--
Processed at Specific Gravity of 1.40			
Btu/lb.	12,735	--	--
Lb. SO_2/million Btu	5.2	--	--
Percent weight recovery	71.5	--	--

---

[a] All reserves are in million tons.

Sources: Underground reserves by qualities [18].
Underground seam thicknesses [personal discussions with Iowa Coal Project personnel].
Strippable reserves by qualities *.
Strippable seam thicknesses [personal discussions with Iowa Coal Project personnel].
Washability data taken from [4].

Location of washability samples:

I. Lucas County, coalbed: uncorrelated
II. --
III. --

*Special Note: Reference [18] lists no demonstrated strippable reserves for Iowa. In this program, no reserve limit was specified for strippable Iowa coal.

Table A-10. Reserve and Washability Data for Region 7, Eastern Kentucky.

	Quality I	Quality II	Quality III
Underground Reserves, > 42" Seam	3,862.77[a]	192.44	115.84
Underground Reserves, 28"-42" Seam	4,655.41	323.53	310.20
Strippable Reserves, 42" Seam	2,921.69	317.81	207.43
Strippable Reserves, -- Seam	--	--	--
Btu/lb.	13,880	12,239	13,128
Lbs. SO_2/million Btu	1.4	2.1	4.7
Processed at Specific Gravity of 1.60			
Btu/lb.	14,315	13,323	13,688
Lb. SO_2/million Btu	1.2	2.0	3.5
Percent weight recovery	94.0	86.1	90.3

---

[a] All reserves are in million tons.

Sources: Underground reserves by qualities [18].
Underground seam thicknesses [24, p. 127].
Strippable reserves by qualities [18].
Strippable seam thicknesses [25, p. 86].
Washability data taken from [4].

Location of washability samples:

I. Floyd County, Upper Elkhorn #2 Bed
II. Bell County, Maddix Bed
III. Harlan County, Low Splint Bed

Table A-11. Reserve and Washability Data for Region 8, Western Kentucky.

	Quality I	Quality II	Quality III
Underground Reserves, > 36" Seam	8,719.89[a]	--	--
Underground Reserves, -- Seam	--	--	--
Strippable Reserves, > 42" Seam	2,732.80	--	--
Strippable Reserves, 28"-42" Seam	1,171.20	--	--
Btu/lb.	12,513	--	--
Lbs. SO_2/million Btu	7.4	--	--
<u>Processed at Specific Gravity of 1.40</u>			
Btu/lb.	13,313	--	--
Lb. SO_2/million Btu	4.3	--	--
Percent weight recovery	81.8	--	--

[a] All reserves are in million tons.

<u>Sources</u>: Underground reserves by qualities [18].
Underground seam thicknesses [24, p. 137].
Strippable reserves by qualities [18].
Strippable seam thicknesses [25, p. 88].
Washability data taken from [4].

Location of washability samples:

I. Hopkins County, Coalbed #9
II. --
III. --

Table A-12. Reserve and Washability Data for Region 9, Maryland.

	Quality I	Quality II	Quality III
Underground Reserves, > 42" Seam	341.81[a]	89.71	--
Underground Reserves, 28"-42" Seam	388.58	81.46	--
Strippable Reserves, -- Seam	--	--	--
Strippable Reserves, 35" Seam	124.59	21.26	--
Btu/lb.	13,111	12,662	--
Lbs. SO_2/million Btu	1.7	3.9	--
<u>Processed at Specific Gravity of 1.40</u>			
Btu/lb.	14,273	13,990	--
Lb. SO_2/million Btu	1.1	2.6	--
Percent weight recovery	67.8	71.3	--

[a] All reserves are in million tons.

<u>Sources</u>: Underground reserves by qualities [18].
Underground seam thicknesses [24, p. 139].
Strippable reserves by qualities [18].
Strippable seam thicknesses [25, p. 90].
Washability data taken from [4].

Location of washability samples:

I. Garrett County, Upper Freeport Bed
II. Allegany County, Waynesburg Bed
III. --

Table A-13. Reserve and Washability Data for Region 10, North and South Dakota.

	Quality I	Quality II	Quality III
Underground Reserves, -- Seam	--	--	--
Underground Reserves, -- Seam	--	--	--
Strippable Reserves, 16' Seam	16,431.00[a]	--	--
Strippable Reserves, -- Seam	--	--	--
Btu/lb.	6,700	--	--
Lbs. SO_2/million Btu	2.1	--	--
Processed at Specific Gravity of --			
Btu/lb.	--	--	--
Lb. SO_2/million Btu	--	--	--
Percent weight recovery	--	--	--

---

[a] All reserves are in million tons.

Sources: Underground reserves by qualities --.
Underground seam thicknesses --.
Strippable reserves by qualities [18].
Strippable seam thicknesses [25].
Washability data taken from [4].
Location of washability samples:
I. --
II. --
III. --

Special Note: Information on heating value and sulfur content from personal correspondence with Charles A. Koch, USBM, North Dakota.

Table A-14. Reserve and Washability Data for Region 11, Montana.

	Quality I	Quality II	Quality III
Underground Reserves, -- Seam	65,834.00[ab]	--	--
Underground Reserves, -- Seam	--	--	--
Strippable Reserves, 25' Seam	42,561.90	--	--
Strippable Reserves, -- Seam	--	--	--
Btu/lb.	8,416	--	--
Lbs. SO_2/million Btu	0.96	--	--
Processed at Specific Gravity of --			
Btu/lb.	--	--	--
Lb. SO_2/million Btu	--	--	--
Percent weight recovery	--	--	--

---

[a] All reserves are in million tons.

[b] Underground mining was not included in the model for this region because no coal is currently mined underground. It is presumed that strippable reserves will be exhausted before underground mining develops.

Sources: Underground reserves by qualities --.
Underground seam thicknesses --.
Strippable reserves by qualities [18].
Strippable seam thicknesses [25, p. 95].
Washability data taken from [4].
Location of washability samples:
I. --
II. --
III. --

Table A-15. Reserve and Washability Data for Region 12, New Mexico.

	Quality I	Quality II	Quality III
Underground Reserves, -- Seam	2,136.00[ab]	--	--
Underground Reserves, -- Seam	--	--	--
Strippable Reserves, 11' Seam	2,258.00	--	--
Strippable Reserves, -- Seam	--	--	--
Btu/lb.	10,618	--	--
Lbs. SO_2/million Btu	1.3	--	--
Processed at Specific Gravity of 1.60			
Btu/lb.	11,887	--	--
Lb. SO_2/million Btu	1.1	--	--
Percent weight recovery	82.4	--	--

[a] All reserves are in million tons.

[b] Underground mining was not included in the model for this region because no coal is currently mined underground. It is presumed that strippable reserves will be exhausted before underground mining develops.

Sources:
Underground reserves by quality [18].
Underground seam thicknesses --
Strippable reserves by qualities [18].
Strippable seam thicknesses [25, p. 97]
Washability data taken from [4].

Location of washability samples:

I. San Juan County, Coalbed #8
II. --
III. --

Table A-16. Reserve and Washability Data for Region 13, Ohio.

	Quality I	Quality II	Quality III
Underground Reserves, > 42" Seam	856.28[a]	3,215.79	6,534.01
Underground Reserves, 28"-42" Seam	270.82	1,815.59	4,701.24
Strippable Reserves, > 37" Seam	153.60	889.41	2,608.60
Strippable Reserves, -- Seam	--	--	--
Btu/lb.	11,598	13,500	12,140
Lbs. SO_2/million Btu	1.1	3.7	7.9
Processed at Specific Gravity of 1.40			
Btu/lb.	13,189	13,915	12,662
Lb. SO_2/million Btu	1.0	1.8	4.7
Percent weight recovery	82.8	90.4	75.0

[a] All reserves are in million tons.

Sources:
Underground reserves by qualities [18].
Underground seam thicknesses [24, p. 162].
Strippable reserves by qualities [18].
Strippable seam thicknesses [25, p. 100].
Washability data taken from [4].

Location of washability samples:

I. Perry County, Middle Kittanning Bed
II. Tuscarauas County, Lower Kittanning Bed
III. Vinton County, Lower Kittanning Bed

Table A-17. Reserve and Washability Data for Region 14, Oklahoma-Texas.

	Quality I	Quality II	Quality III
Underground Reserves, -- Seam	--	--	--
Underground Reserves, -- Seam	--	--	--
Strippable Reserves, 7' Seam	3,706.00[a]	--	--
Strippable Reserves, -- Seam	--	--	--
Btu/lb.	7,822	--	--
Lbs. SO_2/million Btu	3.8	--	--
Processed at Specific Gravity of --			
Btu/lb.	--	--	--
Lb. SO_2/million Btu	--	--	--
Percent weight recovery	--	--	--

[a] All reserves are in million tons.

Sources:
Underground reserves by qualities --.
Underground seam thicknesses --.
Strippable reserves by qualities [18].
Strippable seam thicknesses [25, p. 111].
Washability data taken from [4].

Location of washability samples:

I. --
II. --
III. --

Special Note: Heating value and seam thicknesses from personal conversations with Texas USBM office. These reserve figures are for Texas only.

Table A-18. Reserve and Washability Data for Region 15, Pennsylvania.

	Quality I	Quality II	Quality III
Underground Reserves, > 42" Seam	3,232.80[a]	8,812.21	1,435.28
Underground Reserves, 28"-42" Seam	3,621.05	4,307.75	1,368.12
Strippable Reserves, > 42" Seam	95.71	142.67	44.25
Strippable Reserves, < 42" Seam	272.83	406.06	125.98
Btu/lb.	13,207	13,623	13,576
Lbs. SO_2/million Btu	1.0	4.2	6.3
Processed at Specific Gravity of 1.40			
Btu/lb.	--	14,589	14,351
Lb. SO_2/million Btu	--	1.6	2.8
Percent weight recovery	--	78.5	77.0

[a] All reserves are in million tons.

Sources:
Underground reserves by qualities [18].
Underground seam thicknesses [24, p. 190].
Strippable reserves by qualities [18].
Strippable seam thicknesses [25, p. 105].
Washability data taken from [4].

Location of washability samples:

I. --
II. Cambria County, Lower Freeport Bed
III. Clearfield County, Lower Kittanning Bed

Special Note: These reserve figures do not include anthracite coal.

Table A-19. Reserve and Washability Data for Region 16, Tennessee.

	Quality I	Quality II	Quality III
Underground Reserves, > 42" Seam	38.03[a]	56.13	71.19
Underground Reserves, 28"-42" Seam	231.55	173.85	93.62
Strippable Reserves, -- Seam	--	--	--
Strippable Reserves, 38" Seam	129.41	100.30	116.53
Btu/lb.	14,336	13,038	13,496
Lbs. SO_2/million Btu	1.2	2.0	5.3
Processed at Specific Gravity of 1.40			
Btu/lb.	--	14,517	13,921
Lb. SO_2/million Btu	--	1.2	3.4
Percent weight recovery	--	74.0	87.0

[a] All reserves are in million tons.

Sources: Underground reserves by qualities [18].
Underground seam thicknesses [24, p. 206].
Strippable reserves by qualities [18].
Strippable seam thicknesses [25, p. 108].
Washability data taken from [4].

Location of washability samples:

I. --
II. McCreary County, Upper Elkhorn #3 Bed, (Kentucky)
III. Anderson County, Big Mary Bed

Table A-20. Reserve and Washability Data for Region 17, Utah.

	Quality I	Quality II	Quality III
Underground Reserves, -- Seam	3,780.00[a,b]	--	--
Underground Reserves, -- Seam	--	--	--
Strippable Reserves, 14' Seam	262.00	--	--
Strippable Reserves, -- Seam	--	--	--
Btu/lb.	12,047	--	--
Lbs. SO_2/million Btu	1.5	--	--
Processed at Specific Gravity of --			
Btu/lb.	--	--	--
Lb. SO_2/million Btu	--	--	--
Percent weight recovery	--	--	--

[a] All reserves are in million tons.

[b] Underground mining was not included in the model for this region because no coal is currently mined underground. It is presumed that strippable reserves will be exhausted before underground mining develops.

Sources: Underground reserves by qualities --.
Underground seam thicknesses --.
Strippable reserves by qualities [18].
Strippable seam thicknesses [25].
Washability data taken from [4].

Location of washability samples:

I. --
II. --
III. --

Special Note: Heating value and sulfur content figures from personal correspondence with S. R. Wilson, USBM, Utah.

Table A-21. Reserve and Washability Data for Region 18, Virginia.

	Quality I	Quality II	Quality III
Underground Reserves, > 42" Seam	762.92[a]	182.57	--
Underground Reserves, 28"-42" Seam	1,370.03	512.48	--
Strippable Reserves, 42" Seam	520.76	157.80	--
Strippable Reserves, -- Seam	--	--	--
Btu/lb.	13,454	14,661	--
Lbs. SO_2/million Btu	1.0	1.6	--
Processed at Specific Gravity of 1.30			
Btu/lb.	--	14,967	--
Lb. SO_2/million Btu	--	1.2	--
Percent weight recovery	--	81.1	--

[a] All reserves are in million tons.

Sources: Underground reserves by qualities [18].
Underground seam thicknesses [24].
Strippable reserves by qualities [18].
Strippable seam thicknesses [25, p. 114].
Washability data taken from [4].

Location of washability samples:

I. --
II. Wise County, Bottom Bed
III. --

Table A-22. Reserve and Washability Data for Region 19, Washington-Oregon.

	Quality I	Quality II	Quality III
Underground Reserves, -- Seam	--	--	--
Underground Reserves, -- Seam	--	--	--
Strippable Reserves, 22' Seam	508.90[a]	--	--
Strippable Reserves, -- Seam	--	--	--
Btu/lb.	8,000	--	--
Lbs. SO_2/million Btu	1.5	--	--
Processed at Specific Gravity of --			
Btu/lb.	--	--	--
Lb. SO_2/million Btu	--	--	--
Percent weight recovery	--	--	--

[a] All reserves are in million tons.

Sources: Underground reserves by qualities --.
Underground seam thicknesses --.
Strippable reserves by qualities [18].
Strippable seam thicknesses [25, p. 116].
Washability data taken from [4].

Location of washability samples:

I. --
II. --
III. --

Special Note: Heating value and sulfur content from personal correspondence with J. R. Welch, USBM, Washington.

Table A-23. Reserve and Washability Data for Region 20, West Virginia.

	Quality I	Quality II	Quality III
Underground Reserves, > 42" Seam	10,540.11[a]	5,495.38	6,249.00
Underground Reserves, 28"-42" Seam	7,755.00	2,866.92	1,201.80
Strippable Reserves, ≥ 42" Seam	3,049.39	582.59	221.78
Strippable Reserves, < 42" Seam	1,071.42	204.69	77.92
Btu/lb.	12,339	13,084	12,177
Lbs. SO_2/million Btu	1.2	2.2	5.4
<u>Processed at Specific Gravity of 1.60</u>			
Btu/lb.	13,274	14,282	13,503
Lb. SO_2/million Btu	1.1	1.2	3.6
Percent weight recovery	86.1	88.0	79.6

---

[a] All reserves are in million tons.

Sources: Underground reserves by qualities [18].
Underground seam thicknesses [24, p. 275].
Strippable reserves by qualities [18].
Strippable seam thicknesses [25, p. 118].
Washability data taken from [4].

Location of washability samples:

I. Logan County, Stockton-Lewiston Bed
II. Preston County, Upper Freeport Bed
III. Barbour County, Middle Kittanning Bed

Table A-24. Reserve and Washability Data for Region 21, Wyoming.

	Quality I	Quality II	Quality III
Underground Reserves, -- Seam	--	--	--
Underground Reserves, -- Seam	--	--	--
Strippable Reserves, 67' Seam	23,845.30[a]	--	--
Strippable Reserves, -- Seam	--	--	--
Btu/lb.	9,400	--	--
Lbs. SO_2/million Btu	1.1	--	--
<u>Processed at Specific Gravity of --</u>			
Btu/lb.	--	--	--
Lb. SO_2/million Btu	--	--	--
Percent weight recovery	--	--	--

---

[a] All reserves are in million tons.

<u>Sources</u>: Underground reserves by qualities --.
Underground seam thicknesses --.
Strippable reserves by qualities [18].
Strippable seam thicknesses [25].
Washability data taken from [4].

Location of washability samples:

I. --
II. --
III. --

Demand Levels

The analysis required specification of the demand levels for coal in each of the 18 consumption (demand) regions for the period 1976-90. In fact, several alternative demand scenarios were specified to investigate the effect of the different demand levels on the other variables in the model. Each demand scenario, however, was based on the estimated 1973 coal consumption in each region (Table A-25).

The demand data for regions 1-12 were taken from [22]. For regions 1 and 3-11, the state totals shown in [22] were simply added together for the states in each demand region. Since regions 2 and 12 are both in the same state (Missouri), one-half of the state demand was assigned to each region. The demand levels for the various regions in Iowa (regions 13-18) were obtained from [12]. This reference source listed the consumption of coal for each industrial user and each coal-fired generating station in Iowa by city of location. Each of the users was grouped according to their proximity to the six cities chosen as demand points, and the sum of the coal consumption for these groups was obtained to complete Table A-25.

The model requires that the demand be stated in heating value terms, rather than by weight. Therefore, the average heating value of all coal burned in 1973 was determined from [22, Table 5]. This value of 11,825 Btu/lb. was converted to 23.65 billion Btu/thousand tons for purposes of expressing all regional demands in heating value terms.

Table A-25. Estimated 1973 Regional Coal Consumption Levels.

Region Number	Consumption (1,000 tons)	Region Number	Consumption (1,000 tons)
1	27,611	10	11,576
2	8,693	11	130,026
3	85,689	12	8,693
4	31,685	13	1,220
5	35,744	14	1,131
6	28,852	15	510
7	16,894	16	643
8	66,494	17	665
9	75,011	18	1,838

Source [22].

Quality Constraints

The primary issue with respect to coal quality is the sulfur content and the sulfur dioxide emissions that result. Both state and Federal pollution control agencies have authority to regulate air quality through control of stack emissions from burning coal or limits on the sulfur content of the coal input. In general, new installations must comply with Federal standards, whereas current users of coal are subject to state regulations that must comply with Federal guidelines.

The quality constraints in the model were specified in terms of the maximum pounds of sulfur dioxide per million Btu heat input that can be emitted into the air. To reflect regional differences and the standards faced by current users, state rather than Federal regulations were used primarily. The quality standards of the state or city that represented the major consumer of coal were used in each region. For example, the Chicago standard was used for region 3 (Illinois and Indiana) and the New York City standard for region 6 (New England).

State standards were obtained from [15] and [6]. In most cases, these standards were specified in pounds sulfur dioxide per million Btu. Where other standards were specified, standard conversion factors were used. Where standards were specified for different size plants, the limits imposed on the largest plants were used. If the standards are to be adjusted in future years, this is also reflected in the model. The specified sulfur dioxide emission levels allowed in each consumption region are summarized in Table A-26.

Table A-26. Sulfur Standards by Regions.

Region	1976-77	1978-80	1981-85	1986-90
	- - - - - - - - - - lbs. SO_2/million Btu - - - - - - - - -			
1	2.4	2.4	2.4	2.4
2	3.2	3.2	3.2	3.2
3	1.8	1.8	1.8	1.8
4	2.4	1.6	1.6	1.6
5	1.2	1.2	1.2	1.2
6	1.2	1.2	1.2	1.2
7	1.2	1.2	1.2	1.2
8	2.3	2.3	1.6	1.6
9	1.2	1.2	1.2	1.2
10	3.0	3.0	3.0	3.0
11	1.2	1.2	1.2	1.2
12	2.3	2.3	2.3	2.3
13	6.0	5.0	5.0	5.0
14	6.0	5.0	5.0	5.0
15	6.0	5.0	5.0	5.0
16	6.0	5.0	5.0	5.0
17	6.0	5.0	5.0	5.0
18	6.0	5.0	5.0	5.0

Mining Capacities

To obtain an estimate of current regional mining capacity, it was assumed that production for the year 1973 in each region represented maximum utilization of existing mining capacity; i.e., no more coal could have been mined without investing in new mines. The 1973 production for both strip (including auger) and underground mines was taken from [22, p. 11]. These figures are shown in Table A-27.

For each succeeding time period, it was assumed that 5 percent of the 1973 initial capacity of each region would be depreciated annually. The mining capacities for 1976-77 of currently existing mines are simply the 1973 numbers multiplied by two to reflect the capacity for the two years in this period and by 0.975 to account for depreciation. The 1978-80 mining capacities are found by multiplying 85 percent of the 1973 figures by three. For clarity, the 85 percent is due to three years depreciation (1976, 1977, and 1978) at 5 percent per year and the three is used because there are three years in the time period. The 1981-85 capacities are found by multiplying the 1973 figures by five to adjust for the number of years and by 0.65 to account for depreciation. Finally, the 1986-90 figures are found by multiplying the 1973 capacities by five to account for the five years in the time period and by 0.40 to account for depreciation.

Table A-27. Mining Capacities.

Region	1973	1976-77	1978-80	1981-85	1986-90
	- - - - - - -	thousand tons	per time	period - - - - - - -	
			Surface		
1	11,613	22,645	29,613	37,742	23,226
2	5,090	9,925	12,980	16,543	10,180
3	2,872	5,600	7,324	9,334	5,744
4	29,002	56,554	73,955	94,257	58,004
5	24,465	47,707	62,386	79,511	48,930
6	245	478	625	796	490
7	33,413	65,155	85,203	108,592	66,826
8	31,337	61,107	79,909	101,845	62,674
9	1,722	3,358	4,391	5,597	3,444
10	6,906	13,467	17,610	22,445	13,812
11	10,724	20,912	27,345	34,853	21,448
12	11,583	22,587	29,537	37,645	23,166
13	6,906	13,467	17,610	22,445	13,812
14	9,127	17,798	23,274	29,663	18,254
15	30,195	58,880	76,997	98,134	60,390
16	4,584	8,939	11,689	14,898	9,168
17	0	0	0	0	0
18	10,524	20,522	26,836	34,203	21,048
19	3,254	6,345	8,298	10,576	6,508
20	19,932	38,867	50,827	64,779	39,864
21	14,461	28,199	36,876	46,998	28,922
			Underground		
1	7,618	14,855	19,425	24,759	15,236
2	3	6	8	10	6
3	3,361	6,554	8,571	10,923	6,722
4	32,570	63,511	83,054	105,853	65,140
5	789	1,539	2,012	2,564	1,578
6	356	694	908	1,157	712
7	40,553	79,078	103,410	131,797	81,106
8	22,342	43,567	56,972	72,612	44,684
9	66	129	168	215	132
13	16,225	31,639	41,374	52,731	32,450
15	46,207	90,104	117,828	150,173	92,414
16	3,636	7,090	9,272	11,817	7,272
18	23,437	45,702	59,764	76,170	46,874
20	95,516	186,256	243,566	310,427	191,032

Mining Costs

The model requires that estimates of mining costs be categorized as to the costs involved in building a new mine (i.e., equipment) and the operating costs (i.e., labor and fuel) for the mine. It was also necessary to specify a "typical" mine size for both strip and underground mining for each region.

The "typical" mine sizes were estimated based on data in [22] (see Table A-31). Once this was done, mining costs on as many mines as possible were developed from both published sources [13,14,21,23] and personal conversations with USBM personnel. Total annual production costs (fixed and variable costs), total direct costs (variable or operating costs), total capital required for initial investment, and total capital required for deferred investment were taken from these sources. Costs were updated to 1975 by applying the following cost escalator coefficients obtained from Robert Reeder, Gates Engineering, Denver, Colorado.

Table A-28. Mining Cost Escalator Coefficients.

Base Year	Escalator Coefficient
1971	1.1
1972	1.1
1973	1.3
1974	1.3

As an example of how to use these escalators, if 1973 data is available, multiply the 1973 value by 1.3 to obtain 1974 costs. Then multiply this value by 1.3 to obtain 1975 costs. These escalators were

used to determine 1975 values for both operating and capital costs. The updated costs are displayed in Tables A-29 and A-30.

The mining cost data in Tables A-29 and A-30 was used as a basis for estimating the specific mining costs used for underground mines and strip mines of at least 500,000 tons per year capacity. However, there was insufficient information available to estimate costs for small strip mines in the published sources. Therefore, a mining cost generator developed by Otte and Boehlje [19] was used to estimate costs for these mines. The Otte-Boehlje model has the capability of calculating production costs for tasks performed in a small dozer-scraper mining operation. Total costs per ton of coal removed and the capital outlay required to obtain a specified level of annual production are determined using a set of mining engineering parameters and accepted mining methods. Parameters used include size and type of equipment, overburden characteristics and depth, reclamation requirements, royalties, acquisition rights, and overhead costs. The specific mining costs used in the model are shown in Table A-31.

Table A-29. Representative 1975 Strip Mining Costs.[a]

Location	Capacity (million tons per year)	Total Annual Prod. Cost (all costs)	Total Direct Costs (operating)	Initial Capital Investment	Deferred Capital Investment	Total Capital Investment	Seam Thick-ness	Overburden Thickness
		($/ton)	($/ton)	($)	($)	($)	- - - feet - - - -	
Northern West Virginia	1.0	10.27	6.46	25,964,100	9,087,435	35,051,536	6.0	108
Northern West Virginia	3.0	7.57	4.95	57,130,200	19,955,570	77,125,770	6.0	108
Western Kentucky	1.0	9.65	5.86	27,967,992	9,788,797	37,756,789	5.5	100
Western Kentucky	1.0	7.37	4.95	16,891,404	5,911,991	22,803,395	4.5	85
Western Kentucky	3.0	6.38	4.11	50,735,004	17,757,251	52,510,255	5.5	100
Oklahoma	1.0	13.04	8.51	32,635,920	11,422,572	44,058,492	1.3	32
Southwest	1.0	7.50	5.10	16,112,124	5,639,243	21,751,367	8.0	80
Southwest	5.0	4.94	4.26	58,459,668	20,460,883	78,920,551	8.0	90
Montana	5.0	3.44	2.47	28,313,364	9,501,677	37,815,041	25.0	75
Wyoming	5.0	3.91	2.94	28,399,044	24,139,187	52,538,231	25.0	75
North Dakota-Montana	1.0	5.86	3.91	13,018,872	11,066,041	24,084,913	10.0	35
North Dakota-Montana	5.0	4.16	2.94	42,329,388	35,979,979	78,309,387	10.0	40
Eastern Province	4.8	9.03	6.61	76,656,034	26,552,000	103,208,000	6.0	0-100
Interior Province	9.2	8.04	6.04	92,279,000	37,434,000	129,713,000	6.0	70
Great Plains	9.2	5.62	4.55	50,482,000	44,641,000	95,123,000	25.0	70

[a] Source [21,23]

Table A-30. Representative 1975 Underground Mining Costs.[a]

Capacity	Total Annual Prod. Cost (all costs)	Total Direct Costs (operating)	Total Capital Requirement Initial Investment	Deferred Investment	Total Investment	Coal Bed Thickness
(million tons per year)	($/ton)	($/ton)	($)	($)	($)	(inches)
1.03	12.84	9.97	21,865,558	15,305,890	37,171,448	48
2.06	11.76	9.31	36,931,401	25,851,980	62,783,381	48
3.09	11.51	9.14	53,125,995	37,188,196	90,314,191	48
1.06	12.41	9.62	21,193,783	14,835,648	36,029,431	72
2.04	11.44	8.99	35,268,441	24,687,908	59,956,349	72
3.18	10.99	8.72	50,211,759	35,148,231	85,359,990	72
4.99	10.90	8.70	75,577,645	52,904,351	128,481,996	72
1.00	12.07	9.77	11,248,809	7,874,166	19,122,975	30
2.00	10.06	7.03	36,571,136	25,599,795	62,170,931	72
6.50	7.59	5.12	85,336,381	42,250,000	127,586,381	48
4.70	9.24	7.42	71,194,630	37,180,000	180,374,630	--

[a] Source [13,14].

Table A-31. Mining Costs Used in the Model.

Region	Operating Cost[a]	Mine Capacity	Capital Cost for New Mines
	($/ton)	(1,000 TPY)	($)
		Surface	
1	6.50	500	16,317,500
2	7.00	700	22,844,500
3	4.83	1,000	27,968,000
4	5.65, 4.12	1,000	15,000,000
5	5.65, 4.12	1,000	15,000,000
6	8.54	50	605,231
7	7.75	200	1,508,105
8	5.35, 4.50	1,200	33,561,000
9	9.00	75	605,231
10	3.72	1,000	13,018,000
11	2.36	3,000	16,987,000
12	4.04	3,000	35,075,400
13	5.25	750	12,668,250
14	3.75	750	24,373,750
15	9.80, 8.15	100	1,388,931
16	8.98	100	1,388,931
17	4.83	1,000	27,968,000
18	9.00	70	2,086,071
19	4.85	1,000	16,112,000
20	9.75, 8.00	150	1,087,429
21	2.67	3,000	16,987,800
		Underground	
1	10.33, 9.62	700	14,700,000
2	10.33	10	210,000
3	9.62	400	8,400,000
4	10.33, 9.62	1,000	21,000,000
5	10.33, 9.62	400	8,400,000
6	10.33	150	3,150,000
7	10.33, 9.62	400	8,400,000
8	9.97	1,000	21,000,000
9	10.33, 9.62	33	693,000
13	10.33, 9.62	1,000	21,000,000
15	10.33, 9.62	1,000	21,000,000
16	10.33, 9.62	400	8,400,000
18	10.33, 9.62	300	6,300,000
20	10.33, 9.62	750	15,750,000

[a] For regions that have two operating cost figures listed, the first number refers to the costs for thin seamed mines and the second refers to costs for thick seamed mines. Seam thickness for each region is defined in Tables A-4 through A-24.

APPENDIX B

TECHNICAL DESCRIPTION OF THE MODEL AND MODEL STRUCTURE

Table B-1 provides a generalized representation of the multiperiod, interregional competition model used to evaluate the national coal economy. This matrix indicates the basic structure of the complete four-period model. Subscripts, variable (row and column) names, and input-output coefficients are defined as follows:

Subscripts

r = 1, 2, ... 21, designates supply regions.

s = 1, 2, ... 18, designates demand regions.

q = 1, 2, ... 6, designates coal quality.

t = 1, 2, 3, 4, designates the time period

Row names

SCr-t, a designation of the surface mining capacity constraints in region r in time period t, e.g., SC01-2.

UCr-t, a designation of the underground mining capacity constraints in region r in time period t, e.g., UC01-2.

MTr-q-t, a designation of the mined coal transfer rows for region r, quality q, and time t, e.g., MT13-3-1.

PTr-q-t, a seven or eight character designation of the processed coal transfer rows for region r, quality q, and time t, e.g., PT13-6-1. q = 1, 2, 3 represents the quality levels of coal as mined. q = 4 represents q = 1 quality coal after processing, q = 5 represents q = 2 coal after processing, and q = 6 represents q = 3 coal after processing.

DDs-t, a designation of the demand level constraints in region s in time t, e.g., DD17-1.

QQs-t, a designation of the demand quality constraints in region s in time t, e.g., QQ17-1.

RAq-r, RBq-r, RCq-r, designations of the reserve constraints in region r of coal of quality level q which was classified as low cost strippable (RA), high cost strippable (RB), low cost underground mineable (RC), and high cost underground mineable (RD), e.g., RA1-20, RB1-20, RC1-20, RD1-20.

Column names

MAr-q-t, MBr-q-t, MDr-q-t, designations of the number of thousand ton units of low cost strippable (MA), high cost strippable (MB), low cost underground mineable (MC), and high cost underground mineable coal (MD), mined in region r of quality q in time t, e.g., MA15-3-1, MB15-1-1, MC18-2-1, MD13-1-1.

NUr-t and NSr-t, designations of the number of new underground (NU) and surface (NS) mines opened in region r in time period t, e.g., NU01-1, NS01-1.

PNr-q-t, a designation of the number of thousand ton units of coal of quality level q that are shipped without processing from region r in time t to the demand centers, e.g., PN10-1-1.

PPr-q-t, a designation of the number of thousand ton units of coal of quality level q that are processed in region r in time t prior to shipment to the demand centers, e.g., PP4-1-1.

Tr-s-q, Ur-s-q, Vr-s-q, Wr-s-q, designations of the number of thousand ton units of coal of quality level q transported from region r to region s in time periods one (T), two (U), three (V), and four (W), e.g., T01-03-5, U01-03-5, V01-03-5, W01-03-5.

The objective function was named "CCOST" and the right-hand side vector was named "K."

Coefficients

a_1 = capacity, in thousand tons per time period, of a new surface mine opened in region r in time period 1.

a_2 = capacity, in thousand tons per time period, of a new underground mine opened in region r, in time period 1.

a_3 = the inverse of the fractional processing weight recovery for coal of quality 1 in region 1.

a_4 = the heating value, in billion Btu per thousand tons, of unprocessed coal from region r.

a_5 = the heating value, in billion Btu per thousand tons, of processed coal from region r.

a_6 = the sulfur content, in pounds of SO_2 per million Btu of unprocessed coal from region r multiplied by a_4.

a_7 = the sulfur content, in pounds of SO_2 per million Btu of processed coal from region r multiplied by a_5.

a_8 = capacity, in thousand tons per time period, of a new surface mine opened in region r in time period 2.

a_9 = capacity, in thousand tons per time period, of a new underground mine opened in region r in time period 2.

C_1, C_9 = cost in dollars per thousand tons, to mine low cost strippable coal in region r in time periods 1 and 2, respectively.

C_2, C_{10} = cost in dollars per thousand tons, to mine high cost strippable reserves in region r in time periods 1 and 2, respectively.

C_3, C_{11} = cost, in dollars per thousand tons, to mine low cost underground reserves in region r in time periods 1 and 2, respectively.

C_4, C_{12} = cost, in dollars per thousand tons, to mine high cost underground reserves in region r in time periods 1 and 2, respectively.

C_5, C_{13} = cost, in dollars to open a new surface mine in time periods 1 and 2, respectively.

C_6, C_{14} = cost, in dollars to open a new underground mine in time periods 1 and 2, respectively.

C_7, C_{15} = cost, in dollars per thousand output tons, to process coal mined in region r of quality level 1 in time periods 1 and 2, respectively.

C_8, C_{16} = cost, in dollars per thousand tons, to transport coal from region r to region s in time periods 1 and 2, respectively.

K_1 = the surface mining capacity, in thousand tons per time period, existing in region r at the beginning of time period 1.

K_2 = the underground mining capacity, in thousand tons per time period, existing in region r at the beginning of time period 1.

K_3, K_7 = the demand for coal, in billion Btu in region s in time periods 1 and 2, respectively.

K_4 = the air quality standard in pounds of SO_2 per million Btu for region s in time period 1 multiplied by K_3.*

$K_5 = K_1$ adjusted for depreciation to time period 2.

$K_6 = K_2$ adjusted for depreciation to time period 2.

K_8 = the air quality standard in pounds of SO_2 per million Btu for region s in time period 2 multiplied by K_7.*

$K_9, K_{10}, K_{11}, K_{12}$ = the region r reserves, in thousand tons, of low cost strippable, high cost strippable, low cost underground, and high cost underground coal, respectively.

*Special Note: The seemingly curious definition of K_4 can be readily understood if one writes the quality constraint QQs-1 as:

$$\frac{a_6 \text{ Tr-s-1} + a_7 \text{ Tr-s-4}}{K_3} \le S^*$$

where S^* is the sulfur emission standard. This form of the equation is analogous to equation [9] in the explanation of the model in the text. Multiplying the above equation by K_3 yields the K_4 coefficient. A similar argument can be made for the definition of K_8.

Table B-1. Generalized Tableau for One Quality Level, Two Time Period Case.

Column / Row	MAr-1-1	MBr-1-1	MCr-1-1	MDr-1-1	NSr-1	NUr-1	PNr-1-1	PPr-1-1	Tr-s-1	Tr-s-4	MAr-1-2	MBr-1-2	MCr-1-2	MDr-1-2	NSr-2	NUr-2	PNr-1-2	PPr-1-2	Ur-s-2	Ur-s-4	K
SCr-1	+1.0	+1.25			$-a_1$																$\leq K_1$
UCr-1			+1.0	+1.25		$-a_2$															$\leq K_2$
MTr-1-1	+1.0	+1.0	+1.0	+1.0			-1.0	$-a_3$													= 0
PTr-1-1							+1.0		-1.0												= 0
PTr-4-1								+1.0		-1.0											= 0
DDs-1									$+a_4$	$+a_5$											$\geq K_3$
QQs-1									$+a_6$	$+a_7$											$\leq K_4$
SCr-2					$-a_8$						+1.0	+1.25			$-a_8$						$\leq K_5$
UCr-2						$-a_9$							+1.0	+1.25		$-a_9$					$\leq K_6$
MTr-1-2											+1.0	+1.0	+1.0	+1.0			-1.0	$-a_3$			= 0
PTr-1-2																	+1.0		-1.0		= 0
PTr-4-2																		+1.0		-1.0	= 0
DDs-2																			$+a_4$	$+a_5$	$\geq K_7$
QQs-2																			$+a_6$	$+a_7$	$\leq K_8$
RA1-r	+1.0										+1.0										$\leq K_9$
RB1-r		+1.0										+1.0									$\leq K_{10}$
RC1-r			+1.0										+1.0								$\leq K_{11}$
RD1-r				+1.0										+1.0							$\leq K_{12}$
CCOST	C_1	C_2	C_3	C_4	C_5	C_6	0	C_7	C_8	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	0	C_{15}	C_{16}	C_{16}	

APPENDIX C

THE BASE SOLUTION

In this appendix, the complete model results for all producing and consuming regions are presented for the scenario assuming the regional sulfur dioxide emission standards. Tables C-1 and C-2 show the processing and new mine openings for each of the supply regions. Tables C-3 through C-20 show the sources of coal for each of the 18 consumption regions.

Table C-1. Coal Processed by Regions and Time Periods.[a]

Supply Region	1976-77	1978-80	1981-85	1986-90
	- - - - - - - - - -	- - - - 1,000 tons	- - - - - - - - - -	
Illinois	32,548	31,973	16,544	17,982
Indiana	29,592	57,565	385,650	316,149
Western Kentucky	31,240	46,163	--	--
Ohio	42,369	55,667	252,980	523,914
West Virginia	39,862	145,329	--	--

[a] Regions not listed showed no processing in any time period.

Table C-2. New Mines Opened by Regions, Mine Types, and Time Periods.

Supply Region	1976-77 Surface	1976-77 Underground	1978-80 Surface	1978-80 Underground	1981-85 Surface	1981-85 Underground	1986-90 Surface	1986-90 Underground
	Number of mines							
Alabama-Georgia	--	6.0	--	13.0	6.1	--	--	11.8
Arkansas-Missouri	--	--	--	--	--	--	--	--
Colorado	--	--	--	--	--	--	--	--
Illinois	--	--	--	--	--	--	--	--
Indiana	3.0	--	12.0	--	104.6	--	--	--
Iowa	--	--	--	--	--	--	--	--
Eastern Kentucky	22.0	--	18.0	--	216.5	--	21.4	--
Western Kentucky	--	--	--	--	--	--	--	--
Maryland	--	--	--	--	--	--	--	--
North and South Dakota	--	--	--	--	--	--	--	--
Montana	4.5	--	--	--	--	--	--	--
New Mexico	--	--	--	--	--	--	--	--
Ohio	1.0	--	--	--	108.2	--	40.8	--
Oklahoma-Texas	--	--	--	--	--	--	--	--
Pennsylvania	6.0	14.0	--	12.0	54.4	--	150.1	37.9
Tennessee	6.0	4.0	--	--	65.3	--	--	--
Utah	--	--	3.0	--	10.1	--	1.2	--
Virginia	--	12.0	8.0	2.7	755.2	--	135.2	--
Washington-Oregon	--	--	--	--	--	--	--	--
West Virginia	5.0	--	71.0	--	--	--	--	--
Wyoming	10.0	--	1.8	--	--	--	--	--

Table C-3. Shipments to Demand Region 1 (North Central United States).

Origin	Period	Quality (lb. SO_2/million Btu)	Quality (Btu/lb.)	Amount Shipped (1,000 tons per time period)
Illinois	1976-77	4.3	11,551	13,194
Western Kentucky		7.4	12,513	2,691
Western Kentucky		4.3[a]	13,313	4,820
Montana		0.96	8,416	47,861
Illinois	1978-80	4.3	11,551	12,214
Illinois		3.0[a]	12,995	1,332
Western Kentucky		4.3[a]	13,313	21,911
Montana		0.96	8,416	68,730
Indiana	1981-85	2.9	13,432	92,183
Indiana		2.1[a]	13,598	19,465
Montana		0.96	8,416	44,520
Indiana	1985-90	2.9	13,432	56,990
Indiana		2.1[a]	13,598	93,768

[a] Processed coal.

Table C-4. Shipments to Demand Region 2 (Western Missouri).

Origin	Period	Quality (lb. SO_2/million Btu)	Quality (Btu/lb.)	Amount Shipped (1,000 tons per time period)
Illinois	1976-77	4.3	11,551	2,738
Illinois		3.0[a]	12,995	13,387
Colorado	1978-80	0.7	11,952	7,324
Illinois		4.3	11,551	18,034
Illinois		3.0[a]	12,995	1,943
New Mexico		1.3	10,618	251
Illinois	1981-85	4.3	11,551	10,970
Indiana		2.9	13,432	34,576
Illinois	1986-90	4.3	11,551	11,924
Indiana		2.9	13,432	37,583

[a] Processed coal.

Table C-5. Shipments to Demand Region 3 (Illinois-Indiana).

Origin	Period	Quality		Amount Shipped (1,000 tons per time period)
		(lb. SO_2/million Btu)	(Btu/lb.)	
Eastern Kentucky	1976-77	1.4	13,880	125,860
Western Kentucky		4.3[a]	13,313	20,999
Indiana	1978-80	2.1[a]	13,598	57,565
Eastern Kentucky		1.4	13,880	155,443
Western Kentucky		4.3[a]	13,313	18,880
Indiana	1981-85	1.9[a]	13,179	239,799
Indiana		2.1[a]	13,598	32,420
Eastern Kentucky		1.4	13,880	80,608
Ohio		1.8[a]	13,915	79,483
Indiana	1986-90	1.9[a]	13,179	120,244
Eastern Kentucky		1.4	13,880	28,381
Ohio		1.8[a]	13,915	312,915

[a] Processed coal.

Table C-6. Shipments to Demand Region 4 (Michigan).

Origin	Period	Quality		Amount Shipped (1,000 tons per time period)
		(lb. SO_2/million Btu)	(Btu/lb.)	
Indiana	1976-77	2.9	13,432	23,524
Indiana		2.1[a]	13,598	29,592
West Virginia		1.2[a]	14,282	2,169
Indiana	1978-80	2.9	13,432	20,682
West Virginia		1.2[a]	14,282	63,198
Indiana	1981-85	1.9[a]	13,179	65,432
Eastern Kentucky		1.4	13,880	93,083
Indiana	1986-90	1.9[a]	13,179	71,121
Eastern Kentucky		1.4	13,880	101,177

[a] Processed coal.

Table C-7. Shipments to Demand Region 5 (Western United States).

Origin	Period	Quality		Amount Shipped (1,000 tons per time period)
		(lb. SO_2/million Btu)	(Btu/lb.)	
Colorado	1976-77	0.7	11,952	1,361
Wyoming		1.1	9,400	88,199
Wyoming	1978-80	1.1	9,400	141,640
Utah	1981-85	1.5	12,047	50,469
Wyoming		1.1	9,400	193,879
Colorado	1986-90	0.7	11,952	1,714
Utah		1.5	12,047	56,562
Wyoming		1.1	9,400	206,374

Table C-8. Shipments to Demand Region 6 (New England).

Origin	Period	Quality		Amount Shipped (1,000 tons per time period)
		(lb. SO_2/million Btu)	(Btu/lb.)	
Maryland	1976-77	1.7	13,111	3,487
Virginia		1.0	13,454	7,891
West Virginia		1.2[a]	14,282	36,594
Maryland	1978-80	1.7	13,111	4,559
Virginia		1.0	13,454	10,313
West Virginia		1.2[a]	14,282	60,634
Maryland	1981-85	1.7	13,111	5,597
Ohio		1.8[a]	13,915	30,639
Virginia		1.0	13,454	101,150
Ohio	1986-90	1.8[a]	13,915	38,319
Virginia		1.0	13,454	110,635

[a] Processed coal.

Table C-9. Shipments to Demand Region 7 (Florida-Georgia).

Origin	Period	Quality (lb. SO_2/million Btu)	Quality (Btu/lb.)	Amount Shipped (1,000 tons per time period)
Alabama-Georgia	1976-77	0.8	14,788	23,926
Western Kentucky		4.3	13,313	3,430
Alabama-Georgia	1978-80	0.8	14,788	23,633
Alabama-Georgia		1.7	14,066	19,889
Alabama-Georgia	1981-85	0.8	14,788	43,140
Alabama-Georgia		1.7	14,066	36,306
Alabama-Georgia	1986-90	0.8	14,788	46,891
Alabama-Georgia		1.7	14,066	39,463

Table C-10. Shipments to Demand Region 8 (Virginia, West Virginia, North Carolina, South Carolina).

Origin	Period	Quality (lb. SO_2/million Btu)	Quality (Btu/lb.)	Amount Shipped (1,000 tons per time period)
Western Kentucky	1976-77	7.4	12,513	7,463
Virginia		1.0	13,454	18,922
West Virginia		2.2	13,084	92,141
Western Kentucky	1978-80	7.4	12,513	8,626
Virginia		1.0	13,454	4,458
Virginia		1.6	14,661	26,836
West Virginia		2.2	13,084	146,046
Indiana	1981-85	2.9	13,432	61,175
Virginia		1.0	13,454	123,118
Virginia		1.6	14,661	130,964
Indiana	1986-90	2.9	13,432	115,563
Virginia		1.0	13,454	232,605

Table C-11. Shipments to Demand Region 9 (Kentucky, Tennessee, Alabama, Mississippi).

Origin	Period	Quality (lb. SO_2/million Btu)	Quality (Btu/lb.)	Amount Shipped (1,000 tons per time period)
Alabama-Georgia	1976-77	0.8	14,788	21,974
Illinois		3.0[a]	12,995	8,099
Tennessee		1.2	14,336	20,429
Eastern Kentucky		1.4	13,880	27,173
Virginia		1.0	13,454	46,610
Alabama-Georgia	1978-80	0.8	14,788	42,585
Alabama-Georgia		1.7	14,066	2,832
Illinois		3.0[a]	12,995	11,049
Eastern Kentucky		1.4	13,880	51,170
Tennessee		1.2	14,336	29,961
Virginia		1.0	13,454	58,188
Alabama-Georgia	1981-85	0.8	14,788	64,762
Eastern Kentucky		1.4	13,880	181,401
Tennessee		1.2	14,336	71,543
Virginia		1.0	13,454	41,441
Alabama-Georgia	1986-90	0.8	14,788	67,669
Eastern Kentucky		1.4	13,880	205,180
Tennessee		1.2	14,336	59,444
Virginia		1.0	13,454	58,315

[a] Processed coal.

Table C-12. Shipments to Demand Region 10 (South Central United States).

Origin	Period	Quality (lb. SO_2/million Btu)	Quality (Btu/lb.)	Amount Shipped (1,000 tons per time period)
Western Kentucky	1976-77	7.4	12,513	6,097
New Mexico		1.3	10,618	18,594
Western Kentucky	1978-80	7.4	12,513	9,602
New Mexico		1.3	10,618	29,286
Colorado	1981-85	0.7	11,952	9,334
Illinois		4.3	11,551	20,061
Indiana		2.9	13,432	33,042
Colorado	1986-90	0.7	11,952	4,030
Illinois		4.3	11,551	11,855
Indiana		2.9	13,432	49,919

Table C-13. Shipments to Demand Region 11 (Pennsylvania-Ohio).

Origin	Period	Quality		Amount Shipped (1,000 tons per time period)
		(lb. SO_2/million Btu)	(Btu/lb.)	
Ohio	1976-77	1.8[a]	13,915	42,369
Pennsylvania		1.0	13,207	178,184
West Virginia		2.2	13,084	8,938
West Virginia		1.2[a]	14,282	1,098
Ohio	1978-80	1.8[a]	13,915	55,667
Pennsylvania		1.0	13,207	266,712
West Virginia		2.2	13,084	18,325
West Virginia		1.2[a]	14,282	21,497
Ohio	1981-85	1.1	11,598	153,600
Ohio		1.8[a]	13,915	142,858
Pennsylvania		1.0	13,207	384,046
Ohio	1986-90	1.8[a]	13,915	172,680
Pennsylvania		1.0	13,207	545,770

[a] Processed coal.

Table C-14. Shipments to Demand Region 12 (Eastern Missouri).

Origin	Period	Quality		Amount Shipped (1,000 tons per time period)
		(lb. SO_2/million Btu)	(Btu/lb.)	
Illinois	1976-77	3.0[a]	12,995	11,062
Colorado		0.6	13,380	1,163
Colorado		0.7	11,952	3,772
Illinois	1978-80	3.0[a]	12,995	17,649
Colorado		0.6	13,380	6,568
Illinois	1981-85	3.0[a]	12,995	16,544
Indiana		1.9	13,179	28,534
Illinois	1986-90	3.0[a]	12,995	17,982
Indiana		1.9	13,179	31,016

[a] Processed coal.

Table C-15. Shipments to Region 13 (Central Iowa).

Origin	Period	Quality		Amount Shipped (1,000 tons per time period)
		(lb. SO_2/million Btu)	(Btu/lb.)	
Illinois	1976-77	4.3	11,551	1,128
Western Kentucky		7.4	12,513	1,264
Illinois	1978-80	4.3	11,551	3,046
Iowa		7.1	11,746	1,533
Western Kentucky		7.4	12,513	820
Illinois	1981-85	4.3	11,551	5,560
Western Kentucky		7.4	12,513	1,497
Illinois	1986-90	4.3	11,551	6,044
Western Kentucky		7.4	12,513	1,627

Table C-16. Shipments to Region 14 (Western Iowa).

Origin	Period	Quality		Amount Shipped (1,000 tons per time period)
		(lb. SO_2/million Btu)	(Btu/lb.)	
Colorado	1976-77	0.7	11,952	467
Western Kentucky		7.4	12,513	1,691
Western Kentucky	1978-80	7.4	12,513	2,084
Wyoming		1.1	9,400	1,707
Indiana	1981-85	2.9	13,432	3,054
Western Kentucky		7.4	12,513	2,868
Indiana	1986-90	2.9	13,432	3,319
Western Kentucky		7.4	12,513	3,117

Table C-17. Shipments to Demand Region 15 (North Central Iowa).

Origin	Period	Quality		Amount Shipped (1,000 tons per time period)
		(lb. SO_2/million Btu)	(Btu/lb.)	
Illinois	1976-77	4.3	11,551	472
Western Kentucky		7.4	12,513	529
Illinois	1978-80	4.3	11,551	1,273
Western Kentucky		7.4	12,513	343
Illinois	1981-85	4.3	11,551	2,324
Western Kentucky		7.4	12,513	626
Indiana	1986-90	2.9	13,431	1,497
Western Kentucky		7.4	12,513	1,406

Table C-18. Shipments to Demand Region 16 (Southeast Iowa).

Origin	Period	Quality		Amount Shipped (1,000 tons per time period)
		(lb. SO_2/million Btu)	(Btu/lb.)	
Western Kentucky	1976-77	7.4	12,513	666
Western Kentucky		4.3[a]	13,313	516
Western Kentucky	1978-80	7.4	12,513	432
Western Kentucky		4.3[a]	13,313	1,393
Indiana	1981-85	2.9	13,432	1,736
Indiana		7.4	12,513	1,630
Indiana	1986-90	2.9	13,432	1,887
Indiana		7.4	12,513	1,772

[a] Processed coal.

Table C-19. Shipments to Demand Region 17 (Northeast Iowa).

Origin	Period	Quality		Amount Shipped (1,000 tons per time period)
		(lb. SO_2/million Btu)	(Btu/lb.)	
Illinois	1976-77	4.3	11,551	615
Western Kentucky		7.4	12,513	689
Illinois	1978-80	4.3	11,551	1,660
Western Kentucky		7.4	12,513	447
Illinois	1981-85	4.3	11,551	3,031
Western Kentucky		7.4	12,513	816
Illinois	1986-90	4.3	11,551	3,924
Western Kentucky		7.4	12,513	887

Table C-20. Shipments to Demand Region 18 (East Central Iowa).

Origin	Period	Quality		Amount Shipped (1,000 tons per time period)
		(lb. SO_2/million Btu)	(Btu/lb.)	
Western Kentucky	1976-77	7.4	12,513	1,905
Western Kentucky		4.3[a]	13,313	1,474
Western Kentucky	1978-80	7.4	12,513	1,235
Western Kentucky		4.3[a]	13,313	3,981
Indiana	1981-85	2.9	13,432	4,963
Western Kentucky		7.4	12,513	4,660
Indiana	1986-90	2.9	13,432	5,394
Western Kentucky		7.4	12,513	5,065

[a] Processed coal.

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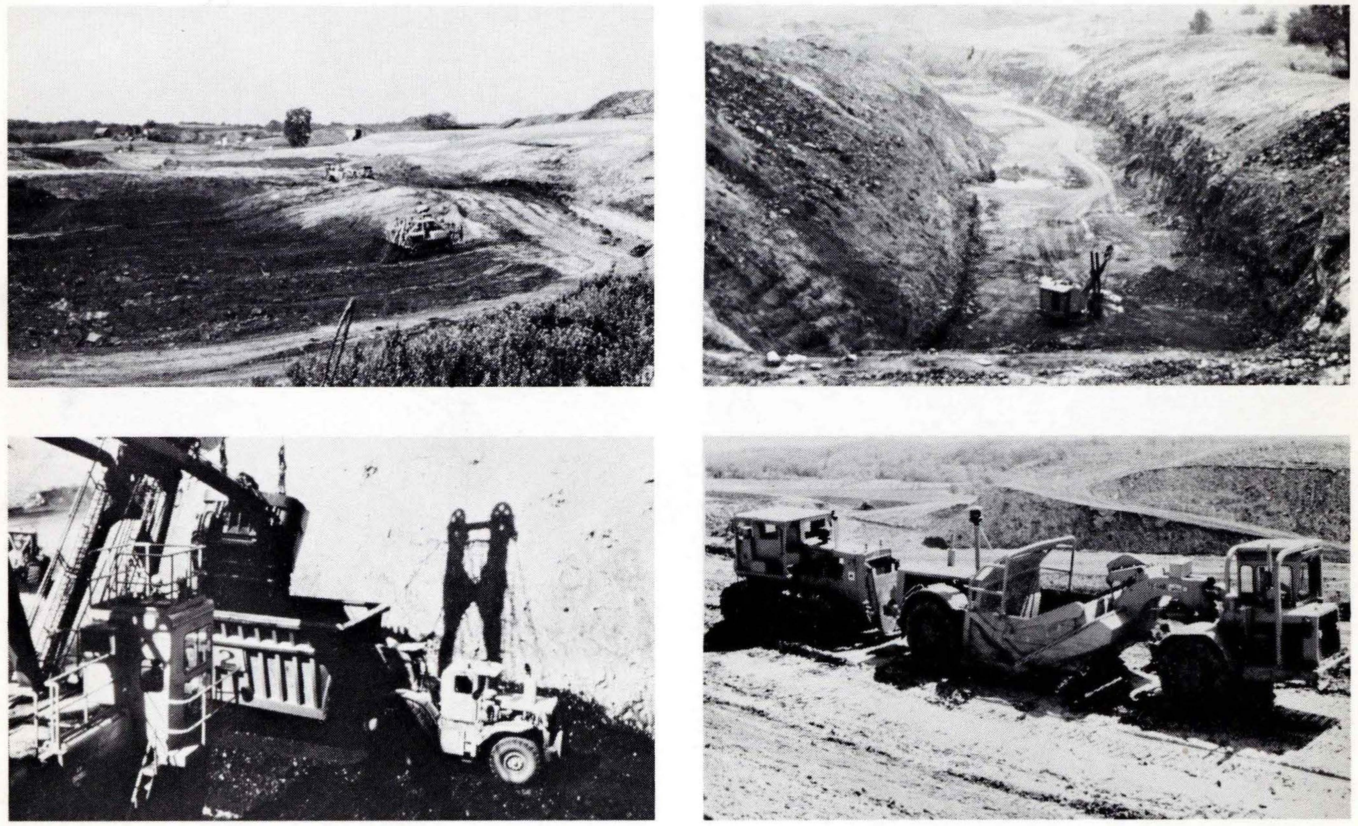

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