27
1-28-25
25 up to NTIS

**PRICE AND AVAILABILITY OF WESTERN COAL IN THE
MIDWESTERN ELECTRIC UTILITY MARKET,
1974-1982**

by

J. G. Asbury and K. W. Costello

MASTER

ARGONNE NATIONAL LABORATORY

ENERGY AND ENVIRONMENTAL SYSTEMS DIVISION

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

The facilities of Argonne National Laboratory are owned by the United States Government. Under the terms of a contract (W-31-109-Eng-38) between the U. S. Atomic Energy Commission, Argonne Universities Association and The University of Chicago, the University employs the staff and operates the Laboratory in accordance with policies and programs formulated, approved and reviewed by the Association.

MEMBERS OF ARGONNE UNIVERSITIES ASSOCIATION

The University of Arizona	Kansas State University	The Ohio State University
Carnegie-Mellon University	The University of Kansas	Ohio University
Case Western Reserve University	Loyola University	The Pennsylvania State University
The University of Chicago	Marquette University	Purdue University
University of Cincinnati	Michigan State University	Saint Louis University
Illinois Institute of Technology	The University of Michigan	Southern Illinois University
University of Illinois	University of Minnesota	The University of Texas at Austin
Indiana University	University of Missouri	Washington University
Iowa State University	Northwestern University	Wayne State University
The University of Iowa	University of Notre Dame	The University of Wisconsin

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately-owned rights.

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

PRICE AND AVAILABILITY OF WESTERN COAL IN THE
MIDWESTERN ELECTRIC UTILITY MARKET,
1974--1982*

by

J. G. Asbury and K. W. Costello

Energy and Environmental Systems Division

October 1974

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

*Supported by the U. S. Environmental Protection Agency, Contract No. EPA-IAG-D4-0308, and by the National Science Foundation Research Applied to National Needs (RANN) Division, Contracts No. AG-352 and GI32989A2.

MASTER

DISTRIBUTION OF THIS DOCUMENT UNLIMITED

leg

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	7
SUMMARY	8
1.0 INTRODUCTION	15
2.0 PATTERNS OF WESTERN COAL SUPPLY	16
2.1 WESTERN COAL REGIONS	16
Northern Great Plains Province	16
Rocky Mountain Province	22
2.2 TRANSPORTATION MODES	23
3.0 COST ANALYSIS	26
3.1 PRODUCTION COSTS	26
The Forecast Problem	29
Bureau of Mines Cost Studies	31
Production-Cost Forecasts	31
3.2 TRANSPORTATION COSTS	36
Existing Tariffs	36
Healing Value of Coal	40
Transportation Cost Forecast	41
4.0 PRICE OF WESTERN COAL IN THE MIDWESTERN ELECTRIC UTILITY MARKET	47
4.1 UNCONSTRAINED SUPPLY OF WESTERN COAL	47
4.2 CONSTRAINTS ON WESTERN COAL SUPPLY	50
Production Constraints	51
Transportation Constraints	52
4.3 ESTIMATED SUPPLY PRICE	53
Unconstrained Supply	53
Constrained Supply	57
ACKNOWLEDGMENTS	64

List of Figures

<u>No.</u>	<u>Title</u>	<u>Page</u>
S1	1974 Prices of Western Coal in the Midwest Market, Demand Growth < 25%/Year	10
S2	1974 Prices of Western Coal in the Midwest Market, Demand Growth > 25%/Year	11
S3	1982 Prices of Western Coal in the Midwest Market, Demand Growth < 25%/Year	12
S4	1982 Prices of Western Coal in the Midwest Market, Demand Growth > 25%/Year	13
1	Western Coal Reserves and Transportation Routes to Midwestern Urban Areas	17
2	Expected Annual Tonnage of Wyoming Coal Deliveries by 1980	21
3	Price of Surface Mine Coal under Different Demand Conditions	30
4	Cost Indexes for Selected Coal-Mining Factor Inputs, Deflated Values	33
5	Coal Transportation Rates	39
6	AAR Combined Cost Index -- Nominal, Deflated	43
7	Annual Percent Changes in Nominal Railroad Rates, Costs, and Revenues	44
8	1974 Delivered-Coal Price by Coal Type, Unconstrained Supply	49
9	1974 Prices of Western Coal in the Midwest Market, Demand Growth < 25%/Year	54
10	1978 Prices of Western Coal in the Midwest Market, Demand Growth < 25%/Year	55
11	1982 Prices of Western Coal in the Midwest Market, Demand Growth < 25%/Year	56
12	1974 Prices of Western Coal in the Midwest Market, Demand Growth > 25%/Year	58
13	1978 Prices of Western Coal in the Midwest Market, Demand Growth > 25%/Year	59
14	1982 Prices of Western Coal in the Midwest Market, Demand Growth > 25%/Year	60

List of Tables

<u>No.</u>	<u>Title</u>	<u>Page</u>
S1	1982 Mine Prices for Subbituminous Coals of Different Heating Values	9
1	Recent Coal-Supply Contracts	19
2	Wyoming Coal Production, Current and Projected	18
3	The Cost of Delivered Coal as a Function of Market Distance. Two Western Coal Regions	27
4	Reserves Estimates and Price and Cost Data for Four Western Coal Regions	28
5	Estimated Production Cost of Western Surface Mine and Deep Mine Coal	35
6	Burlington Northern's Rates of Shipping Western Coal into the Midwest Region	37
7	Transportation Costs to Chicago for an Annual Shipment of One Million Tons	41
8	Transportation Costs	46
9	Price of Delivered Coal, Unconstrained Supply	48
10	1974 Mine Prices of Subbituminous Coals for Different Shipping Distances, Demand Growth < 25%/Year	61
11	1978 Mine Prices of Subbituminous Coals for Different Shipping Distances, Demand Growth < 25%/Year	61
12	1982 Mine Prices of Subbituminous Coals for Different Shipping Distances, Demand Growth < 25%/Year	62
13	1974 Mine Prices of Subbituminous Coals for Different Shipping Distances, Demand Growth > 25%/Year	62
14	1978 Mine Prices of Subbituminous Coals for Different Shipping Distances, Demand Growth > 25%/Year	63
15	1982 Mine Prices of Subbituminous Coals for Different Shipping Distances, Demand Growth > 25%/Year	63

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

PRICE AND AVAILABILITY OF WESTERN COAL IN THE
MIDWESTERN ELECTRIC UTILITY MARKET, 1974-1982

by

J. G. Asbury and K. W. Costello

ABSTRACT

The prices of low sulfur Western coals selling in the Midwestern electric utility market have been estimated for the period 1974 to 1982. The price estimates follow from a cost analysis of Western coal production and transportation that takes into account possible constraints on the rate of Western coal development.

Lowest prices for "new" Western coal will occur under conditions of demand growth less than 25% per year. This lowest-cost coal will consist mostly of subbituminous coal produced from large surface mines in the Powder River Basin in Wyoming and Montana. For Western coal demand growth in excess of 25% per year, shortages of large-scale surface mine equipment will force the opening of less efficient surface mines and will cause production costs to increase.

Analysis of railroad rates shows that current transportation costs can be represented by the relation $r = 6.3 + 600/X$, where r is the unit cost of transportation (mills per ton-mile) and X is the size of the annual shipment (thousands of tons per year). Transportation costs, expressed in constant dollars, are projected to increase by 3% per year.

Information provided by this study should assist government regulatory bodies and electric utility companies in evaluating alternative sulfur dioxide control strategies.

SUMMARY

The prices of low sulfur Western coals selling in the Midwestern electric utility market have been estimated for the period 1974 to 1982. The price estimates follow from a cost analysis of Western coal production and transportation that takes into account possible constraints on the rate of Western coal development.

Lowest prices for "new" Western coal will occur under conditions of demand growth less than 25% per year. This lowest-cost coal will consist mostly of low-rank (8300-8800 Btu/lb) subbituminous coal produced from large surface mines in the Powder River Basin in Wyoming and Montana. Output of higher quality subbituminous coal will also expand; however, constraints on reserves availability will cause the market share of this coal to decline. For Western coal demand growth in excess of 25% per year, shortages of large-scale surface mine equipment will force the opening of smaller surface mines in the Powder River Basin and will encourage the development of underground bituminous mines in other Western coal regions.

Shipment by railroad will remain the principal transportation mode to the Midwest, with rail-water routes favored for many plants located on the Great Lakes and the Inland Waterway System. Our analysis of current railroad rates shows that they are reasonably well approximated by the relation $r = 6.3 + 600/X$, where r is the unit cost of transportation (mills per ton-mile) and X is the size of the annual shipment (thousands of tons per year). Transportation costs, expressed in constant dollars, are projected to increase by 3% per year.

A simplified presentation of delivered coal price estimates for 1974 and 1982 is given in Figs. S1-S4.* The figures, which correspond to two different demand-growth scenarios, show prices as a function of market distance for coal produced and delivered under high-volume, long-term contract. The price frontiers shown in Figs. S1 and S3 refer to deliveries of bituminous and subbituminous coals produced under conditions of low-demand growth. Demand growth in excess of 25% per year will allow the marketing of subbituminous coal produced from less efficient surface mines. Estimated costs under the high-demand growth scenario are shown in Figs. S2 and S4. The nominal price

*All prices are expressed in constant April 1974 dollars.

advantage of subbituminous coal ($\sim 10^4/10^6$ Btu at the Ohio-Indiana border in 1974) is largely offset by the superior combustion properties (particularly the higher ash-fusion temperatures) of the bituminous coal.

Under both the high- and low-demand growth scenarios, higher rank subbituminous coals are likely to remain scarce. This means that producers of the higher-rank coals will be able to raise their mine prices to levels that will equate the delivery prices (cents per million Btu basis) of the high- and low-rank coals. Table S1 lists estimated 1982 mine prices of subbituminous coals of different heating values for an assumed shipping distance of 1200 miles.

TABLE S1. 1982 Mine Prices for Subbituminous Coals
of Different Heating Values
(Shipping Distance = 1200 miles)

Coal Heating Value (Btu/lb)	Mine Price			
	Demand Growth < 25%/yr.		Demand Growth > 25%/yr.	
	\$/ton	(¢/MBtu)	\$/ton	(¢/MBtu)
8300	3.66	(22.0)	5.49	(33.1)
9000	4.84	(26.9)	6.84	(38.0)
9500	5.70	(30.0)	7.81	(41.1)
10500	7.39	(35.2)	9.72	(46.3)

Fig. S1. 1974 Prices of Western Coal in the Midwest Market, Demand Growth < 25%/Year

Fig. S2. 1974 Prices of Western Coal in the Midwest Market, Demand Growth > 25%/Year

Fig. S3. 1982 Prices of Western Coal in the Midwest Market, Demand Growth < 25%/Year

Fig. S4. 1982 Prices of Western Coal in the Midwest Market, Demand Growth > 25%/Year

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

1.0 INTRODUCTION

Faced with the problem of complying with sulfur dioxide control regulations, electric utilities in the Midwest have been increasing their purchases of low sulfur Western coal. Whether, and to what extent, Midwestern demand for Western coal will continue to increase depends upon a number of factors. Foremost among these are: (1) the evolution of future sulfur dioxide control regulations as determined by federal, state, and local governments; (2) the growth of coal-fired generating capacity; (3) the costs of using Western coal relative to the costs of using alternative fuels and control technologies; and (4) the electric rate regulatory processes as they affect the ability of utilities to recover the costs of alternative control technologies.*

By estimating the future price and availability of Western coal selling in the Midwestern market, the present study provides a basis for estimating the cost of one method of meeting sulfur dioxide control regulations. Accordingly, the information developed in this study should assist regulatory bodies and electric utilities in their efforts to evaluate alternative control strategies.

As reported here, the study findings are divided into three parts, corresponding to Secs. 2, 3, and 4 below. Section 2 describes the major Western coal-producing regions and discusses existing and planned transportation modes to the Midwest. Section 3 analyzes coal production and transportation costs, taking into account possible constraints on Western coal supply. Finally, Sec. 4 presents supply price forecasts for the years 1974, 1978, and 1982.

Unless otherwise stated, all prices and costs presented in this report are expressed in constant April 1974 dollars.

*Rate regulation policies and processes can affect utility preferences for capital- and fuel-intensive technologies. Present rate regulation, to the extent that it allows automatic passthrough of fuel cost increases while it requires regulatory approval of rate increases associated with capital additions, may bias utility decisions toward fuel-intensive systems.

2.0 PATTERNS OF WESTERN COAL SUPPLY

2.1 WESTERN COAL REGIONS

The Western coal and lignite fields are located within two great coal provinces: the Northern Great Plains Province, which includes eastern Montana, western North Dakota, and northeastern Wyoming; and the Rocky Mountain Province, which embraces western and southern Wyoming, most of Colorado and Utah, and northeastern New Mexico.

Northern Great Plains Province

As shown in Fig. 1, the Northern Great Plains Province consists of two regions, one underlain by lignite and the other by subbituminous coal. The heating value of the lignite in western North Dakota and eastern Montana ranges from 6000 Btu/lb to 7200 Btu/lb, while the subbituminous coals in the Powder River basin range from 7800 Btu/lb to 9800 Btu/lb.* Sulfur content varies from deposit-to-deposit in both regions, but is generally in the range of 0.2-1.0 weight percent. Vast quantities of the low sulfur reserves of both regions are recoverable by efficient strip mining methods.

Although somewhat nearer Midwestern markets, the North Dakota lignite suffers a transportation disadvantage with respect to the subbituminous coals of Montana and Wyoming.** The high water content (~35%) and the correspondingly low Btu value of the lignite makes long distance haulage uneconomical. Although production of lignite is expected to increase substantially over the next several decades, most of this output will be consumed locally, either by the region's electric utility plants or by lignite gasification plants.***

*See: "Strippable Reserves of Bituminous Coal and Lignite in the United States," U.S. Bureau of Mine Information Circular 8531 (1971); "Strippable lignite Reserves of North Dakota," Bumines IC 8537 (1972); and "Strippable Coal Reserves of Wyoming," Bumines IC 8538 (1972).

**In 1973 the Burlington Northern Railway shipped nearly as many tons of Montana subbituminous coal through North Dakota as tons of lignite were mined throughout North Dakota.

***Among companies who have announced plans to build lignite gasification complexes in North Dakota are: Natural Gas Pipe Line Co. (a subsidiary of Peoples Gas), Michigan-Wisconsin Pipe Line Co., and El Paso Natural Gas Co.

Fig. 1. Western Coal Reserves and Transportation Routes to Midwestern Urban Areas

The competitive position of Powder River Basin coal in the electric utility coal market is indicated by Table 1, which lists all the coal contracts reported in Coal Age over the past year. As seen from the table, the Powder River Basin accounted for about half of the tonnage involved in these long-term coal contracts. Vast tonnages of coal lie in thick (30-130 ft) beds near the surface making the Basin's mining costs the lowest in the country. The U.S. Bureau of Mines estimates that Campbell County, Wyoming, alone, contains about 20 billion tons of economically strippable reserves.* Other counties holding large reserves are Converse, Johnson, and Sheridan in Wyoming; and Big Horn, Powder River, and Rosebud in Montana.

Although the Montana part of the Powder River Basin has traditionally outproduced the Wyoming part, this situation is likely to change in the near future. Ownership patterns, state governmental tax and regulatory policy, and citizen acceptance are generally more favorable to large-scale development in Wyoming than in Montana. Some indication of the rate of expansion of the Wyoming coal fields is provided by Table 2. Most of the projected increase in Wyoming output will occur in the Powder River Basin region. Figure 2 shows the destinations of the projected 1980 Wyoming coal output.

TABLE 2. Wyoming Coal Production, Current and Projected^a

Year	Total Production (10 ⁶ tons)	Consumption (10 ⁶ tons)		
		Electric Utilities		Coal Gasification
		In State	Out of State	
1973	13.0	5.5	7.5	--
1980	85	22	51	12

^aFigures in the table developed from material presented in Coal Age, May 1974.

*Bumines IC 8538, op. cit.

TABLE 1. Recent Coal-Supply Contracts

Supplier	Source of Coal	Customer	Btu/lb	Amount	Duration	Price	Month Reported
Kerr-McGee	Powder River Basin, WY	Gulf States Utilities	≈ 8650	2.5x10 ⁶ ton/yr	20 yr	—	12/73
17 Coal Cos.	W. KY, TN, WV	TVA		72,000 ton/wk 14x10 ⁶ ton total		\$105x10 ⁶ (total)	12/73
Falcon Coal	E. KY	Detroit Ed.		1.5x10 ⁶ ton total	15 yr	≈ \$205x10 ⁶ (total, incl. escal.)	1/74
Amax	Powder River Basin, WY	S.W. Elec. Power Co., AR		1.75x10 ⁶ ton/yr		—	11/73
Amax	Powder River Basin, WY	AR P & L		42.5x10 ⁶ ton (total)		—	—
Decker Coal	Powder River Basin, MT	Detroit Ed.	9600	4x10 ⁶ ton/yr (by '76) 7x10 ⁶ ton/yr (by '81)	26 yr	\$10 ⁹ for coal \$2.10 ⁹ transportation & storage	—
Kerr McGee	Powder River Basin, WY	Central LA Electric	8525	550 Mwe	20+10 yr	\$100x10 ⁶ (20 yr)	9/73
Kerr McGee	Powder River Basin, WY	AR P & L	8525	5x10 ⁶ ton/yr (by '78)	20+10 yr	\$300x10 ⁶	8/73
Carter Oil	Powder River Basin, WY	IN & MI Electric		5x10 ⁶ ton/yr (by 7/76) (Western low sulfur)	30 yr	—	2/74
U.S. Pipe and Foundry Co.	AL	AL Power Co.		2x10 ⁶ ton/yr (by '76) (Low sulfur)	21 yr	\$1 Billion	2/74
U.S. Pipe and Foundry Co.	Adeger, AL	AL Power Co.		1.25x10 ⁶ ton/yr (by '74) (Low sulfur)	14 yr	—	2/74

TABLE 1. (Contd.)

Supplier	Source of Coal	Customer	Btu/lb	Amount	Duration	Price	Month Reported
Belco	W. VA	Duke Power Co.		10 ⁶ ton/yr (by '75) (Low sulfur)	10+10 yr	\$1.25x10 ⁶ (total)	3/74
U.S. Steel	W. PA	Ontario Hydro.		3x10 ⁶ ton/yr (by '76)	30 yr	—	4/74
U.S. Pipe and Foundry Co.	AL	AL Power Co.		2x10 ⁶ ton/yr (by '77) (Low sulfur)	21 yr	—	4/74
MAPCO	KY	2 utilities		2x10 ⁶ ton/yr (by '74) 3x10 ⁶ ton/yr (by '76)	20 yr	\$6x10 ⁶ (total, incl. escal.)	5/74
McCulloch Oil	UT	American Elec. Power	~12,200	14x10 ⁷ ton (min.) (total) (Low sulfur)	Long Term	> \$1 B (Special cost + Var. Profit Contract - profits ~Δ inflation as measured by WPI)	7/74
12 Cos.	E. TN	TVA		5.4x10 ⁶ (by '75) (total)	—	\$72 M	7/74

Source: Coal Age issues from 8/73 through 7/74.

Fig. 2. Expected Annual Tonnages of
Wyoming Coal Deliveries by 1980
(Millions of tons per year)

Source: Coal Age, May 1974.

Although most of the expected increase in Powder River Basin output will occur in Wyoming, Montana mines currently account for most of the Basin coal shipped to Midwestern markets. The major Montana coal operators include: Decker Coal Company (4 million tpy -- tons per year), shipping to Commonwealth Edison's Powerton, Joliet, Fisk, and Crawford plants; Peabody Coal (2.0 million tpy), shipping to Minnesota Power and Light; and Western Energy Company (4.3 million tpy) supplying Commonwealth Edison and United Power Association. Westmorland Resources will open a 1.5-million-tpy mine in late 1974.

Rocky Mountain Province

The largest commercial deposits of coal in the Rocky Mountain Province are the bituminous and subbituminous fields in western and southern Wyoming, the bituminous coals of the Uinta Region of western Colorado and eastern Utah, and the subbituminous coals in northwestern New Mexico. (See Fig. 1).

Although output from each of these regions will increase substantially over the next several decades, the Rocky Mountain Province coals that will be most competitive with Powder River Basin coals in the Midwestern markets are those located in Wyoming and in the Uinta Region. The unit costs of production are higher in the New Mexico fields than in the Powder Basin* and transportation distances to the Midwest are greater. Moreover, growing demand by the Southwest electric utility and coal-gasification industries is likely to exert substantial upward pressure on New Mexico coal prices.

Of the coal regions in the Rocky Mountain Province, the Hanna Region in south-central Wyoming is currently the most important supplier to the Midwestern markets. Although it is not expected to maintain its relative market share, the Hanna Region now exports approximately as much coal to the Midwest as the Powder River Basin. Despite the Hanna Region's smaller reserves and higher mining costs, the Hanna coals have been commercially attractive: (1) because of their relatively high Btu content, 9700-11,300 Btu/lb versus 7800-9800 Btu/lb for the Powder River Basin, and (2) because of their proximity to a major east-west rail line (Union Pacific). The major coal companies now operating in the Hanna Region are: Arch Mineral Corporation

*See: "Cost Analysis of Model Mines for Strip Mining of Coal in the United States," *Bumines IC 8535* (1972).

(~ 4.5 million tpy), currently supplying coal to Commonwealth Edison, Wisconsin Electric Power, Kansas City Power and Light, and utilities in Iowa and Missouri; Medicine Bow Coal Company (~ 3 million tpy by late 1974) under contract to ship coal to Northern Indiana Public Service Co.; Energy Development Company (~ 0.5 million tpy), a subsidiary of Iowa Public Service Company, currently shipping coal to Sioux City, Iowa; and Rosebud Coal Sales Co. (~ 2.0 million tpy), shipping coal to Nebraska Public Power and Iowa Power and Light.

Another source of low-sulfur Western coal for the Midwestern market are the high-rank bituminous coal in the Uinta Region of Colorado and Utah. Although production costs are higher -- underground mining is required, transportation costs (on a Btu-mile basis) are from 20% to 35% lower because of the coal's higher heating value. The attractiveness of the Uinta Region's coal is indicated by the recent contract between American Electric Power and McCulloch Oil. Terms of this contract provide for delivery of 1.25 million tons annually beginning in 1974 and for peak delivery of 6.5 million tons annually by 1978.

The Rocky Mountain and the Northern Great Plains Provinces contain many commercially attractive coal regions other than those cited above. However, because the Powder River Basin, the Hanna Basin, and the Uinta Region are especially attractive and because they capture many of the salient features of Western coal supply, we shall focus on these regions in the remainder of this report.

2.2 TRANSPORTATION MODES

As discussed above, the coal fields currently supplying the largest quantities of Western coal to the Midwestern markets are located in south-central Wyoming (Hanna Region) and southeastern Montana (Powder River Basin). Future sources of Western coal will include northeastern Wyoming (Powder River Basin) and the Uinta Region of Colorado and Utah. For each of these regions, shipment by rail currently represents the only local large-scale transportation mode. Moreover, in most of the Western coal regions a single railroad company monopolizes coal shipments. The Union Pacific Railroad is the only railroad company serving the Hanna Region, and the Burlington Northern is the only railroad shipping from the Powder River Basin.

Shipment by slurry pipeline represents the only feasible alternative to rail shipment from Western coal fields. Energy Transportation Systems, Inc., (ETS) plans to build a 25-million-tpy, coal-slurry line from the Powder River Basin to Arkansas. Although the Wyoming legislature has granted ETS rights to export 20,000 acre-feet of water per year, the legislature has imposed a moratorium on further water allocations, pending results of a study of the state's underground water supplies. Other than the ETS proposal, there have been no plans announced to move coal eastward by slurry pipeline.

Although all Western coal for export currently leaves the coal field by railroad, some of it is transferred at intermediate points for final shipment by barge or ship. Commonwealth Edison receives Hanna Basin coal directly via the Union Pacific Railroad at its Waukegan and State Line power plants. However, other Commonwealth Edison plants receive Montana coal by barge via the Havana Terminal on the Illinois River. Detroit Edison will receive Montana coal via the Great Lakes Waterway.* Coal shipped by Burlington Northern to a terminal near Superior, Wisconsin, will be transferred to ships for final movement over Lakes Superior and Huron to the Detroit area. Another rail-barge system is being developed by American Electric Power (AEP), who will build a coal transfer facility on the Ohio River near Metropolis, Illinois. This facility will transfer Western coal from railroad cars to barge for delivery to AEP plants on the Ohio River System.** Another transloading facility has been proposed by Burlington Northern, this one to be built on the Mississippi River near St. Louis. Like the AEP transloader, this facility will have the effect of making Western coal available at many new delivery points on the inland waterway system.

Although the rail-barge mode for shipping Western coal can offer direct transportation savings, its selection over direct rail shipment is often dictated by other considerations.*** For example, many existing plants

*Coal Age, June 1974. One-half million tons of coal will be shipped this year, 1 million in 1975, 5 million in 1976, and 10 million annually by 1978.

**Coal Age, June 1973.

***Commonwealth Edison pays a price premium, equal to about 15¢/MBtu, for Western rail-barge coal delivered to its plants on the Illinois Waterway System over the price paid for coal shipped directly by rail to other plants in its system.

are equipped exclusively to receive waterborne coal. Rather than abandon existing facilities and construct rail access lines and railroad-car unloading facilities, a utility forced to shift from high sulfur to low sulfur coal, is more likely to make arrangements to receive Western coal by water.

In addition to transportation mode, a number of other factors affect the cost of transporting Western coal. These include: transportation distance, Btu content of the coal, quantity of coal shipped per month, duration of contract, and ownership of hopper cars (utility vs railroad). These and other factors are discussed in greater detail below.

3.0 COST ANALYSIS

The cost of supplying Western coal to distant markets can be expressed by the following relation

$$c = \frac{1}{H} \left(c_t \cdot D + c_p \right)$$

Here, c equals the cost of the delivered coal ($\$/10^6$ Btu), c_t is the unit cost of transportation ($\$/\text{ton-mile}$), c_p is the mining (production cost ($\$/\text{ton}$), D is the distance to market (miles), and H is the heating value of the coal (10^6 Btu/ton).^{*} Once the unit cost of production and transportation c_p and c_t are known, the cost competitiveness of different Western coals selling in distant markets can be determined.

Table 3 compares cost tradeoffs involved in supplying coal from two hypothetical coal regions. Region A, producing coal with a heating value 6500 Btu/lb, is located D miles west of the market center, while Region B, coal heating value equal to 9000 Btu/lb, is 300 miles farther west. For the case illustrated in Table 3, it is assumed that production costs equal $\$3.00/\text{ton}$ in both regions and that transportation rates equal 7 mills/ton-mile for shipments from both regions. As shown in the table, the cost of coal from Region B is slightly higher than coal from Region A for distances less than 200 miles, but is lower for distances greater than 200 miles. Although the situation in Table 3 is hypothetical, it does illustrate the important relationship between heating value and transportation costs, and it explains the cost advantage of subbituminous coal over lignite in distant markets.

In the following, we examine empirical cost data for coal produced in Western coal fields and shipped to Midwestern markets. From these data and on the basis of simple cost relationships, we estimate delivered costs of Western coal for the period 1974 to 1982.

3.1 PRODUCTION COSTS

The largest future source of Western coal for the Midwestern electric utility market are likely to be the subbituminous deposits of the Powder River Basin. Mining costs in the Basin are the lowest in the country and the Basin contains the largest deposits of strippable reserves.

^{*}In this simple formulation, we ignore economies of haul.

TABLE 3. The Cost of Delivered Coal as a Function of Market Distance. Two Western Coal Regions.^a

Coal Region/ Market Distance	Coal Heat- ing Value (10 ⁶ Btu/ton)	Production Cost (\$/ton)	Transpor- tation Cost (\$/ton-mile)	Delivered Coal Cost (\$/10 ⁶ Btu)		
				D=50 mi	200	1000
Region A / Distance = D	13	3.00	0.007	.26	.34	.77
Region B / Distance = D + 300	19	3.00	0.007	.29	.34	.64

^aHypothetical example.

There are many other Western regions now producing low sulfur coal or lignite; however, the extent of their penetration of Midwestern markets will be limited either by high production or transportation costs or by availability of recoverable reserves. Table 4 compares four major coal and lignite regions in terms of current production and transportation costs and commercially recoverable reserves.

With the exception of those for the Uinta Region, the reserves figures listed in Table 4 are based on U.S. Bureau of Mines estimates. The Uinta deep reserve figure was developed from data presented in the Keystone Coal Industry Manual. The production cost ranges given in Table 4 are rough estimates that are based on recent Bureau of Mines price data published in the Minerals Yearbook and on cost data presented in recent Bureau of Mines Model Mines Studies.

Of the coal regions listed in Table 4, only the Hanna Region is fully cost competitive with the Powder River Basin in the Midwestern market. However, the relatively small quantity of reserves in the Hanna Basin suggests that "price leadership" will rest with the Powder River Basin for the foreseeable future.* This means that the price of Hanna Basin coal in Midwestern markets is likely to be determined by the price of delivered Powder River Basin coal. Because of its lower transportation cost, Hanna Basin coal should command a price premium at the mine from \$1.50 to \$3.00 per ton over Powder River Basin coal.

*See Section 4.1 below.

TABLE 4. Reserves Estimates and Price and Cost
Data for Four Western Coal Regions

Region	Reserves (10 ⁶ tons)	Production Costs (\$/10 ⁶ Btu)	Transportation Costs to Chicago (\$/10 ⁶ Btu)
Powder River Basin (Wy.)	18,000 ^{a,b}	9-18 ^{e,f}	46-49 ^h
Williston Basin (N.D.)	5,000 ^{a,c}	12-24 ^{e,f}	48-52 ^h
Hanna Basin	1,000 ^a	15-27 ^f	36-39 ^h
Uinta Region	15,000 ^d	28-36 ^{f,g}	42 ^h

^aBumines Information Circular 8531, "Strippable Reserves of Bituminous Coal and Lignite in the United States" (1971).

^bBumines IC 8538, "Strippable Coal Reserves of Wyoming" (1972).

^cBumines IC 8537, "Strippable Lignite Reserves of North Dakota" (1972).

^dKeystone Coal Industry Manual, 1973.

^eBumines IC 8535, "Cost Analyses of Model Mines for Strip Mining of Coal in the United States" (1972).

^fBumines, Minerals Yearbook.

^gBumines IC 8632, "Basic Estimated Capital Investment and Operating Costs for Underground Bituminous Coal Mines" (1974).

^hSee Table 7, below.

Uinta Region coal, although it does not appear to be cost competitive with strip mine coal, offers several compensating advantages. First, because it is of high-rank bituminous quality, Uinta Region coal possesses mechanical and chemical properties that make it less costly to handle and burn at electric generating facilities. Second, because it is produced by underground mining methods, it is not exposed to the environmental control regulations and equipment shortages that may constrain the development of large-scale surface mines.

The Forecast Problem

Except for the problem of constrained output, the problem of forecasting the cost of producing Western coal is essentially that of forecasting the costs of the equipment, labor, and materials inputs to mine development and operation. The technology of large-scale mining methods is well enough established, and the rate of change sufficiently slow, that the physical "mix" of factor inputs for particular mining methods can be assumed constant over the next decade or so.

The occurrence of constraints on the supply of surface mine coal could have a significant impact on the marginal cost and, therefore, on the price of Western coal. The effect is illustrated in Fig. 3. The figure shows hypothetical supply and demand curves for Western coal produced from mines coming onstream in 1982.* If 1982 demand for "new" subbituminous coal is given by Curve DD, then output Q_1 can be supplied at price P_1 by new large-scale surface mines. However, if demand reaches D'D' while large-scale surface mine output is constrained to lie below X, then the price will rise to P_2 , the cost of producing Western coal from smaller, less efficient mines. In this case, the mining companies producing the inframarginal output (0 to Q_2) will earn an economic rent equal to the difference between P_2 and the actual costs of production.** As should be clear from the figure, constraints on the output of Western coal can have a significant impact on the marginal cost and, therefore, on the price of the coal.

Specific types of constraints and their effect on the price of Western coal are discussed in greater detail in Sec. 4 below. Here we shall only develop price estimates corresponding to the cost of unconstrained output (P_1 in Fig. 3). These costs are estimated not only for surface mine subbituminous coal but also for deep mine bituminous coal.

*The breaks in the demand relations at P_3 are drawn only to illustrate the effects of substitute technologies on demand for Western coal. These substitute technologies could include systems either for the stack gas removal of SO_2 or for the desulfurization of Midwestern coal. For $P_3 < P_1$, there is little demand for Western coal.

**Under conditions of perfect competition, these rents would ultimately flow to the owners of the constraining factor input; for example, to the owners of the facilities needed to manufacture large surface mine equipment. Under less than perfect competition, others may try to capture part of these rents; for example, railroad companies by charging higher freight rates for coal produced from more efficient mines than for coal produced from less efficient mines.

Fig. 3. Price of Surface Mine Coal under Different Demand Conditions

Bureau of Mines Cost Studies

The cost estimates developed here are based upon analyses recently published by the U.S. Bureau of Mines.* Bumines analyzed production costs for both surface and deep mines. Surface mine costs were estimated for hypothetical "model" surface mines of different capacities located in different parts of the United States. These model mines included a 5-million-ton/yr surface mine located in the Wyoming Powder River Basin. The Bumines' deep mine cost study included analyses of four underground bituminous mines with annual capacities ranging from 1 to 5 million tons. Coal-seam thickness for each of the underground mines was assumed to be 6 feet. The underground mine design (continuous miner, production panels on the 8-entry system), upon which the cost analyses are based, is not region-specific; rather, the design is considered appropriate for several regions of the country, including parts of the Uinta Region in eastern Utah.

The Bureau of Mines analyses show that the largest cost components for both surface and underground mining are the initial capital outlay, the wage payments to operating labor, and the expenditures for material supplies. Other costs include operator payments to the union welfare fund, tax payments to state governments, and rent and royalty fees.

Production-Cost Forecasts

In forecasting Western coal mining costs, we first escalated the Bumines costs to April 1974 values and then extrapolated by cost trend to future dates.

In estimating 1974 surface mine labor costs, we multiplied the Bumines cost (1969 values) by the factor 1.46, the ratio of mine workers average hourly earnings in April 1974 to average hourly earnings in 1969.** Payroll overhead was adjusted by the same factor, while mining supplies (explosives, tires, electric power, etc.) were adjusted by the percentage changes in the wholesale price indexes of the individual commodities. In general, the Bumines underground mine costs (expressed in 1973 dollars) were adjusted in the same fashion as the surface mine costs.

*Bumines IC 8535 (1972), op. cit; Bumines IC 8632 (1974), op. cit.

**Employment and Earnings, Bureau of Labor Statistics, U.S. Dept. of Labor (Monthly Reports).

With few exceptions, we followed the Bumines accounting procedures for estimating annual capital charges. One exception concerns the discount rate used in estimating annual capital charges. We used a discount rate equal to 16% per year rather than the Bumines figure of 12%. Discussions with mining company personnel indicated that the 16% figure corresponds more closely with the industry cashflow expectations. Another departure from the Bumines accounting procedure concerns our handling of the depletion allowance for future years. Rather than retain the 1974 rate, we assumed a complete phase-out by 1982, with one-half of the cashflow benefits eliminated by 1978 and the remainder by 1982.

Several of the wage and price trends used to forecast factor-input costs are shown in Fig. 4.* The index values shown in the figure have been deflated by the wholesale price index. Expressed in real terms, the costs of explosives and the cost of construction machinery and equipment have been relatively constant over the past ten years. The behavior of these cost trends and that of other mining supplies (not shown in Fig. 4) indicate that these costs have generally tended to move in concert with the overall level of wholesale prices. Consequently, in making our cost forecasts, we assumed that the real costs of mining equipment and supplies will be constant over the next ten years.

Unlike the cost of mine equipment and supplies, the cost of labor inputs has been increasing in recent years. Except for the steep downturn in 1974 (caused by the abrupt increase in the wholesale level), miners' hourly earnings have been increasing relative to the wholesale price index at approximately 3% per year. In our forecast of wage costs, we have assumed that mine workers will recover their 1974 loss in the pending wage agreement and that wage costs will then resume their 3% rate of increase.

Another important labor cost, but one not included in miners' wages, are the mine operators' contribution to the United Mine Workers (UMW) of America Welfare and Retirement Fund.** This fund was established in 1946 when bituminous coal operators agreed to contribute a royalty of \$0.05 per ton of coal

*Monthly Labor Review, Bureau of Labor Statistics, U. S. Dept. of Labor.

**See: "Wage Chronology, Bituminous Coal Mine Operators and United Mine Workers of America, October 1933 - November 1974," Bulletin 1799, U.S. Dept. of Labor, Bureau of Labor Statistics (1973).

Fig. 4. Cost Indexes for Selected Coal-Mining Factor Inputs, Deflated Values.

produced. Contributions by the bituminous coal operators rose quickly to \$0.40 per ton by 1952, but then remained at this level until the 1971 Wage Agreement. Under terms of the 1971 agreement, the Bituminous Coal Operators Association agreed to an immediate increase in contributions to \$0.60 per ton and to subsequent programmed increases that will have brought payments to \$0.80 per ton by November 1974. Western producers of subbituminous coal and lignite have not been directly covered by the wage agreements between the UMW and the bituminous coal operators. However, separate royalty agreements that cover most Western production have been worked out between coal companies and mine workers. Under these agreements, royalties currently amount to \$0.20 per ton of coal produced. The smaller royalty for Western subbituminous coal is usually justified on the basis of the lower quality and lower labor requirements of subbituminous coal and lignite.

Most observers expect welfare fund contributions for both bituminous and lower rank coals to increase substantially under the pending wage settlement. Our "best guess" is that low-rank-coal welfare contributions will double over the next four years and that bituminous coal payments will increase by 60%. The impact of future increases that are programmed into the wage settlement could be ameliorated, in real terms, by persistent inflation; however, the new wage contract may "index" welfare payments, including increases, to changes in the Consumer Price Index.

Except for a final adjustment, the foregoing summarizes the methods used to project the important mining costs for the period 1974 to 1982. The final adjustment was to increase the estimated capital, labor-wage, and supply costs by 20%. This correction is justified by coal industry observations that the Bureau of Mines cost estimates correspond to "relatively ideal" mine development and operating conditions, conditions that are rarely encountered in practice. Discussions with mining company engineers indicate that a 20% increase in capital, labor-wage, and supply costs is a reasonable way to bring the Bureau of Mines estimates into line with real-world mining conditions.

Table 5 summarizes our projections of surface and deep mine coal production costs for the years 1974, 1978, and 1982. Incorporating the adjustments outlined above, the cost figures correspond with Bureau of Mines estimates for 5-million-tpy mining operations. Surface mine costs expressed in \$/MBtu correspond to a heating value range of 8300 to 9500 Btu/lb. The deep mine coal is assumed to have a heating value of 12,200 Btu/lb.

TABLE 5. Estimated Production Cost of Western Surface Mine and Deep Mine Coal
(April 1974 dollars)

	1974		1978		1982	
	Surface	Deep	Surface	Deep	Surface	Deep
Capital	\$.84	\$ 2.62	\$.97 ^a	\$ 3.08 ^a	\$1.10 ^a	\$ 3.55 ^a
Labor	.44	4.06	.59	5.30	.66	5.94
Union Welfare	.20	.80	.40	1.30	.60	1.50
Supplies	.71	2.50	.71	2.50	.71	2.50
Taxes	.35 ^b	.15	.40	.15	.45	.15
Rent and Royalty	.10	0	.12	0	.14	0
Total \$/ton	\$2.64	\$10.13	\$3.19	\$12.33	\$3.66	\$13.64
(¢/MBtu)	(13.9-15.9)	(41.5)	(16.8-19.2)	(50.5)	(19.3-22.0)	(55.9)

^aAssumes depletion allowance phaseout by 1982; otherwise surface mine capital costs in 1978 and 1982 equal \$.84/ton and deep mine capital costs equal \$2.62/ton.

^bEquals present state and local production and excise taxes in Wyoming. See Coal Age, May 1974, p. 98.

^cAssumes a heating value for surface mine coal from 8300 to 9500 Btu/lb and a heating value for deep mine coal equal to 12,200 Btu/lb.

An interesting feature of the production costs in Table 5 is that the capital costs and the total mining cost exhibit the same trends over the time period in question. Both increase at an annual rate of about 4% for the period 1974-1978 and at an annual rate of 3% for the period 1978-1982. This means that the cost estimates in Table 5 apply to output from both new mines and existing mines for each of the years indicated.

3.2 TRANSPORTATION COSTS

Transportation costs account for about two-thirds of the price of Western coal delivered to the Midwestern market. For unit train deliveries equal to an annual volume of one million tons, transportation rates currently average about 6.9 mills/ton-mile. As we show below, transportation rates expressed in constant dollars, have been increasing at an annual rate of about 3% per year.

Existing Tariffs

Two railroad companies account for the bulk of coal shipments to the Midwest: the Burlington Northern and the Union Pacific Railroad. Burlington Northern transportation rates for coal shipped from Montana and Wyoming to various Midwestern points are presented in Table 6. The Burlington Northern rates in effect after July 1, 1974 and several other rates obtained from Union Pacific Railroad are plotted in Fig. 5.* The Union Pacific rates correspond to shipments from the Hanna Region to Wisconsin Electric's Oak Creek power plant near Milwaukee, Wisconsin and to the Commonwealth Edison plant at Waukegan, Illinois. The Union Pacific rates provide significant discounts as the volume shipped increases, the rates for the Hanna-Oak Creek run breaking at an annual volume of 750,000 tons and the Hanna-Waukegan rate at 450,000 tons.

In order to establish a common basis for rates that apply when the coal hopper cars are under different ownership (railroad vs utility), we have adjusted the rates corresponding to utility ownership upward by 1.0 mills/ton-mile in Fig. 5. This adjustment is equal to the typical rebate offered

*The Union Pacific rates were obtained from Mr. Taylor, Rate Department Union Pacific Railroad, Omaha, Nebraska.

TABLE 6. Burlington Northern's Rates of Shipping Western Coal into the Midwest Region

	Origin	Destination	Miles	Cars	Minimum Annual Volume Tons (000)	Rates Effective July 1	Rates (mills/ton-mile)
Illinois	Belle Ayr, WY	E. St. Louis	1,154	Carrier	1,500	1973 - 697¢	6.0
						1974 - 766¢	6.6
	Decker, MT	Plains	1,281	Carrier	1,500	1974 - 1002¢	7.8
	Decker, MT	Waukegan	1,268	Carrier	250-500	1974 - 1030¢	8.1
Indiana	Decker, MT	Hammond	1,252	Carrier	250-500	1974 - 1057¢	8.4
There are no rates to Chicago itself, but the above moments to Plains, Waukegan and Hammond provide coal for power plants in the Chicago area. At present, there are also no rates in effect to Indianapolis.							
Iowa	Belle Ayr, WY	Des Moines	811	Carrier	5*	1974 - 815¢	10.0
Michigan	Decker, MT	Allouez	1,099	Shipper	1,300	1973 - 643¢	5.9
						1974 - 707¢	6.4
Coal is shipped to Allouez, Wisconsin then transloaded at BN docks for movement by lake vessels to Detroit.							
Minnesota	Colstrip, MT	Cohasset	773	Carrier	1,750	1970 - 274¢	3.5
						1971 - 291¢	3.8
						1972 - 302¢	3.9
						1973 - 323¢	4.2
						1974 - 363¢	4.7

TABLE 6 (contd.)

	Origin	Destination	Miles	Cars	Minimum Annual Volume Ton (000)	Rates Effective July 1	Rates (mills/ton-mile)
Minnesota (Contd.)	Colstrip, MT	Minneapolis	793	Carrier	700	1971 - 420¢	5.3
						1972 - 444¢	5.6
						1973 - 473¢	6.0
						1974 - 532¢	6.7
	Colstrip, MT	St. Paul	782	Carrier	400	1971 - 445¢	5.7
						1972 - 469¢	6.0
						1973 - 499¢	6.4
						1974 - 558¢	7.1
Wisconsin	Colstrip, MT	Columbia	1,037	Shipper	2000	1974 - 530¢	5.1

Presently there are no existing rates to Milwaukee.

*Trainload minimum only.

Source: Mr. Allan Boyce, Director of Cost Control, Burlington Northern Railroad

Fig. 5. Coal Transportation Rates

to utilities who purchase railroad cars and enter into leaseback agreements with the railroads.

As a means of parameterizing the dependence of freight rates on annual volume shipped, we fitted an average unit cost function of the form $r = a + b/x$ to the points in Fig. 5. The first and second terms on the right-hand side of this relation can be interpreted as the unit variable cost and the unit fixed cost associated with a minimum annual shipment equal to x .* An "eyeball" estimated relation is given by

$$r = 6.3 + 600/X \quad , \quad (2)$$

where r equals average unit cost (in mills per ton-mile) for a minimum shipment equal to x -thousand tons/yr.

As shown in the figure, the average transportation cost for an annual shipment of one million tons is approximately 6.9 mills/ton-mile. Variations about this rate are due to differences in such factors as terminal costs, duration of contract, and total rail traffic over a particular route.**

Heating Value of Coal

A factor that directly affects the cost of transporting coal energy from the Western states is the heating value of the coal. Although coal shipped to the Midwestern market from the Hanna Region and the Powder River Basin Region in Wyoming travel roughly equal distances, the higher heating value of the Hanna coal yields a 10-20% transportation saving. The much longer distance to the Midwestern market of Uinta Region coal is largely offset by the heating value of the Region's high-rank bituminous coal. Table 7 compares transportation costs to the Chicago area and lignite produced in four Western regions. The Btu values used in comparing transportation costs are merely representative and do not reflect the full range of heating values found within the producing regions.

*Fixed costs include all costs that would be incurred whether or not the shipment in question was made.

**Depending on the existing traffic of coal and other commodities over a particular route, the fixed-cost recovery rate may be higher or lower than the value given in Eq. 2 above.

TABLE 7. Transportation Costs to Chicago for an Annual Shipment of One Million Tons (6.9 mills/ton-mile)

Coal Region/ Point of Origin	Coal Heating Value (Btu/lb)	Distance (miles)	Transportation Cost (\$/10 ⁶ Btu)
Powder River Basin Gillette, Wy.	8300-8800	1172	46-49
Williston Basin Dickinson, N.D.	6300-6800	940	48-52
Hanna Basin Hanna, Wy.	10,000-10,800	1128	36-39
Uinta Region Helper, Utah	12,200	1477	42

Transportation Cost Forecast

Coal freight rates, like all railroad transportation rates, are subject to regulatory approval by the Interstate Commerce Commission. The problem of forecasting transportation rates, therefore, might be expected to include not only an estimation of future transportation costs, but also a prediction of future ICC regulatory policy. In practice, however, the role of the ICC is obviated by the economics of long-haul coal transportation. The efficiency of unit train operations has allowed railroads to hold transportation rates well below the levels formally allowed by the ICC. As a result, rates over a particular route are effectively determined through bilateral negotiations between the railroad company and the electric utility. The bilateral agreements establish rates for a specified schedule of transportation services and usually provide a mechanism whereby the rates are periodically adjusted to reflect changes in the cost of these services.

Burlington Northern adjusts its rates according to the BN Standard Coal Escalation Formula.* The BN Formula is based in turn on Indexes of Railroad Material Prices and Wage Rates of the Association of American Railroads (AAR). Under the BN Formula, year-to-year escalation of transportation rates has been roughly equal to 80% of the change in the AAR Index for Material

*The Union Pacific Railroad uses a similar formula.

Prices, Wage Rates and Supplements Combined.* The behavior of this latter index for the Western District over the period 1963-1973 is shown in Fig. 6. As shown in the figure, the index, after adjustment for movements in the general level of wholesale prices, has increased fairly constantly at the rate of 3.75% per year. When combined with the 0.80 factor, this corresponds to a transportation cost increase equal to 3.0% per year.

Given the absence of competing transportation modes and unit train costs that are well below ICC rate ceilings, the railroads have tended to set coal rates at levels sufficient to cover full costs of service. Unlike the situation for other commodities where ICC regulatory policies and competition from truckers have forced railroads to defer roadbed maintenance and capital replacement needs, the market for coal transportation services has allowed railroads to set rates adequate to recover the full cost of service. This relative pricing freedom is evidenced in Fig. 7 where changes in railroad revenue per ton-mile for all commodities are compared with changes in the AAR Combined Cost Index and with changes in actual coal freight rates as charged by Burlington Northern.**

Although there is no guarantee that recent trends of Western-coal freight rates will continue into the future, we believe that a simple extrapolation of this trend constitutes the best available estimate of future transportation costs. Although the projected increase in the real cost of transportation runs counter to the historic experience of the railroad industry,

*We were unable to obtain Burlington Northern's actual Escalation Formula. The 80% factor was quoted by several of the company's employees. This factor apparently reflects direct cost escalation of material and labor inputs as offset by improvements in productivity. If C equals the cost per ton-mile of transportation services, I equals the level of the AAR index, and P equals productivity, then the following relation holds among annual percentage changes in these variables:

$$\Delta C/C = \Delta I/I - \Delta P/P$$

Thus in recent years $\Delta P/P \approx 0.2 \Delta I/I$.

**The percent changes in Burlington Northern rates were developed from the data in Table 6. For a given year, the change plotted in Fig. 7 represents the average of the changes in the table.

Fig. 6. AAR Combined Cost Index --
Nominal, Deflated

Fig. 7. Annual Percent Changes in Nominal
Railroad Rates, Costs, and Revenues

it is consistent with the observation that most of the productivity gains in long-haul coal transportation by railroad have already been won and that future productivity gains by this segment of the industry are likely to be small.

Starting from a base rate of 6.9 mills/ton-mile for an annual shipment of one million tons (see Fig. 5) and using a constant escalation rate of 3% per year, we have estimated railroad transportation costs for the years 1974, 1978, and 1982. Table 8 shows transportation costs from three Western coal regions to several Midwestern markets for these years. The costs for rail-water routes shown in the table are based on a 1974 average barge rate of 3.7 mills/ton-mile and a rail-barge transloading cost of \$0.30 per ton. These costs, like the rail costs, were assumed to increase at 3% per year.

TABLE 8. Transportation Costs (April 1974 Dollars)

Midwestern Point (D = distance in miles) ^a	Source of Western Coal		
	1974	1978	1982
		<u>Powder River Basin</u>	
Chicago (D = 1172)	\$ 8.08 (\$9.20) ^b	\$ 9.10 (\$10.36)	\$10.24 (\$11.66)
Detroit (D = 1444)	9.96 (9.78)	11.21 (11.01)	12.63 (12.39)
Milwaukee (D = 1257)	8.66	9.77	11.00
Indianapolis (D = 1266)	8.74	9.84	11.07
Cincinnati (D = 1304)	9.14 (9.67)	10.14 (10.88)	11.37 (12.25)
Cleveland (D = 1512)	10.43	11.74	13.21
		<u>Hanna Basin</u>	
Chicago (D = 1128)	\$ 7.78	\$ 8.76	\$ 9.87
Detroit (D = 1400)	9.66	10.87	12.24
Milwaukee (D = 1213)	8.37	9.42	10.60
Indianapolis (D = 1273)	8.78	9.90	11.14
Cincinnati (D = 1361)	9.40 (10.24)	10.58 (11.54)	11.89 (12.99)
Cleveland (D = 1468)	10.13	10.92	12.84
		<u>Uinta Region</u>	
Chicago (D = 1477)	\$10.20	\$11.47	\$12.91
Detroit (D = 1749)	12.07	13.59	15.30
Milwaukee (D = 1562)	10.78	12.13	13.66
Indianapolis (D = 1585)	10.94	12.32	13.85
Cincinnati (D = 1612)	11.30 (11.53)	12.53 (13.03)	14.09 (14.67)
Cleveland (D = 1817)	12.54	14.11	15.89

^aRailroad distances measured from the Handy Railroad Atlas of the United States (Rand McNally).

^bNumbers in parenthesis correspond to rail-water routes.

4.0 PRICE OF WESTERN COAL IN THE MIDWESTERN ELECTRIC UTILITY MARKET

Physical reserves of Western coal are adequate to meet likely demand for many years to come. Rather than resource limitation, it is the price of Western coal relative to the cost of alternative fuels and technologies that will determine Western coal's market share. Over the long run, the price of Western coal can be expected to equal cost of supply; in the short run, price may be seriously affected by technical and institutional constraints on the rate of Western coal development.

4.1 UNCONSTRAINED SUPPLY OF WESTERN COAL

In the absence of constraints on the production and transport of Western coal, the supply price of delivered coal should equal the sum of production and transportation costs given in Tables 5 and 8. These prices are listed in Table 9 for subbituminous coal shipped from Gillette, Wyoming and bituminous coal from Helper, Utah.

The subbituminous-coal price range in Table 9 corresponds to heating values that range from 8300 to 9500 Btu/lb. Coal reserves having the lower heating values (corresponding to the higher end of the price range) are abundant through much of the Powder River Basin. Subbituminous reserves with the higher heating values (≥ 9500 Btu/lb) are relatively limited, although such coal is available in the Hanna Basin, in parts of Powder River Basin (especially in the Decker-Colstrip area in southeastern Montana), and in other Western coal regions. The price estimate for bituminous coal is based on an assumed heating value of 12,200 Btu/lb. Such coal can be produced by underground mining in the Uinta Region of Colorado and Utah.

The dependence of Western coal price on distance is illustrated in Fig. 8 for several types of coal. The "price frontiers" shown in the figure do not correspond exactly with the price estimates given in Table 9, rather Fig. 8 is intended as an approximate graphical method of showing the dependence of coal price on railroad transportation distance. The effects of differences in railroad routing and of alternative transportation modes are not shown in the figure. The constant-price frontiers represent points of equal straight-line distance from the Hanna Basin (assumed to be at the "center of mass" of the coal-producing regions). The delivered-coal price estimates

TABLE 9. Price of Delivered Coal, Unconstrained Supply
(\$/ton and ¢/MBtu)

Subbituminous (Powder River Basin)			
	1974	1978	1982
Chicago	\$10.72 (\$11.84) ^a 56.4-64.6¢ ^b (62.3-71.3¢)	\$12.29 (\$13.55) 64.7-74.0¢ (71.3-81.6¢)	\$13.90 (\$15.32) 73.2-83.7¢ (80.6-92.3¢)
Detroit	12.60 (12.42) 66.3-75.9 (65.4-74.8)	14.40 (14.20) 75.8-86.7 (74.7-85.5)	16.29 (16.05) 85.7-98.1 (84.5-96.7)
Milwaukee	11.30 59.5-68.1	12.96 68.2-78.1	14.66 77.2-88.3
Indianapolis	11.38 59.9-68.6	13.03 68.6-78.5	14.73 77.5-88.7
Cincinnati	11.78 (12.31) 62.0-71.0 (64.8-74.2)	13.33 (14.07) 70.2-80.3 (74.1-84.8)	15.03 (15.91) 79.1-90.5 (83.7-95.8)
Cleveland	13.07 68.8-78.7	14.93 78.6-89.9	16.87 88.8-101.6
Bituminous (Uinta Region)			
Chicago	\$20.33 83.3¢	\$23.80 97.5¢	\$26.55 108.8¢
Detroit	22.20 91.0	25.92 106.2	28.94 118.6
Milwaukee	20.91 85.7	24.46 100.2	27.30 111.9
Indianapolis	21.07 86.4	24.65 101.0	27.49 112.3
Cincinnati	21.43 (21.71) 87.8 (89.0)	24.86 (25.36) 101.9 (103.9)	27.73 (28.31) 113.6 (116.0)
Cleveland	22.67 92.9	26.44 108.4	29.53 121.0

^aNumbers in parentheses correspond to rail-water routes.

^bPrice range corresponds to heat-value range for subbituminous coal of 8300 and 9500 BTU/lb.
Heat value for bituminous coal assumed to equal 12,200 Btu/lb.

Fig. 8. 1974 Delivered-Coal Price by Coal Type, Unconstrained Supply

correspond to an effective railroad distance equal to 1.28 times the straight-line distance. A transportation distance of 300 miles was added for bituminous coal, corresponding to the additional mileage to the Colorado-Utah border.

Figure 8 illustrates several important characteristics of Western coal supply. First, the figure shows that in the absence of supply constraints, the least expensive Western coal throughout the Midwest region is high-rank (9500 + Btu) subbituminous coal. Because of transportation economics, the cost difference between the high-rank and the low-rank subbituminous coals increases with market distance, rising from about \$0.07/MBtu in Iowa to about \$0.10/MBtu in eastern Ohio. Although the cost advantage of subbituminous coal relative to bituminous coal decreases with distance, it amounts to over \$0.14/MBtu as far east as central Ohio.

The conclusion that high-rank subbituminous is the lowest cost Western coal is consistent with the observation that until recently this was the only Western coal shipped to distant markets. As discussed below, the recent contracts for low-rank subbituminous are indicative of constraints on the supply of high-rank subbituminous coal. (See Table 1, Sec. 2.1.)

4.2 CONSTRAINTS ON WESTERN COAL SUPPLY

Recent purchases by electric utilities of relatively low rank subbituminous coal indicate that constraints are already limiting production of higher-rank subbituminous coal. Whereas previously, production from high-rank subbituminous deposits in the Hanna Basin and in southeastern Montana were adequate to meet demand; recent contracts call for delivery of low-rank coal (see Table 1, Sec. 2.1). Even without an exact specification of the factors that have brought about this shift in supply, it is possible to conclude that "price leadership" has, in effect, shifted to the producers of the low-rank subbituminous coal. The relative abundance of the low-rank coal insures that for the foreseeable future, price will be determined by the costs and constraints affecting the production and transport of this coal. Although production of higher rank (lower cost) coal will continue, the owners and producers of this coal can be expected to maximize their "economic rents" by raising their mine prices to levels that bring the prices of their delivered coal into line with the price of delivered low-rank coal.

Production Constraints

Of the many constraints that may affect the price and availability of low-rank subbituminous coal, the most serious are potential shortages of capital inputs in large-scale surface mine operations. Other constraints, such as those resulting from federal and state legislation to protect the environment, are likely to have a small impact on the production of low-rank coal for export to distant markets.* Environmental legislation may remove certain lands (those lying near rivers and streams and near scenic and recreational sites) from commercial use and may add to reclamation costs; however, the impact on reserves availability and unit cost should not be large. Even were the cost of land reclamation to rise to \$5,000 per acre (the highest estimate so far advanced and far in excess of intrinsic land value), the increase in production costs for mines producing from 20-foot seams would be less than \$0.15 per ton. Another constraint, sometimes mentioned, that could affect price would result from collusive behavior by mining companies to set prices or to limit output. However, the large number of companies with holdings in the Powder River Basin (over forty) suggests that such action is unlikely.

The capital constraints that are most likely to affect output are shortages of large-scale mining equipment, particularly of draglines with bucket capacities greater than 50 cubic yards. The most efficient machine for overburden removal, a large dragline, is usually included in every large-scale surface mine design. Each of the three domestic manufacturers of these machines (Bucyrus-Erie, Marion Power Shovel, and Page Engineering) currently enjoys an order backlog ranging from four to five years. Orders from Western coal mining companies account for about 30% of the manufacturers' backlog. The manufacturers' total delivery rate, which now equals about 20 machines per year, has been expanding at about 25% per year and, according to industry officials, should continue expanding at this rate over the remainder of this decade.

The current four-to-five year backlog of large capacity draglines effectively prevents the development of new maximum-efficiency mines (beyond those already announced) before 1979. The only way to circumvent the long

*Such legislation will have a greater impact on coal-gasification and liquefaction industries. Because it is likely to restrict development of these industries, it may increase the availability of surface mine coal for export.

Development times is by scaling down equipment-size requirements. Lead times on draglines with capacities less than 50 cubic yards range from 1-1/2 to 3 years. Modifying mine-design to fit equipment availability entails a substantial cost penalty, however. According to Bureau of Mines cost analyses, unit production costs for a one-million-tpy strip mine incorporating a 21-cubic-yd dragline are about 50% higher than for a 5-million-tpy mine utilizing a 65-cubic-yd dragline. Nevertheless, in the case of greatly expanded short-run demand, the Western coal industry, by sacrificing scale economies, can reduce the supply lag by about two years. Moreover, because there are many equipment substitutes for small draglines -- power shovels, scrappers, etc. -- and because construction industry demand for this equipment and the workers needed to operate it is slack, output from small-scale mines is virtually unconstrained.

Another means of avoiding constraints imposed by shortages of large-scale surface mine equipment is a shift to underground coal from other coal regions. As fig. 8 shows, such a shift also entails a substantial cost penalty to Midwest users. However, the added cost is partly offset by the superior combustion properties of bituminous coal, particularly the higher ash-fusion temperature, which permits more efficient boiler design and operation. This property is especially important if Western coal is to substitute for Eastern coal in power plants designed to operate at high boiler temperatures. Many such plants are located in the Upper Ohio Valley where the price difference between Western bituminous and subbituminous coal is smallest.

Transportation Constraints

Shortages of transportation equipment and materials represent another possible constraint on the supply of Western coal. Because railroad transportation over existing routes will account for the bulk of coal shipped to the Midwest, critical components include railroad replacement parts and maintenance supplies, railroad locomotives, and freight cars. Specific items currently in short supply are rail- and cross-ties and gondolas and open-hopper cars.

Fortunately, the financial condition of the major Western railroads has enabled them to maintain their roads to higher standards than most of the nation's other railroads. Should shortages of rail- and cross-ties persist, the physical condition of the Western roads will allow a relatively long deferral of track maintenance. Moreover, the Western roads are in a better condition to compete successfully for supplies that are available.

The supply of coal-freight cars is probably the most critical constraint on Western coal transportation. The national shortage of gondolas and open-hopper cars amounted to 5100 and 6100 cars, respectively, in June 1974.* Although these shortages represent only a small portion of the total U.S. fleet of these cars (gondolas: 187,000; open hoppers; 365,000,** new-car delivery times currently are from 1 to 1-1/2 years. The delivery times reflect the high level of demand for freight cars, generally, during the 1971-73 economic expansion. In recent months, while demand for coal-freight cars has remained high, demand for other types of cars (box cars, covered hoppers, flat cars, etc.) has decreased substantially. One of the effects of the decline in demand for other types of cars will be to enable the car-building industry to increase output of coal-freight cars and to work off their present order-backlogs.

Forecasting the future availability of coal cars is a different undertaking. However, the history of the carbuilding industry suggests that car shortages are unlikely to be a serious constraint on Western coal development. In the past, carbuilders have demonstrated an ability to respond quickly to surges in demand. For example, the industry managed to reduce a total car backlog of 60,000 in 1965 to less than 20,000 cars by mid-1967. The 1968 backlog of 51,000 fell to 20,000 by 1970. Thus, if history repeats, the industry will work off the present backlog and have excess capacity within two years. Over the next decade, car availability should continue to depend mainly on the overall level of economic activity. However, it appears unlikely that coal-car delivery times will exceed the development times for coal mines.

4.3 ESTIMATED SUPPLY PRICE

Unconstrained Supply

Western coal price estimates for the case of unconstrained supply are shown in Figs. 9, 10, and 11 for the years 1974, 1978, and 1982. The price estimates in the figures correspond to the prices in Table 9 for bituminous coal and relatively low-rank (8300 Btu/lb) subbituminous coal.

*Railway Age, July 8, 1974.

**Railway Age, April 29, 1974.

Fig. 9. 1974 Prices of Western Coal in the Midwest Market, Demand Growth < 25%/Year

Fig. 10. 1978 Prices of Western Coal in the Midwest Market, Demand Growth < 25%/Year

Fig. 11. 1982 Prices of Western Coal in the Midwest Market, Demand Growth < 25%/Year

The prices of all subbituminous coals have been set equal under the assumption that higher rank subbituminous coals will remain scarce even under conditions of relatively low demand growth. This means that producers of the higher rank coals will be able to raise their mine prices to levels that will equate the delivery prices of the high- and low-rank subbituminous coals.

Tables 10, 11 and 12 list mine prices as a function of transportation distance for subbituminous coals having different heating values. As the tables show, it is advantageous for the producers of the higher rank coals to sell in the more distant markets.

Constrained Supply

As discussed in Sec. 4.2, the most critical constraint on the supply of Western coal is the availability of large-scale surface mine equipment. Production of large draglines is currently expanding at about 25% per year and is expected to continue at this rate over the next decade. This rate of expansion coincides with the projected rate of expansion of surface mine output in Wyoming and Montana. Output in these states was approximately 25 million tons in 1973,* while expected output from newly announced mines should bring total production to 120 million tons by 1980 ($24(1.25)^7 \approx 120$). Because of the four-to-five-year delivery time for large draglines, already announced mines may have virtually exhausted the available supply of draglines to 1980. This suggests that a 25% per year growth rate may constitute a reasonable upper limit on efficient surface mine development.

As discussed in Sec. 4.2, the Bureau of Mines has estimated that unit production costs for a one-million-tpy surface mine are approximately 50% greater than for a five-million-tpy mine. Using this as a measure of added production costs for the case of constrained supply, we arrive at the delivered-coal price estimates given in Figs. 12, 13, and 14. Tables 13, 14, and 15 list mine prices for several ranks of subbituminous coal for different shipping distances.

*Montana surface mine production in 1973 was approximately 10.5 million tons while Wyoming's was ≈ 13.5 million tons (see Keystone Coal Industry Manual, pp 683, 809-810). Wyoming's output should increase to 85 million tons by 1980 (see Table 2 above), while Montana's output should rise to 35 million tons.

Fig. 12. 1974 Prices of Western Coal in the Midwest Market, Demand Growth > 25%/Year

Fig. 13. 1978 Prices of Western Coal in the Midwest Market, Demand Growth > 25%/Year

Fig. 14. 1982 Prices of Western Coal in the Midwest Market, Demand Growth > 25%/Year

TABLE 10. 1974 Mine Prices of Subbituminous Coals for Different Shipping Distances, Demand Growth < 25%/Year.

Coal Heating Value (Btu/lb)	Shipping Distance (miles)					
	800		1200		1600	
	\$/ton	(¢/MBtu)	\$/ton	(¢/MBtu)	\$/ton	(¢/MBtu)
8300	2.64	(15.9)	2.64	(15.9)	2.64	(15.9)
9000	3.33	(18.5)	3.56	(19.8)	3.80	(21.1)
9500	3.82	(20.1)	4.22	(22.2)	4.62	(24.3)
10500	4.81	(22.9)	5.54	(26.4)	6.26	(29.8)

TABLE 11. 1978 Mine Prices of Subbituminous Coals for Different Shipping Distances, Demand Growth < 25%/Year.

Coal Heating Value (Btu/lb)	Shipping Distance (miles)					
	800		1200		1600	
	\$/ton	(¢/MBtu)	\$/ton	(¢/MBtu)	\$/ton	(¢/MBtu)
8300	3.19	(19.2)	3.19	(19.2)	3.19	(19.2)
9000	3.98	(22.1)	4.23	(23.5)	4.52	(25.1)
9500	4.56	(24.0)	4.98	(26.2)	5.45	(28.7)
10500	5.69	(27.1)	6.49	(30.9)	7.35	(35.0)

TABLE 12. 1982 Mine Prices of Subbituminous Coals for Different Shipping Distances, Demand Growth < 25%/Year.

Coal Heating Value (Btu/lb)	Shipping Distance (miles)					
	800		1200		1600	
	\$/ton	(¢/MBtu)	\$/ton	(¢/MBtu)	\$/ton	(¢/MBtu)
8300	3.66	(22.0)	3.66	(22.0)	3.66	(22.0)
9000	4.54	(25.2)	4.84	(26.9)	5.15	(28.6)
9500	5.19	(27.3)	5.70	(30.0)	6.19	(32.6)
10500	6.47	(30.8)	7.39	(35.2)	8.32	(39.6)

TABLE 13. 1974 Mine Prices of Subbituminous Coals for Different Shipping Distances, Demand Growth > 25%/Year.

Coal Heating Value (Btu/lb)	Shipping Distance (miles)					
	800		1200		1600	
	\$/ton	(¢/MBtu)	\$/ton	(¢/MBtu)	\$/ton	(¢/MBtu)
8300	3.96	(24.8)	3.96	(24.8)	3.96	(24.8)
9000	4.93	(27.4)	5.17	(28.7)	5.40	(30.0)
9500	5.51	(29.0)	5.91	(31.1)	6.31	(33.2)
10500	6.73	(31.8)	7.41	(35.3)	8.13	(38.7)

TABLE 14. 1978 Mine Prices of Subbituminous Coals for Different Shipping Distances, Demand Growth > 25%/Year.

Coal Heating Value (Btu/lb)	Shipping Distance (miles)					
	800		1200		1600	
	\$/ton	(¢/MBtu)	\$/ton	(¢/MBtu)	\$/ton	(¢/MBtu)
8300	4.79	(29.9)	4.79	(29.9)	4.79	(29.9)
9000	5.90	(32.8)	6.16	(34.2)	6.44	(35.8)
9500	6.59	(34.7)	7.01	(36.9)	7.49	(39.4)
10500	7.94	(37.8)	8.74	(41.6)	9.60	(45.7)

TABLE 15. 1982 Mine Prices of Subbituminous Coals for Different Shipping Distances, Demand Growth > 25%/Year.

Coal Heating Value (Btu/lb)	Shipping Distance (miles)					
	800		1200		1600	
	\$/ton	(¢/MBtu)	\$/ton	(¢/MBtu)	\$/ton	(¢/MBtu)
8300	5.49	(33.1)	5.49	(33.1)	5.49	(33.1)
9000	6.53	(36.3)	6.84	(38.0)	7.14	(39.7)
9500	7.30	(38.4)	7.81	(41.1)	8.30	(43.7)
10500	8.80	(41.9)	9.72	(46.3)	10.65	(50.7)

ACKNOWLEDGMENTS

We should like to thank L.J. Hoover, R.N. Bright, R.P. Carter, N.F. Sather, and M.L. Wilkey of the Argonne National Laboratory Energy and Environmental Systems Division, and G.W. Bassett, of the University of Illinois at Chicago, for useful comments and suggestions.

Among the many industry, government, and union people who generously assisted us were:

- R. Todd, Commonwealth Edison Co.,
- R. Fine, Wisconsin Electric Power Co.,
- C. Bcmis, Detroit Edison Co.,
- E. Wesp, American Electric Power,
- A. Boyce, Burlington Northern, Inc.,
- W. J. Sullivan, Union Pacific Railroad Co.,
- E. Hamilton, Interstate Commerce Commission, and
- T. Bethell, United Mine Workers of America.

Finally, we are especially indebted to Professor A.P. Hurter, Director of the Department of Management Science and Industrial Engineering of Northwestern University, and K. Packravan, a student working with the Department of Economics of The University of Chicago, for making available to us their previous work on this problem.