Coal recoverability in the Hilight quadrangle, Powder River Basin, Wyoming: a prototype study in a western coal field

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Abbreviations and Conversions

To convert from	To	Multiply by
Inches (in)	Centimeters	2.54
Feet (ft)	Meters	0.3048
Miles (mi)	Kilometers	1.609344
Pounds (lbs)	Kilograms	0.4536
Short Tons (2,000 lbs)	Metric tons (2,204.6 lbs)	0.90718474

All tonnage values in this report are in short tons.

ABSTRACT

Accurate data regarding the amount of coal within the United States is essential for making informed decisions concerning national, regional, and local energy policies. As a prototype study by the U.S. Geological Survey (USGS), our investigation of coal resources within the Hilight 7½-minute quadrangle, an area in the southern Powder River Basin, Wyoming, has resulted in estimates of the amount of ***available*** coal, ***recoverable*** coal, and ***economically recoverable*** coal. We calculated the original coal resources of the area to be 3.6 billion short tons. Our estimates show that (1) available coal, which is that part of the original coal resource that is accessible for mine development under current regulatory and land-use constraints, represents about 95 percent of the original resource; (2) recoverable coal, which is the amount of coal that remains after mining losses and cleaning losses are subtracted from the available coal, represents about 89 percent of the original resource; and (3) economically recoverable coal, which is that part of the recoverable coal that can be mined, cleaned, and marketed at a profit, represents only 10.7 percent of the original resource, at a coal sales price of as much as $3.00 per ton. At a coal sales price of as much as $4.00 per ton, 20.3 percent of the original resource is economically recoverable. The average sales price for coal in the southern Powder River Basin was $3.22 per ton (as of January 1998).

ACKNOWLEDGMENTS

This report is the culmination of efforts of several people. Charlie Gaskill of the U.S. Bureau of Land Management supplied land-use information. Within the USGS, Vickie L. Clark provided valuable computer assistance and M. Devereux Carter furnished resource data from the National Coal Resources Data System (NCRDS). Laura R. H. Biewick provided the data files from which recoverable resources were calculated. Laura N. R. Roberts, Edwin R. Landis, and W.R. Keefer provided thoughtful reviews of the manuscript.

INTRODUCTION

Procedures and methodologies used to estimate the Nation's reserves of coal have traditionally used historical mining recovery factors and applied them throughout coal regions to obtain the estimated recoverable coal tonnage. These traditional estimates did not consider restrictions related to the environment and societal concerns, site-specific geology, mining and preparation technology, and economics. However, as this study shows, these restrictions significantly impact the amount of coal that is ultimately economically recoverable.

Our study includes resource analysis (table 1) and economic evaluation (table 2) of

Table 1. Original coal resources, unavailable resources, available resources, mining losses, and recoverable resources in the Hilight quadrangle by coal ownership. (All tonnage values are in short tons; not rounded to significant figures)

Wyodak Coal Unit	*Coal Ownership*	***Original Resources***	*Previously Mined Resources*	***Unavailable Resources[2]*** *(fig. 4)*	*Percent of Original Resource*	***Available Resources***	*Percent of Original Resource*	***Mining Losses on Available Coal***	*Percent of Original Resource*	***Recoverable Resources***	*Percent of Original Resource*
Main	Federal	2,733,082,513	0	127,589,484	4.7	2,605,493,029	95.3	182,384,512	6.7	2,423,108,517	88.7
	State	111,366,604	0	1,011,607	0.9	110,354,997	99.1	7,724,850	6.9	102,630,147	92.2
	Private	1,090,774	0	0	0.0	1,090,774	100.0	76,354	7.0	1,014,420	93.0
	TOTAL	**2,845,539,891**	**0**	**128,601,091**	**4.5**	**2,716,938,800**	**95.5**	**190,185,716**	**6.7**	**2,526,753,084**	**88.8**
Lower	Federal	758,941,142	0	37,618,615	5.0	721,322,527	95.0	50,492,577	6.7	670,829,950	88.4
	State	31,578,843	0	385,941	1.2	31,192,902	98.8	2,183,503	6.9	29,009,399	91.9
	Private	211,031	0	0	0.0	211,031	100.0	14,772	7.0	196,259	93.0
	TOTAL	**790,731,016**	**0**	**38,004,556**	**4.8**	**752,726,460**	**95.2**	**52,690,852**	**6.7**	**700,035,608**	**88.5**
TOTAL	Federal	3,492,023,655	0	165,208,099	4.7	3,326,815,556	95.3	232,877,089	6.7	3,093,938,467	88.6
	State	142,945,447	0	1,397,548	1.0	141,547,899	99.0	9,908,353	6.9	131,639,546	92.1
	Private	1,301,805	0	0	0.0	1,301,805	100.0	91,126	7.0	1,210,679	93.0
	GRAND TOTAL	**3,636,270,907**	**0**	**166,605,647**	**4.6**	**3,469,665,260**	**95.4**	**242,876,568**	**6.7**	**3,226,788,692**	**88.7**

[2] Mining restricted by the Hilight gas plant, a railroad corridor, producing oil and gas wells, and an alluvial valley floor.

Table 2. Economically recoverable coal resources by sales-price level in the Hilight quadrangle. (All tonnage values are in short tons; not rounded to significant figures)

Coal Ownership	*Original Resources*	*Recoverable Resources*	*Economically Recoverable Resources:* ***As much as $3.00 Per Ton Sales Price***	*Percent of Original Resource*	*Economically Recoverable Resources:* ***As much as $4.00 Per Ton Sales Price***	*Percent of Original Resource*	*Economically Recoverable Resources:* ***As much as $5.00 Per Ton Sales Price***	*Percent of Original Resource*
Federal	3,492,023,655	3,093,938,467	371,887,218	10.6	692,589,682	19.8	1,347,968,414	38.6
State	142,945,447	131,639,546	16,637,301	11.6	43,574,200	30.5	67,055,981	46.9
Private	1,301,805	1,210,679	668,421	51.3	1,014,420	77.9	1,014,420	77.9
GRAND TOTAL	**3,636,270,907**	**3,226,788,692**	**389,192,940**	**10.7**	**737,178,302**	**20.3**	**1,416,038,815**	**38.9**

coal in the Hilight 7½-minute quadrangle, located about 35 miles south of Gillette, Wyoming, within the Powder River Basin of northeastern Wyoming (fig. 1). The Powder River Basin contains some of the most significant deposits of low-sulfur subbituminous coal in the world (Molnia and Pierce, 1992) including thick Wyodak coals studied in this report. These coals are in the Fort Union Formation (Paleocene).

The area contained within the Hilight quadrangle was studied previously by the U.S. Geological Survey (Molnia and others, 1997) to determine the amount of coal available for mining (available coal). Coal recoverability studies are a natural continuation of coal availability studies; this report describes the results of our coal recoverability calculations and compares them with the availability calculation previously completed by Molnia and others (1997). The results of similar coal recoverability evaluations of other quadrangles within the Appalachian and Illinois Basins are found in Rohrbacher and others (1993a, 1993b, 1994a, 1994b); Scott (1995, 1997); Teeters (1997); and U.S. Bureau of Mines (1995).

DEFINITIONS

This study includes determinations of available, recoverable, and economically recoverable resources. Figure 2 shows how estimates of available coal are derived (Carter and Gardner, 1989; Eggleston and others, 1990; Molnia and others, 1999). Figure 3 shows how estimates of recoverable coal resources and economically recoverable coal resources are derived.

The following definitions apply:

- *Available resource*—That part of the original coal resource that is accessible for mine development under current regulatory and land-use constraints. Alluvial valley floors and producing oil and gas wells are examples of constraints which may restrict coal mining in their immediate vicinities.

- *Recoverable resource*—That part of the available coal that is left after mining losses and cleaning losses are subtracted. Costs involved with the extraction and cleaning of the coal are not considered, nor is the potential selling price of the coal.

- *Economically recoverable resource*—That part of the recoverable coal that can be mined, cleaned, and marketed at a profit (depends on the mine location, the characteristics of the coal bed, the quality of the coal, and the mining methods used). Also known as a reserve.

Figure 1. Location of the Hilight quadrangle.

Figure 2. Coal availability calculation.

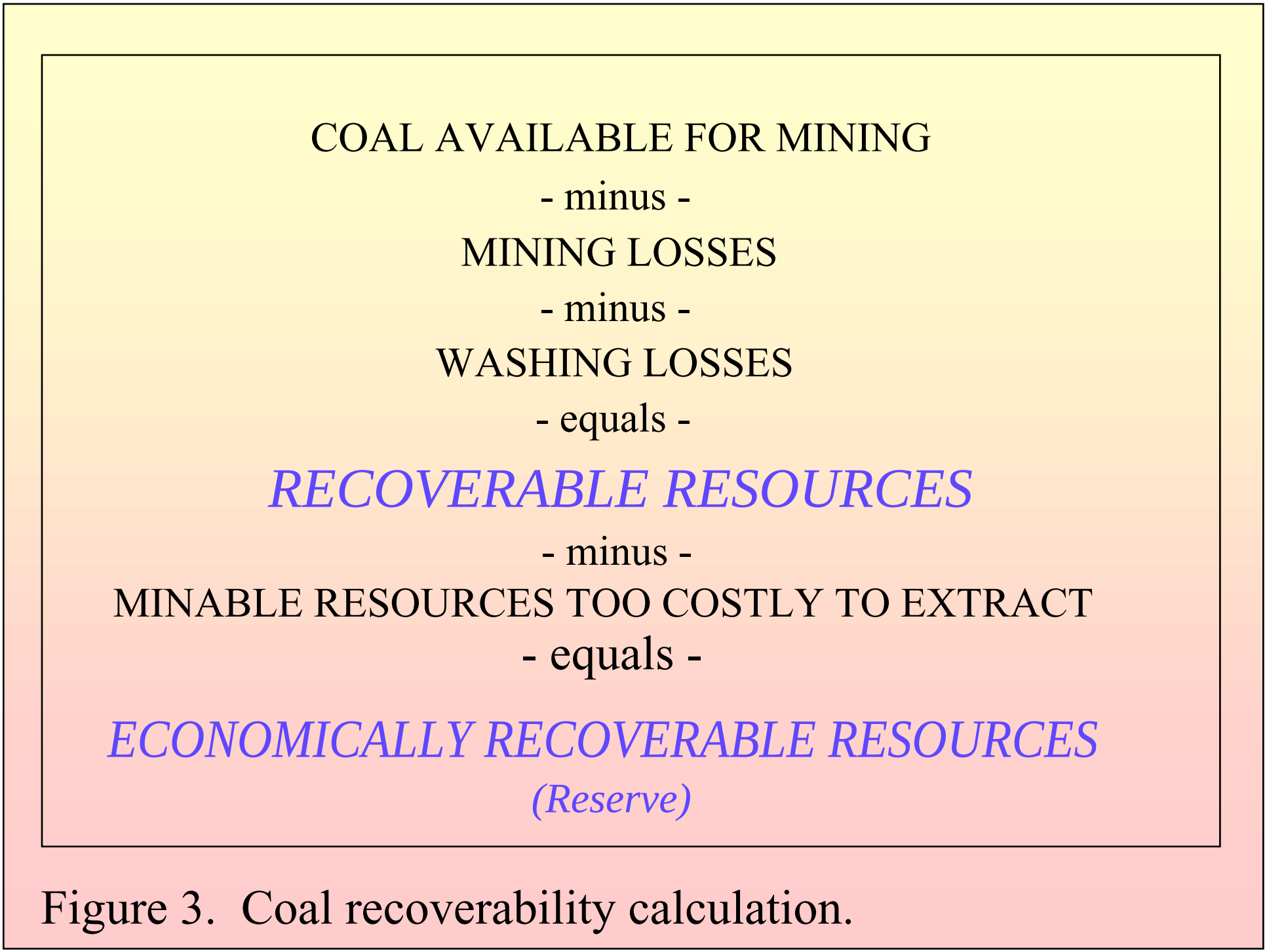


Figure 3. Coal recoverability calculation.

The recoverable resource is a subset of the available resource; the economically recoverable resource is a subset of the recoverable resource. For example, some available coal resources may not be extractable and thus would not be considered recoverable resources. Similarly, some recoverable coal resources may not be profitable to extract and thus would not be considered economically recoverable resources.

OBJECTIVES

In coal recoverability studies, the available coal resource estimates are analyzed to determine that part which is economically recoverable. Coal recoverability addresses the many technologic, economic, and environmental restrictions that affect the profitable extraction of coal. Mining production costs, current mining machinery and methods, present and near-future market conditions, and the impact of the Clean Air Act regulations all determine what coal resources can be profitably developed.

Coal recoverability estimates contribute to local, State, and Federal energy policy decisions and assist governments and planners in determining the socio-economic effects on their regions as the profitable coal resources become depleted.

Other objectives of the coal recoverability program include:

1. Improving methodologies for calculating recoverable coal resources and the associated mine operating costs.

2. Using those methodologies to refine estimates of the Nation's coal reserves.

3. Examining the probable effects that clean air legislation and other environmental restrictions would have on coal production.

4. Assisting Federal land-managing agencies in the evaluation of coal resources on Public Lands.

MINING RESTRICTIONS USED IN THIS STUDY

Restrictions to mining vary with location and local land-management regulations. Thus, different study areas can have different mining restrictions and availability considerations. This report reflects our assumptions concerning restrictions to mining, which are based on local practices in the Powder River Basin, Wyoming and Montana. In addition, the U.S. Bureau of Land Management in Casper, Wyoming, provided guidance concerning

restrictions to mining. A more detailed determination of restrictions and other availability considerations would be necessary as part of leasing and mine-planning phases of property development.

Features in this study that we considered to be restrictions to mining (fig. 4) are: a railroad corridor, an alluvial valley floor, a gas processing plant, and several actively producing oil and gas wells. (See Molnia and others, 1997, for a discussion of these restrictions.)

A proposed coalbed-methane recovery area, the Gillette South Coal Bed Methane Project (U.S. Bureau of Land Management, 1999), includes a large part of the Hilight quadrangle. The results presented in this report assume that the methane project is not a restriction to coal mining. However, as an alternative scenario, we did calculate how much coal might be restricted if mining were not allowed in the coalbed-methane area.

We did not consider coal quality to be a factor in determining the availability or recoverability of the coal resources. However, the quality of a coal is a factor in its marketability because government regulation of environmental pollutants can favor coals of certain qualities.

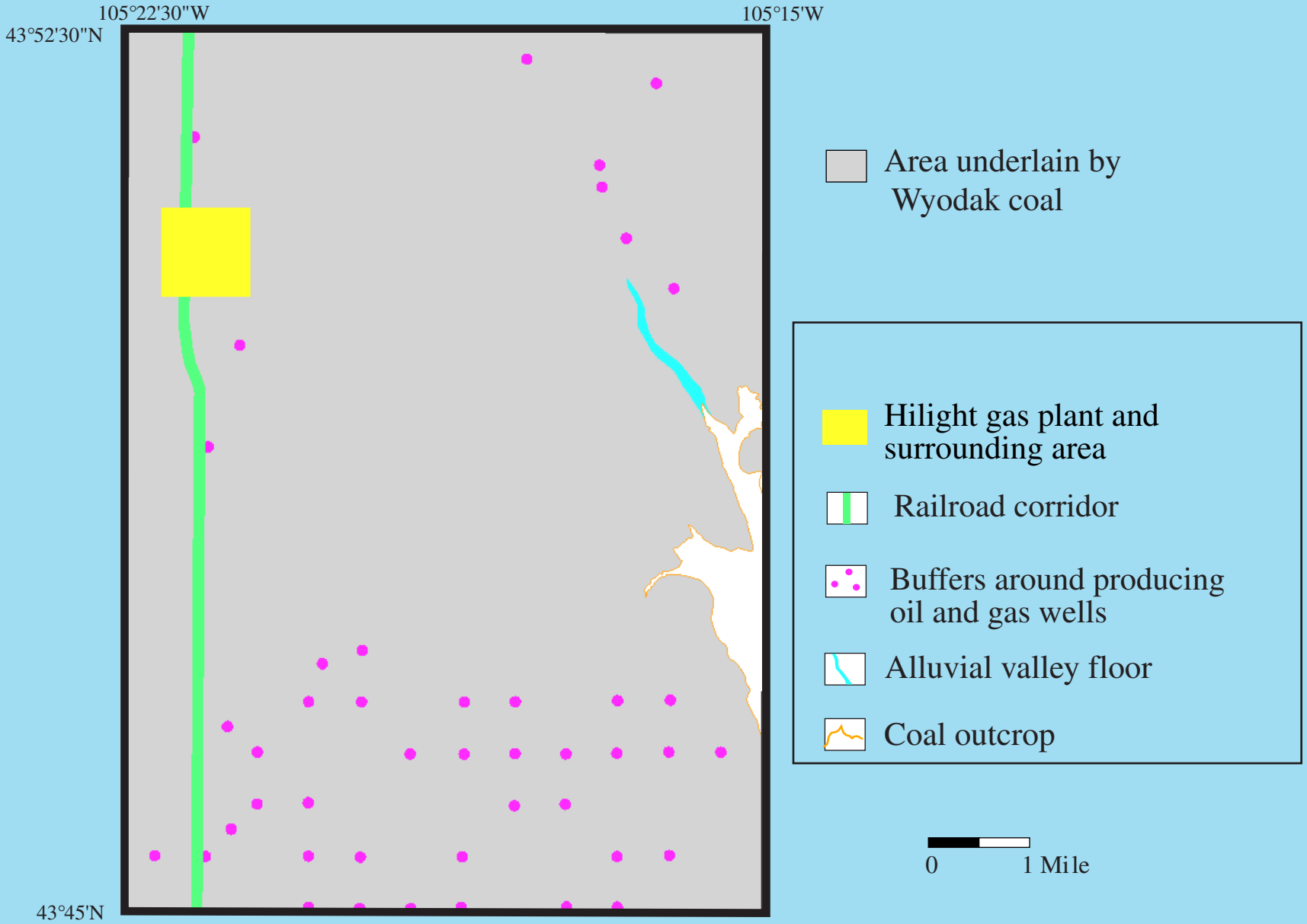
METHODOLOGY

The study began with the calculation of original resources using a geologic data set previously compiled by Molnia and others (1997). However, in our study, parting thicknesses of 2 ft or less are included as part of the coal resource because such partings would typically be mined as part of the coal. Next, using the restrictions to mining shown in figure 4 and the methodology explained in Rohrbacher and others (1993b), we calculated available resources for the Hilight quadrangle.

As the next step, we developed preliminary mining scenarios for each coal seam, to determine the recoverable resource. Mining cost models were also developed and the recoverable resource tonnage estimates were incorporated into the cost models to calculate the economically recoverable coal resources at different selling prices. The tonnage of economically recoverable coal will necessarily vary with changes in coal prices and production costs.

Cost factors for determining economically recoverable resources from recoverable resource estimates are described by Rohrbacher and others (1993b) and Suffredini and others (1994). In our study, we calculated economically recoverable resources for the following three sales-price levels:

Figure 4. Restrictions to mining in the Hilight quadrangle.



- As much as $3.00 per ton
- As much as $4.00 per ton
- As much as $5.00 per ton

The $3.00-per-ton price in the first sales-price level is slightly lower than the actual average sales price for southern Powder River Basin coal as of January 1998. At that time, the average sales price for coal at the mine load-out (the "free on board" or f.o.b. cost) was $3.22 per ton. We calculated economically recoverable resources for the other two sales-price levels to investigate the effect of coal sales-price increases.

We utilized a coal property-evaluation software package called COALVAL, developed by the U.S. Bureau of Mines (Plis and others, 1993; Suffredini and others, 1994), to efficiently handle the large quantity of cost data associated with our study. COALVAL has the capability to evaluate as many as 25 coal seams, each to be mined with as many as seven different mining methods. The software package produces summary spreadsheets that list the cost (per clean ton) to mine the resources (f.o.b. the load-out) for each property, seam, and mining method. COALVAL performs DCF-ROR[1] (discounted cash flow - rate of return) analyses, and was updated by using 1998 cost indices to calculate 1998 costs for coal production.

COALVAL uses specific mining scenarios to determine coal production costs. Specifically, the software calculates the operating costs associated with mining coal and determines the quantity of coal in each bed available in different production cost ranges (for example, number of tons recoverable at a coal sales price of as much as **X** dollars per ton; number of tons recoverable at **X** to **Y** dollars per ton, etc.).

For purposes of this report, coal is defined to be economically recoverable if the costs connected with its production are less than its sales price, on a per-ton basis, f.o.b. load-out. This approach results in general estimates of the economically recoverable reserves remaining in the quadrangle.

Although general procedures and assumptions developed for the Appalachian coal recoverability analyses are applicable to coal fields in other regions, some specific assumptions and different methods of analysis were used in our Hilight quadrangle study. In particular, we assumed that all mining, for the foreseeable future, would be limited to surface methods (truck and shovel mining) and that this mining would be necessarily restricted to the Wyodak coal beds as discussed in Molnia and others (1997).

In addition, we assumed that parting thicknesses of 2 ft or less would not be

[1] Defined as the rate of return that makes the present worth of future generated cash flow over the life of a project equal to the present worth of all after-tax investments (Barnes, 1980, p. 137).

removed from the coal beds, and coal beds greater than 4 ft would be mined in conjunction with the Main Wyodak coal bed if the "waste rock-to-coal ratio" (stripping ratio) was 4:1 or less. Finally, we decided to perform the coal recoverability analysis on the basis of this rock-to-coal ratio for each bed instead of on the basis of coal-bed thickness only (figs. 5, 6, and 7).

As a result of the above assumptions and procedural modification for the Hilight quadrangle, we determined that two minable coal-bed units were present—the Main Wyodak, which consists of the Main Wyodak coal bed plus the Rider Wyodak coal bed (Molnia and others, 1997), and the Lower Wyodak. We also divided each of the two minable units into separate sub-units for a more accurate analysis of mining costs. The sub-units are based on the rock-to-coal ratio within each coal-bed unit; as these ratios increase, so do the costs.

In an additional departure from previous coal recoverability studies, Hilight quadrangle coal resources were calculated for the three types of coal ownership that exist within the area—Federal, State, and private. Although the majority of the land surface is privately owned, the majority of the coal is Federally-owned. However, we believed it important to know what coal resources were owned by State and private interests, in addition to those owned by the Federal government.

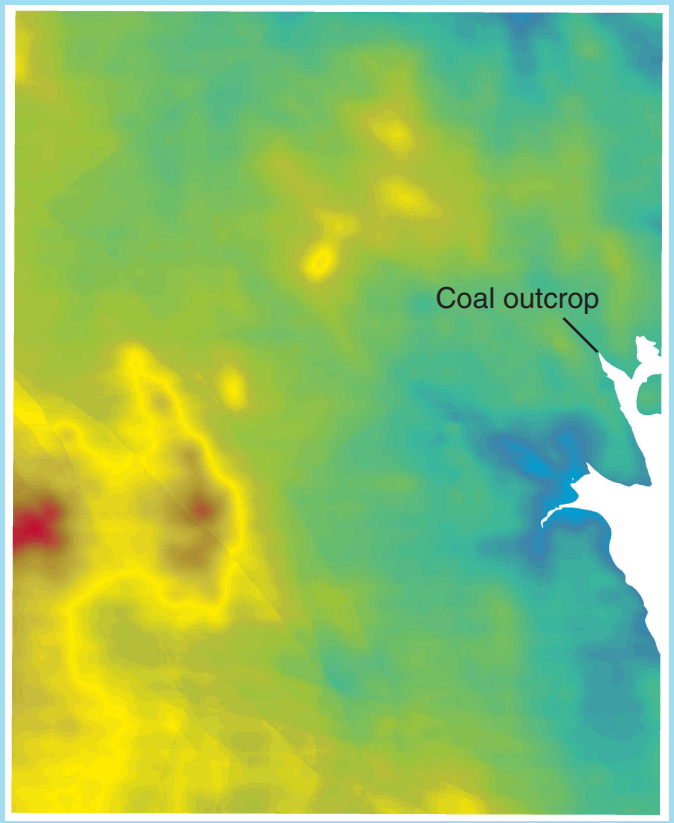
RESULTS

We calculated the original in-place resource of the Wyodak coal zone within the Hilight quadrangle to be 3,636 million tons. There are no previously mined-out areas within the quadrangle. Resource losses due to restrictions total approximately 167 million tons, which leaves an available resource of 3,470 million tons, or 95 percent of the original resource. If these 3,470 million tons were to be completely developed for mining, 243 million tons of coal would be lost in the actual mining process, resulting in an extractable resource of 3,227 million tons (89 percent of original in-place resource). Because the mined coal would not require washing, there would be no processing losses. Thus, this extractable resource is also the recoverable resource.

Table 1 summarizes the original resources, unavailable resources, available resources, mining losses, and recoverable resources for the study area. The recoverable resources were then evaluated with cost models to determine the amount of economically recoverable resources at three sales-price levels, as shown in table 2.

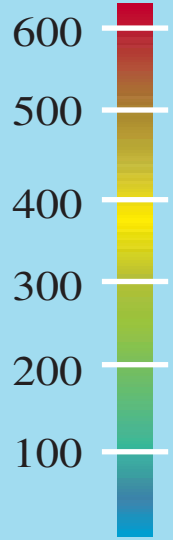
Our modeling determined that only coal resources with a rock-to-coal ratio of 2:1 or less (equivalent to a production cost of as much as $3.00 per ton) are currently economically recoverable. This category of economically recoverable coal represents only 10.7 percent (389 million tons) of the original resource, as shown graphically in figures 8 and 9. A rock-to-coal ratio of 3:1 resulted in a production cost greater than the current selling price ($3.22

Figure 5. Thickness of overburden and interburden to be removed during mining.



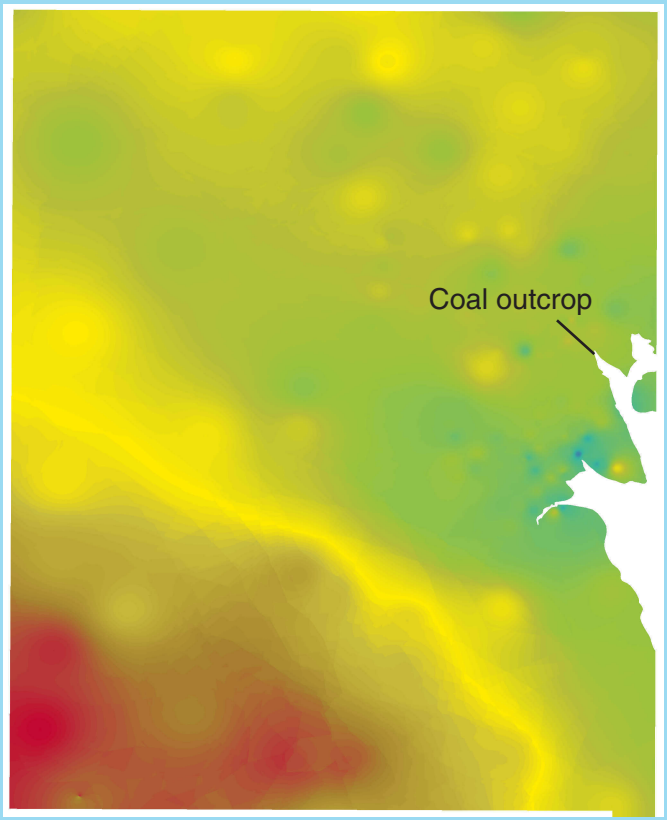
Hilight quadrangle

3 Miles



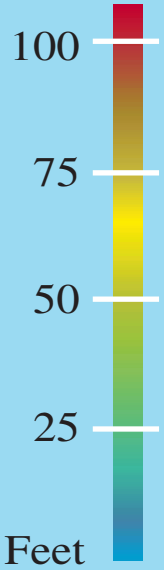
The coal recoverability process calculates the amount of overburden and interburden (waste rock) which would need to be removed to access the coal beds of interest.

Figure 6. Total coal thickness: Rider + Main + Lower Wyodak.



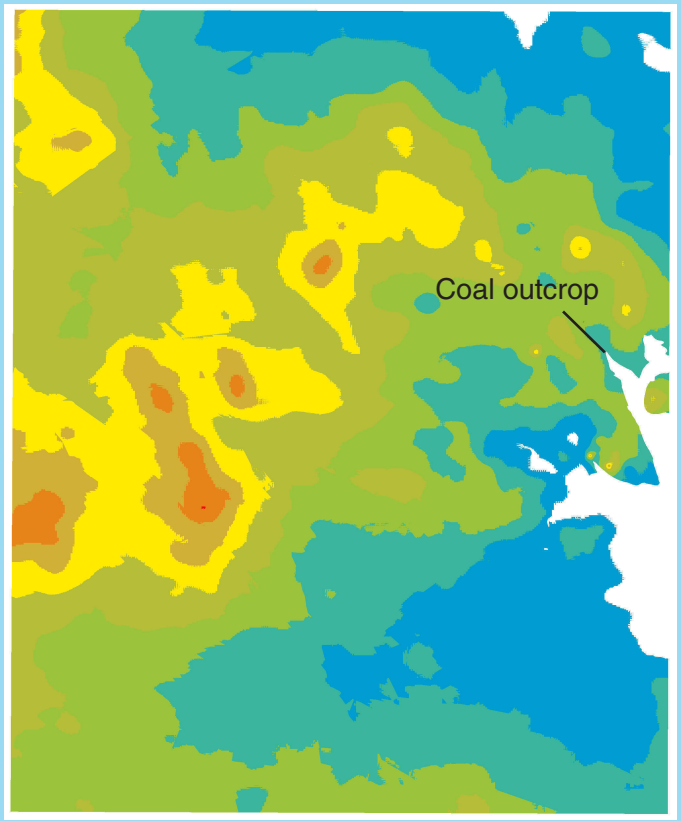
Hilight quadrangle

3 Miles



From drill hole data, we derive the total thickness of coal beds that meet the mining criteria for adequate thickness and coal quality. Coal thickness includes partings that are two feet thick or less.

Figure 7. Ratio of waste rock to coal (stripping ratio).



Hilight quadrangle

3 Miles

Stripping ratio

It is most economic to mine areas that have the lowest stripping ratios (for example, 1:1 or 2:1). In current practice in the Powder River Basin, it is not profitable for coal mines to operate in areas where the stripping ratio is higher than about 2:1.

per ton of coal as of January 1998). The amount of economically recoverable coal nearly doubles when a sales price of as much as $4.00 per ton is used; at that price, 20.3 percent (737 million tons) of the original resource is economically recoverable.

At a sales price of as much as $5.00 per ton, the amount of economically recoverable coal nearly doubles again, to 38.9 percent (1,416 million tons). However, this large resource includes coal that would have a rock-to-coal ratio of as much as 4:1, which is higher than current rock-to-coal ratios in operating mines in the Powder River Basin.

Table 2 also shows the amount of economically recoverable Federal, State, and private coal at the same three coal sales-price levels. At a sales price of as much as $3.00 per ton, for example, 10.6 percent (372 million tons) of the Federal coal, 11.6 percent (17 million tons) of the State coal, and 51.3 percent (0.7 million tons) of the private coal in the quadrangle are economically recoverable.

The amount of the economically recoverable coal resource that meets standards for sulfur dioxide emissions (and thus is "compliance coal") could not be determined because of inadequate numbers of coal-quality data points. An unpublished reclamation plan for the proposed Keeline mine within the Hilight quadrangle (Neil Butte Company, 1985) provided a limited amount of coal-quality information; the remainder of our coal-quality data was from samples taken outside the quadrangle. The reclamation plan for the Keeline mine indicated that coals within that lease tract are subbituminous C in rank. On an as-received basis, their sulfur content averages 0.6 percent (and varies from 0.3 percent to 2.0 percent); their ash content averages 7.9 percent; and their heating value averages 8,350 Btu per pound.

These data indicate that some of the coal resources in the quadrangle have a potential sulfur dioxide content greater than 1.2 pounds per million Btu, which would place those resources in a non-compliant-quality status. However, the data are insufficient to identify the location of those resources within the Keeline mine tract or to estimate the tonnage that contains this potential sulfur-dioxide-emission content. In any case, those coals could still be mined, especially if they are blended with coals of lower sulfur content.

Although most of the Hilight quadrangle is located within the Gillette South Coal Bed Methane Project, we believe it is unlikely that this project would restrict coal-mine development. Nonetheless, in table 3, we show the effect on the available and the recoverable resources if mining were not allowed within the area of the coalbed-methane project. If the project area were a restriction, only 14.8 percent of the original resource would be available for mining and only 13.7 percent of the original resource would be recoverable. The economically recoverable coal resource would also be significantly reduced if the project area were a restriction; however, we did not calculate that resource for this scenario.

Table 3. Original coal resources, unavailable resources, available resources, mining losses, and recoverable resources in the Hilight quadrangle by coal ownership, **assuming the coalbed-methane area is not available for mine development.** (All tonnage values are in short tons; not rounded to significant figures)

Wyodak Coal Unit	*Coal Ownership*	***Original Resources***	*Previously Mined Resources*	***Unavailable Resources[3]*** *(fig. 4)*	*Percent of Original Resource*	***Unavailable Resources in Methane area***	*Percent of Original Resource*	***Available Resources***	*Percent of Original Resource*	***Mining Losses on Available Coal***	*Percent of Original Resource*	***Recoverable Resources***	*Percent of Original Resource*
Main	Federal	2,733,082,513	0	127,589,484	4.7	2,234,763,651	81.8	370,729,378	13.6	25,951,056	0.9	344,778,322	12.6
	State	111,366,604	0	1,011,607	0.9	96,456,314	86.6	13,898,683	12.5	972,908	0.9	12,925,775	11.6
	Private	1,090,774	0	0	0.0	1,090,774	100.0	0	0.0	0	0.0	0	0.0
	TOTAL	**2,845,539,891**	**0**	**128,601,091**	**4.5**	**2,332,310,739**	**82.0**	**384,628,061**	**13.5**	**26,923,964**	**0.9**	**357,704,097**	**12.6**
Lower	Federal	758,941,142	0	37,618,615	5.0	578,590,649	76.2	142,731,878	18.8	9,991,231	1.3	132,740,647	17.5
	State	31,578,843	0	385,941	1.2	21,632,467	68.5	9,560,435	30.3	669,230	2.1	8,891,205	28.2
	Private	211,031	0	0	0.0	211,031	100.0	0	0.0	0	0.0	0	0.0
	TOTAL	**790,731,016**	**0**	**38,004,556**	**4.8**	**600,434,147**	**75.9**	**152,292,313**	**19.3**	**10,660,462**	**1.3**	**141,631,851**	**17.9**
TOTAL	Federal	3,492,023,655	0	165,208,099	4.7	2,813,354,300	80.6	513,461,256	14.7	35,942,288	1.0	477,518,968	13.7
	State	142,945,447	0	1,397,548	1.0	118,088,781	82.6	23,459,118	16.4	1,642,138	1.1	21,816,980	15.3
	Private	1,301,805	0	0	0.0	1,301,805	100.0	0	0.0	0	0.0	0	0.0
	GRAND TOTAL	**3,636,270,907**	**0**	**166,605,647**	**4.6**	**2,932,744,886**	**80.7**	**536,920,374**	**14.8**	**37,584,426**	**1.0**	**499,335,948**	**13.7**

[3] Mining restricted by the Hilight gas plant, a railroad corridor, producing oil and gas wells, and an alluvial valley floor.

COMPARISON TO EARLIER STUDY

Molnia and others (1997) calculated coal *availability* in the Hilight quadrangle as part of an early effort to develop availability methodology for the western United States. That study and our study used different techniques and assumptions; thus the results of the two studies are not directly comparable (table 4).

In addition to a coal availability calculation, our study calculated coal recoverability for the Hilight quadrangle. Our recoverability calculation used the same techniques and assumptions as in our availability calculation. Thus, the availability and recoverability percentages within our study provide a consistent progression from original resource through economically recoverable resource (figs. 8 and 9).

CONCLUSIONS

Results of coal recoverability estimates for the Hilight 7½-minute quadrangle (table 2) indicate that only 10.7 percent (389 million tons) of the original coal resources in the study area can presently be considered economically recoverable. This is approximately the same percentage as was calculated in studies of the Appalachian Basin and the Illinois Basin (Carter and others, 1999).

Nearly 90 percent of the original, in-situ coal resource is estimated to be recoverable in the Hilight quadrangle, whereas only about 30 percent of the original, in-situ coal resource is estimated to be recoverable in the Appalachian and Illinois Basins (Carter and others, 1999). This large difference exists because no previous mining has occurred within the Hilight quadrangle and because there is a relatively small total area where environmental restrictions occur in the Hilight quadrangle. Also, because the Hilight quadrangle is modeled for surface mining, the technical restrictions that can decrease the amount of recoverable coal in underground mining (e.g., overburden thickness, mine barriers, super-adjacent or sub-adjacent coal-bed destruction) are not applicable.

Additional studies of coal recoverability within the Powder River Basin are underway. The results of those studies will need to be analyzed before any basin-wide conclusions can be made.

Table 4. Differences between the two studies of the Hilight quadrangle

Molnia and others (1997) availability study	*This study (availability and recoverability)*
• Original resources: 4.4 billion tons • Percent of original available: 60	• Original resources: 3.6 billion tons • Percent of original available : 95 • Percent of original recoverable: 89 • Percent economically recoverable: 11
• Modeled 5 coal beds	• Modeled 2 coal-bed mining intervals
• Power line and cemetery included as restrictions to mining	• Power line and cemetery *not* included as restrictions to mining
• Entire area of Hilight oil and gas field considered unavailable for mining	• Only areas around individual oil and gas wells considered unavailable for mining

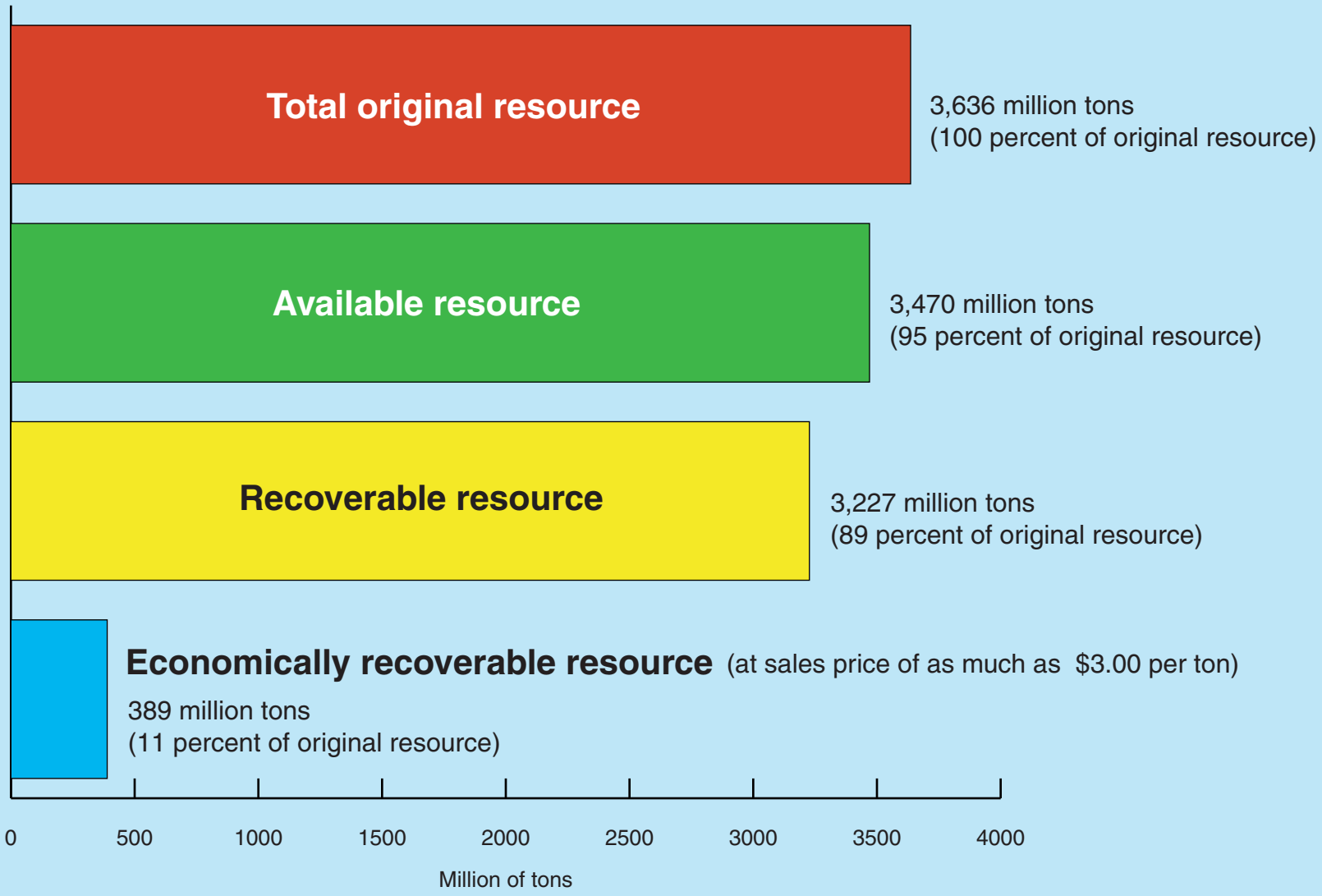


Figure 8. Hilight quadrangle coal availability and recoverability results for this study, in short tons.

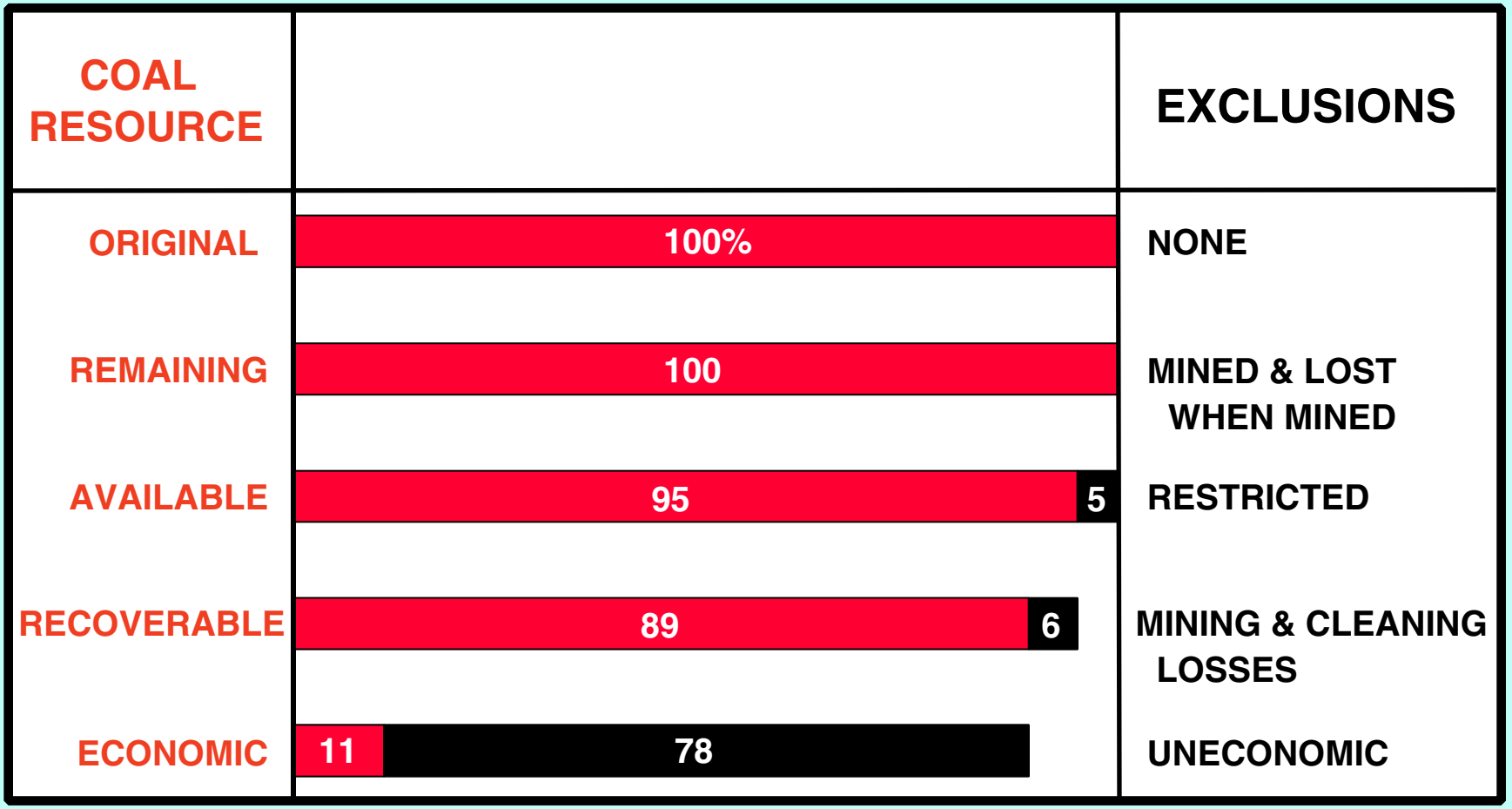


Figure 9. Hilight quadrangle coal availability and recoverability results for this study, in percentages.

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