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Regional Price Targets Appropriate for Advanced Coal Extraction

Katsuaki L. Terasawa
David W. Whipple

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December 1, 1980

Prepared for
U.S. Department of Energy
Through an agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
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ABSTRACT

The object of the study is to provide a methodology for predicting coal prices in regional markets for the target time frames 1985 and 2000 that could subsequently be used to guide the development of an advanced coal extraction system. The model constructed for the study is a supply and demand model that focuses on underground mining, since the advanced technology is expected to be developed for these reserves by the target years. The supply side of the model is based on coal reserve data generated by Energy and Environmental Analysis, Inc. (EEA). Given this data and the cost of operating a mine (data from U. S. Department of Energy and Bureau of Mines), the Minimum Acceptable Selling Price (MASP) is obtained. The MASP is defined as the smallest price that would induce the producer to bring the mine into production, and is sensitive to the current technology and to assumptions concerning miner productivity. Based on this information, market supply curves can then be generated. On the demand side of the model, demand by region is calculated based on an EEA methodology that emphasizes demand by electric utilities and demand by industry. The demand and supply curves are then used to obtain the price targets. This last step is accomplished by allocating the demands among the suppliers so that the combined cost of producing and transporting coal is minimized.

The results of the study show a growth in the size of the markets for compliance and low sulphur coal regions. A significant rise in the real price of coal is not expected even by the year 2000. The model predicts heavy reliance on mines with thick seams, larger block size and deep overburden.

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FOREWORD

This document is one of a series that describes systems level requirements for advanced underground coal mining equipment. These requirements are summarized in Overall Requirements for an Advanced Underground Coal Extraction System, by Martin Goldsmith and Milton L. Lavin (Reference 4). Five areas of performance are discussed:

(1) Production cost.

(2) Miner safety.

(3) Miner health.

(4) Environmental impact.

(5) Recovery efficiency.

This report presents details of a study that projects target prices for coal reserves suitable for contemporary technology. These prices will be used in the revenue portion of a later analysis that will assess the return on investment needed to satisfy production cost requirements. This report also presents information on transportation costs and the marketability of various resources useful to the identification of significant resources not necessarily mineable by current systems.

This work is part of an effort to define and develop innovative coal extraction systems suitable for the significant resources remaining in the year 2000. Sponsorship is provided by the Office of Mining, United States Department of Energy, via an interagency agreement with the National Aeronautics and Space Administration. William B. Schmidt, Director of the Office of Mining, is the Project Officer.

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EXECUTIVE SUMMARY

This report presents the results of an effort to develop an appropriate set of regional coal price targets for the years 1985 and 2000 to guide the development of an advanced coal extraction system. This major research and development project has as its overall objective the eventual development of the hardware associated with a new underground coal extraction system which must be both commercially attractive to the coal mining industry when developed, and demonstrate a measurable safety improvement for miners using the system hardware. Further, there must be no degradation in miner health, conservation,* or the environment as a result of the adoption of the new technology. Specifically, the present effort is designed to assist in the determination of how much more firms would be willing to pay to obtain the new technology in various coal supply regions and reserve blocks, and thus, to provide an estimate of the potential marketability in various target markets. Also, this report is intended to serve as a guide to the geologic characteristics to which advanced coal extraction technology would be applicable.

Section I identifies the major generic difficulties in doing long-term forecasting, drawing especially on the results of the 1979 Jet Propulsion Laboratory (JPL) Conference on Coal Models and Their Use in Government Planning (Reference 8). The present research effort reflects an attempt to mitigate the impact of such conference-identified forecasting difficulties on the derivation of the target prices and market for an advanced coal extraction system. JPL reviewed the existing coal models to determine whether these models provided the information necessary to construct such estimates. It quickly became apparent that none of the existing coal forecasting models generated sufficiently precise and comprehensive estimates of the resource base, mining and transportation costs, and coal demand on a regional basis. Since it was determined that such estimates were an absolute necessity as input in the present project, JPL contracted with Energy and Environmental Analysis, Inc. (EEA) to develop a set of the basic data/estimates that could then be utilized to derive the requisite regional price targets. The results of the EEA effort and JPL's modification and use of the data are the major subjects of this report.

Section II outlines the methodology used to estimate the location and magnitude of coal reserves in the year 2000, and the most salient geologic characteristics of this reserve base. To this end "inferred" reserves were estimated and added to more traditional estimates of "measured" and "indicated" quantities distributed among 15 supply regions. The results of this procedure are contained in

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*Used here, conservation refers to an attempt not to damage coal reserves proximal to mine areas, they may be cost-effective for mining at some future date beyond the target year 2000.

Table 2-3 (page 2-8). Of the 852.8 billion tons of total reserves estimated, over 78 percent (666.7 billion tons) are estimated to be underground reserves. Of these underground reserves, over 30 percent (204.2 billion tons) are estimated to be in the San Juan Region with an equal amount in the regions which collectively comprise Appalachia.

Next, in order to describe these reserves with a level of detail that would facilitate their linkage to a specific mining method, each region's total reserves were subdivided into "reserve blocks" of specific tonnage, sulfur content, and major geologic parameter values. The result is an initial base reserve estimate broken into a total of 1164 "reserve blocks" and characterized as one of 180 "mine types." The form of these initial estimates is illustrated in Table 2-4. This result is in turn restructured by keying on underground mine reserve blocks and the three geologic parameters chosen as having the largest potential impact on the new technology (seam thickness, block size, and overburden depth). This allows the number of mine types to be aggregated from the original 180 to a more manageable 16. Table 2-7 (page 2-14) contains a summary of these key mine-type codes which are used in the final regional price target forecasts, while Table 2-8 (page 2-15) presents the division of the estimated regional underground reserves (in terms of a maximum yearly recovery rate) among these constructed mine types.

Table 2-8 shows that the "yyy" mine type contains almost 60 percent of the estimated underground reserves. A "yyy" reserve/mine has seams greater than 42 inches thick, a block size of greater than 20 million tons, and lies under more than 500 feet of overburden. No other mine-type is estimated to contain more than 18 percent of estimated underground reserves. Further, if the "yyl" type reserves (reserves with thick seam, large block size and less than 500 feet of overburden) are added to the "yyy" type, a full 75 percent of the reserves are estimated to lie in these thick seam, large block size mines.

Section III addresses the set of methodologies used to estimate the costs of traditionally mining these 1164 reserve blocks in 1985 and 2000 in the form of a Minimum Acceptable Supply Price (MASP). The MASP concept (of an average supply price per time period) is detailed and the major assumptions involved identified and evaluated. Again, underground mines are the focus. Emphasis is placed on identification and explication of the necessary assumptions involved in constructing the required mine cost models. Ideally, the JPL moving baseline model and data would have been available for inclusion by EEA in the work described in this section (EEA, Final Report, March 7, 1980). However, given the fact that the moving baseline was still being developed at that time, EEA's assumptions of fixed productivity increases over the period from 1980 to 2000 may be viewed as proxies for the more detailed output of the moving baseline.

Section IV describes the derivation of the demand estimates, by region and coal type, together with the forecast transportation costs between supply and demand regions. The results of these estimates are

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a set of forecast regional production and market price (MASP) levels by coal and mine type for the years 1985 and 2000. The latter half of Section IV contains the breakdown and discussion of this forecast data according to the 16 underground mine types, and suggests caveats regarding the appropriate use of these data in the JPL project. The major results of this section fall into the following two categories and are located in the Tables referenced below:

(1) Coal demand estimates:

(a) Comparative total (Table 4-3, page 4-4).

(b) By sector (Table 4-2, page 4-4).

(2) Forecasts using these data:

(a) Regional production, surface and underground (Table 4-5, page 4-9).

(b) Regional and sulfur category MASPs (Table 4-6, page 4-11).

(c) Regional production (2000) by mine type (Table 4-7, page 4-13).

(d) Remaining regional reserves (2000) by mine type or sulfur category (Table 4-8, page 4-14).

The demand estimates, when compared to the aggregate forecasts of other major models, appear reasonable in the sense that there are alternative estimates which lie above and below those given here (for 1985). Likewise, when the estimates utilized in the present study are broken down into their sectoral components and compared with those generated by Data Resources, Inc. (DRI), the same conclusions can be drawn. As we note, however, significant increases in the demand for coal over the next 20 years is a possibility with potentially far reaching (positive) ramifications for the commercial attractiveness and appropriate development characteristics for an advanced coal extraction system.

The forecast production levels contained in Table 4-5 (page 4-9) are of significant importance. First, while total underground production is forecast to be essentially the same in 1985 as it was in 1976, it is forecast to increase dramatically (by almost 160 percent) by 2000. This foreshadows the potential for a large new market for an advanced underground mining technology. It is important to note that the largest projected increases in underground production are in Central Appalachia and the Uinta Basin.

The forecast marginal MASPs for these production levels and regions are presented in Table 4-6 (page 4-11) and indicate that those of the underground mines in Appalachia and the Uinta Basin are expected to be $25-30 per ton in 1985 and $26-32 per ton in 2000, and

still be competitive in some markets with $7-8 per ton (mine-mouth) surface coal from the Montana/North Dakota and Powder River Basin regions. These prices are consistent with the National Coal Model estimates ($23-30 in 1985 depending on supply demand/scenario), are lower than the ICF/CEUM estimates for Central Appalachia for 1990 ($29-38) and 1995 ($31-42), and are in the same general range as those predicted by Bechtel's RESPONS model. (The above estimates and their models are discussed further in EEA's Status Report, Reference 1.)

Tables 4-7 and 4-8 present the breakdown of forecast regional production and remaining reserves by mine type. The primary interest is in thick seam, large block size mines. It should be noted that 214 million tons per year are forecast to be mined from Uinta region with overburden of more than 500 feet (this will be 70 percent of production from all such mines). On the other hand only 0.2 million tons are forecast to be extracted from Central Appalachian mines with the same characteristics (note that 80 million tons are forecast for all thick seam, large block size mines regardless of the overburden in Central Appalachia). The characteristics of remaining reserves in 2000 presented in Table 4-8 provide additional data relevant to the choice of target markets and technical features desirable in an advanced coal extraction system. The final section of Part IV contains suggestions of the most appropriate ways this data may be used.

Finally, Section V summarizes the qualifications associated with the data and makes recommendations concerning its future modifications and refinements.

SECTION I

INTRODUCTION AND STUDY OBJECTIVES

This report presents the initial attempt at deriving a set of regional coal price estimates based on forecasts of supply and demand conditions for the target time frames 1985 and 2000. These forecasts will in large part determine the degree to which a newly developed advanced coal extraction system will be commercially attractive, i.e., such a system must be profitable enough to induce people to buy it. Therefore, it is crucial that such a system be no more costly per extracted ton than those systems with which it can be expected to compete in the 1985 and 2000 target time frames.

In addition, it has been determined that the system to be developed must demonstrate a measurable improvement in the safety of the miners using it, with no unfavorable impacts on miner health, conservation, or environmental factors. This simultaneous consideration of the profitability, miner health and safety, conservation, and environmental impact performance goals largely explains the need for such an effort outside the coal industry itself. While one might suppose that basic economic incentives would drive the industry members to see their own self-interest in the development of a more productive and cost-effective method of extraction, it is unlikely that the remaining performance goals would enter their research and development process except as regulatory constraints.

A. STUDY APPROACH

Since the "commercial attractiveness" goal for the advanced underground system requires knowledge and comparison of the regional "target" prices, JPL reviewed the existing coal models to determine whether these models provided the information necessary to construct such estimates. It quickly became apparent that none of the existing coal forecasting models generated sufficiently precise and comprehensive estimates of the resource base, mining and transportation costs, and coal demand on a regional basis. Since it was determined that such estimates were an absolute necessity as input in the present project, JPL contracted with Energy and Environmental Analysis, Inc., to develop a set of the basic data/estimates which could then be utilized to derive the requisite regional price targets. The results of the EEA effort and JPL's modification and use of EEA's data are the major subjects of this report.

In the process of constructing a model to forecast such regional coal price targets, the ideal methodology would be to first define the "market environment" in which the innovation to be developed would have to exist. This would involve the estimation of the demand conditions expected to prevail for the coal. This information, along with data on the conventional supply of coal, would yield an estimate

of the derived demand for the technology necessary to produce the coal. Of course, the conventional supply is derived from the existing technology, or production processes, the geological conditions in the various coal reserve blocks, and the prices of the inputs required. Based on the forecasts of price and quantity, an assessment could be made of the profitability, and hence, commercial appeal of the new technology.

Thus, the objective of this study was to assist in the estimation of relative profitability of a new extraction technology in various supply regions and under various geologically-defined mining conditions, and thus to provide an estimate of the potential marketability of advanced extraction systems in various target markets. Therefore, the real attempt was to provide estimates that will facilitate the development of a marketability projection as a function of a number of cost and geologic characteristics rather than as a single, unique guideline or number.

B. FORECASTING DIFFICULTIES

The actual forecasting task, however, is certainly not as straightforward as it might seem, even with the foregoing qualifications. The major source of this difficulty is the long-term nature of the forecasts involved. As part of a JPL effort to determine effective forecast methodology, a conference was held in July 1979 to assess the difficulties in the use of long-term forecasts in the energy area.[1] The discussions from the conference are being documented into a statement of the strengths and weaknesses of current energy forecasting efforts (Reference 8). These assessments became major considerations in the development of the methodology to derive the regional target prices required as guidance for the advanced coal extraction project's production cost targets.

While it is beyond the scope of the present work to detail the results of the conference, it is both important and useful to the substance of the remainder of this study report to provide a brief summary of the conference consensus. Therefore, the following text contains a list and brief discussion of the major concerns identified by the participating panel.

1. Uncertainty and Stochastic Elements

Certainly, the major problem with forecast credibility is the length of time into the future for which a model attempts to forecast. While there is much concern over the credibility of predictions as much as 20 years into the future, it was argued that the unacceptable alternative is sheer subjective speculation. A forecast based on a model provides a methodology to establish reasonable ranges for the crucial variables while the alternative provides no explicit framework to generate such statements.

2. Process versus Econometric Models

Argument over developing process versus econometric models is directly related to the concern with "capturing" behavioral changes over time. Specifically, there has been an increasing tendency to use process models, those which describe technological relationships to the exclusion of behavioral, and hence, major economic variables. However, it can be argued that the exclusive use of process model methodology almost completely discounts the possibility that the expectations of the human participants can affect the process being modeled. (For example, there is no way for the National Coal Model to endogenously control the impact of expectations among its three major time periods, 1985, 1990, and 1995.) The panel suggested that a hybrid approach, i.e., marrying the two, might be more satisfactory.

3. Partial versus General Equilibrium

All of the coal and energy models in current use are only partial equilibrium models, i.e., they have exogenously generated values incorporated with no "feedback" to the sectors whose operation resulted in the given values. This, of course, can result in significant distortions and variations from reality in the model's predictions. (For example, at present the Mid-Term Energy Forecasting System is not able to consider the changes one might expect in the prices and output of industries which depend heavily on energy as an input.)

4. The Appropriate Level of Disaggregation

Relatively accurate forecasts of highly aggregated variables may be as useless to a specific problem as those that are disaggregated to the point that their accuracy is largely suspect. Ideally, the level of model structure detail (for example, the number of supply and demand regions used) would be based on an explicit cost-benefit decision. Most times such a decision is based on data availability and the strength of deadline or cost constraints.

5. Data Limitations

The quantity and quality of data available have proven to be significant constraints in the long-term energy forecasting area. Efforts should be made to identify situations in which the use of the existing data will result in biased forecasts and to consider the possibility that a more appropriate data base should be developed.

6. Lack of Model Assessment

In the final analysis, there is no consensus regarding the most appropriate way to measure the extent to which a model is "good" or "bad," or the benefits accruing from its use. This places an

inordinately high premium on the "art" of the assessor. To the extent possible, the reason for the forecast should be investigated to glean the foundation for all measurable goals. The potential contribution of the model's forecasts to these goals should then be assessed. Finally, care must be taken not to expect too much from the models themselves. That is, the forecast values should be viewed as inputs to a decision process. It should be recognized that they are probability statements and as such are not for use as unique and deterministic point estimates of the future.

SECTION II

THE RESOURCE BASE

The first phase of the JPL effort to define and characterize the resource base upon which to base the Advanced Coal Extraction Systems (ACES) project cost and market guidance involved the estimation by Energy and Environmental Analysis, Inc. (EEA) of the regional deposits of coal reserves which could be mined using present technology. The major objectives of this portion of the EEA effort were: (1) to include all the known coal which would be available to mine in the year 2000 and beyond; and (2) to ensure that these reserves were described at a level of detail which would allow evaluation of the type of mining technology.

This effort was necessitated by the fact that none of the coal reserve descriptions incorporated in other coal models satisfied both the conditions necessary to construct an accurate cost and market guidance for the ACES effort. Specifically, conventional reserve descriptions fail to:

(1) Include total coal reserves. The Bureau of Mines estimates include only "measured" and "indicated" reserves which understate the true quantities of coal in the ground.

(2) Describe the reserves in sufficient detail. For example, areas generally omitted include seam thickness, slope, pitch, and other salient characteristics that in large part determine the most appropriate mining technique, and its cost.

Thus EEA's reserve characterization effort was composed of the following steps, subsequently discussed in turn:

(1) Division of the country into 15 supply regions.

(2) Estimation of total region-specific "recoverable reserves."

(3) Subdivision of each region's total reserves into "reserve blocks" of specific tonnage, Btu and sulfur content, and geologic parameter groupings.

(4) Assignment to each such reserve block the most probable (present technology) mining method.

A. THE SUPPLY REGIONS

The 15 supply regions chosen were determined to be those areas that include all the important bituminous, subbituminous, and lignite deposits in the contiguous United States, and in which coal rank, geology, and quality are roughly homogeneous. The geographical

composition of these supply regions is contained in Table 2-1. For each region the average rank, Btu content, and distribution of reserves over three categories of sulfur content were estimated.[2] The three ranges of percentages in Table 2-1 correspond to the "compliance," "low," and "high" sulfur categories generally used to define coal demand.

B. REGION-SPECIFIC RECOVERABLE RESERVES

Beginning with basic information in the U.S. Geological Survey (USGS) reports and the available summary reports on the geology and occurrence
of coal documented by numerous other sources (EEA, Final Report, Section 6-7), EEA expanded on the coal resources described in such conventional data bases by including the results of recent exploration activities, reserves usually not included due to ownership problems, and by extrapolating the location of "inferred" reserves. Thus, the EEA-estimated reserve base contains "measured," "indicated," and "inferred" reserves[3] in an attempt to more accurately represent the size and location of the potential market for advanced underground extraction systems. Since approximately 61 percent of U.S. coal reserves are classified as "inferred," and since the construction of price targets involves forecasting supply patterns in the year 2000, it was deemed appropriate to include these inferred resources which will likely have become "measured" by that time.

However reasonable such assumptions of inferred coal resources may appear, it is still possible they may be incorrect. For example, during the JPL Coal Conference a major new research effort was reported upon, the objective of which was to provide more accurate estimates of regional coal reserves because of the present degree of unreliability (Reference 8). And even this significant effort left at least one panel member skeptical.[4] His assessment was that the Illinois Geological Survey, which has collected data on over 600,000 boreholes over a 50 year period, has yet to accurately forecast depositional patterns in reserves. Thus, recalling the caveats in Section I regarding the sources of uncertainty, quality of data, and the need for model assessment, JPL plans to monitor the sensitivity of the study-developed price targets to the exclusion of inferred reserves from the resource base, where feasible.

C. DEFINITION OF RESERVE BLOCKS

EEA chose the following sets of geological characteristics as those which would capture the most important factors affecting the cost and type of mining in the reserve block:

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Table 2-1. Supply Regions and Coal Types

	Supply Region	Rank	Btu/lb	Percent of Total Coal by Sulfur Content		
				Compliance	Low	High
1.	Ohio	Bituminous	12,500	---	0.03	0.97
2.	Pennsylvania Maryland Northern W.Va.	Bituminous	13,500	---	0.10	0.90
3.	Southern W.Va. Eastern Kentucky Virginia Northern Tennessee	Bituminous	13,500	0.45	0.43	0.12
4.	Southern Tennessee Alabama	Bituminous	13,500	0.12	0.63	0.25
5.	Western Kentucky Indiana Illinois	Bituminous	11,000	---	0.05	0.95
6.	Kansas Missouri Nebraska Iowa	Bituminous	11,000	---	---	1.00
7.	Oklahoma Arkansas	Bituminous	13,000	---	0.65	0.35
8.	Texas Louisiana Arkansas	Lignite	7,000	---	---	1.00
9.	Montana North Dakota	Lignite	6,000	---	0.80	0.20
10.	Montana	Subbituminous	8,500	0.30	0.70	---
11.	Wyoming (Powder River Basin)	Subbituminous	8,000	0.30	0.70	---
12.	Southern Wyoming North Central Colorado	Subbituminous	9,000	0.40	0.60	---
13.	Northwest Colorado Northern Utah	Bituminous	12,500	0.40	0.60	---
14.	Southern Utah Southern Colorado	Bituminous	11,000	0.20	0.80	---
15.	New Mexico Arizona	Subbituminous	12,000	0.40	0.60	---

For Underground Mines	For Surface Mines
Overburden Depth	Slope
Drift of Shaft Entry	Strip Ratio

Seam Thickness
Pitch
Block Size

Each parameter is divided into ranges known to have generally different effects on the type and cost of mining. Surface mineable reserves are further identified as those best suited for "contour" and "area" stripping; underground mineable reserves are associated with either "room and pillar" continuous mining or "longwall" technology. Table 2-2 summarizes all the possible combinations and presents the values the geologic parameters may take.

Surface mines are characterized by thickness, slope, pitch, stripping ratio, and block size. Surface contour mining is used for medium and steep slopes where the coal outcrops. These conditions are found nearly exclusively in Appalachia. Only one block size is considered for contour mines; this is because economies of scale are assumed not to be relevant to contour stripping, given that the actual equipment and pit layout can occupy only a small area at a time. Area stripping is used for gentle slopes where seams are continuous over broad areas. Unlike contour mines, western area mines include thick (over 119 inches) and pitching seams. Area mines are characterized by large mining blocks and are capable of producing as much as 6.75 million tons or more per year.

Underground mines are characterized by seam thickness, pitch, block size, overburden and whether the mining block is drift or shaft mineable. Room and pillar mines are assigned to most flat and moderately pitching seams with 2000 feet or less of overburden. Seams that are steeply pitching or under deep overburden (over 2000 feet) are considered best mined by the longwall method. Mines in Appalachia may be restricted to small areas of reserves, such as a drift operation, that mines a reserve part way up a narrow ridge. Therefore, small and medium reserve blocks are assigned to drift mines and large blocks to shaft mines.

D. ASSIGNMENT OF RESERVES TO MINE TYPES

In the final stage of EEA's analysis effort, the total reserves previously estimated for each region were assigned to one of the 180 effective mine types as described by the various possible combinations of seven of the nine variables listed in Table 2-2. This is accomplished in a sequence of 11 steps which are briefly described in the following text.[5]

Table 2-2. Mine Type/Reserve Characterization

(1) Type	(2) Method	(3) Seam Thickness, inches	(4) Slope, degrees	(5) Pitch, degrees	(6) Strip Ratio	(7) Block Size*	(8) Overburden Thickness, feet	(9) Drift/ Shaft
SURFACE	Area	28-42	10	0-10	5:1	6		
		42-120	10-20	10-30	10:1	20		
		120	10-30	30	20:1	150	N/A	N/A
	Countour	28-42		0-10	10:1			
		42-120			20:1			
UNDERGROUND	Room & Pillar	28-42		0-10		6	0-500	Drift
		42-120	N/A	10-30	N/A	20	500-2000	Shaft
		120				40		
	Longwall	28-42		0-10		60	500-2000	Drift
		42-120		10-30			2000	Shaft
		120	N/A	30	NA			

*Million metric tons.

(1) Determine Percentage of Reserves that are Surface Mineable. This operation was based on the various maximum economic stripping ratios (which differed by state) and coal type.

(2) Reduce Reserves by Availability Factors. These "availability" factors discounted the estimated total reserves in a region by from 15 to 25 percent in recognition of varying land use, ownership, geologic, and environmental constraints.

(3) Estimate the Distribution of Reserves by Thickness. The categories used in the EEA model were chosen because they conform to present mining practices and with past procedures in estimating resources.

(4) Estimate the Distribution of Reserves by Slope. The distribution of "average slope" was estimated in order to be able to reflect the increased costs associated with surface mining on steep slopes. States were segregated into groups of counties with common terrain, with slope measurements taken from USGS topographic maps in a random checkerboard fashion across the country.

(5) Estimate the Distribution of Reserves by Pitch. Geologic reports (county-level whenever possible) were reviewed and coal-bearing areas distributed into the three categories, with reserves treated as evenly distributed across the coal bearing area in the same proportion as the areas. However, this is a regional pitch estimate and for most United States reserves regional pitch is negligible (usually less than 10 degrees). Locally, pitch may vary dramatically, but as yet it is not possible to reasonably estimate its distribution.

(6) Divide the Surface Reserves into Strip Ratio Categories. The portion of the surface reserves (Step 1) in the standardized 20:1 category was divided into 10:1 and 20:1 groups to more closely reflect the actual distribution.

(7) Distribute the Underground Reserves into Thickness of Overburden Categories. This was done (wherever possible) using the data in the coal summaries.

(8) Determine the Distribution of Reserves by Block Size. This is probably the most involved step in this process. The reserve block is defined as the amount of coal that can logically be committed to a specific type of mining operation. In Appalachia, reserve blocks are limited in size by topographical and geological constraints which affect the continuity and/or extent of the mineable portion of the seam. For example, in central Appalachia steep ridges may contain numerous but small and isolated

coal beds. Thus a single ridge may contain 20 million tons of coal but have individual mines limited to 6 million tons each. This is generally not true for non-Appalachian underground reserves. Therefore separate methodologies were used to assign block sizes to:

(a) Underground reserves in Appalachia.

(b) All other underground reserves (where ownership patterns and economical mine size tend to be more important).

(c) Surface reserves (where contour mines were assigned the smaller reserve blocks and area mines the larger ones).

(9) Estimate the Distribution of Drift or Shaft Entry for Underground Reserves. This was based on outcropping, relationships to drainage, distribution of overburden, and average seam pitch.

(10) Distribute Reserve Blocks to Mine Types. The previous nine steps determine the allocation of total estimated reserves to each of the seven relevant categories. Each of these reserve blocks now is considered a "mine type," and similar mine types (i.e., those with identical seven parameter values) can be aggregated to determine the percentage of reserves in each such category.

(11) Distribute Mine Types into Sulfur Categories. The sulfur distribution was assumed to be random in each region so that each mine type in a region would have the same proportion of compliance, low, and high sulfur reserves. The percentage distributions in Table 2-1 were used to divide the mine types up into sulfur categories.

E. SUMMARY OF THE INITIAL RESOURCE DATA BASE

The estimation of the region-specific recoverable reserves and the determination of the percentage of those that are surface mineable resulted in the estimated reserve base contained in Table 2-3. This then became the input for steps 2-11 described in the preceding section. Given the complexity of the procedure, it will be useful here to consider an example. Table 2-4 contains a set of sample data (estimates) resulting from steps 2-11, and utilizing the initial reserve stock estimates shown in Table 2-3.

Care must be taken to recognize that henceforth all production quantities forecast by the EEA model are in terms of maximum yearly estimated flow rather than as stocks in the ground. The reason for this unique feature will be discussed in Section III in conjunction with the definition of EEA's mine cost estimation methodology.

Table 2-3. Total* Estimated Reserve Stocks by Region and Mining Method, millions of tons

Supply Region	Surface	Underground	Total
1.	6,396	22,844	29,242
2.	6,932	50,819	57,751
3.	13,250	44,136	57,386
4.	383	2,727	3,110
5.	29,148	86,000	115,148
6.	6,398	4,150	10,548
7.	752	1,902	2,654
8.	10,829	-	10,829
9.	39,059	-	39,059
10.	33,213	69,200	102,413
11.	20,664	74,057	94,721
12.	5,324	8,622	13,946
13.	2,327	64,508	66,835
14.	1,596	33,563	35,159
15.	9,848	204,151	213,999
TOTAL	186,121	666,689	852,810

*This is the total estimated stock of measured, indicated, and inferred reserves.

Table 2-4. Sample of Initial Reserve Data Base

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Supply Region	SULFUR	Mine Type*						Annual Estimated Maximum Production
		S	ST	P	SL	SR	BS	
		U	ST	P	BS	OD	E	
01	H	C	1	1	1	3	1	3.8 million metric tons
05	L	R	2	1	3	1	1	9.1 million metric tons
07	C	A	2	1	2	3	1	.5 million metric tons
10	C	A	2	1	1	2	2	3.6 million metric tons
13	L	L	3	1	3	3	1	52.5 million metric tons
15	C	A	3	1	1	2	3	25.2 million metric tons
15	L	A	3	1	1	2	3	37.7 million metric tons

*Values for mine codes are:

C, L, H, corresponds to compliance, low, and high sulfur coal.

S = Surface mine; C = contour mine; A = area mine; U = underground mineable; R = room and pillar mine; L = longwall mine.

ST = Seam thickness: 1 = 28-41 inches; 2 = 42-119 inches; 3 = 119 inches.

P = Pitch: 1 = 0-10°; 2 = 11°-30°; 3 = 30°.

SL = Slope: 1 = 0-10°; 2 = 11°-20°; 3 = 21-30°.

SR = Stripping ratio: 1 = 5:1; 2 = 10:1; 3 = 20:1.

OD = Overburden depth: 1 = 0-500 feet; 2 = 500-2000 feet; 3 = 2000 feet.

E = Entry: 1 = drift; 2 = shaft.

BS = Block size: 1 = 6 million metric tons; 2 = 20 million metric tons; 3 = 40 million metric tons; 4 = 60 million metric tons; 5 = 150 million metric tons.

The first column of Table 2-4 identifies the supply region in which the reserve block lies, while the second indicates whether it contains compliance (C), high (H), or low (L) sulfur coal. The next six columns (3-8) jointly form the "mine type" definition. Column 3 indicates whether the reserve block is surface (S) or underground (U) mineable, and whether it will be an area (A) or contour (C) mine in the former case, or a room and pillar (RP) or longwall (LW) mine in in the latter. Columns (4) and (5) have the same meaning for both surface and underground mines: seam thickness and degree of pitch, respectively. Columns (6)-(8) have different meanings depending on whether the portion of the reserve block under consideration is surface or underground mineable. Finally, column (9) indicates the estimated maximum annual production possible from that particular portion of the reserve block so characterized.

The EEA procedure (described in the 11 steps in the previous text) results in a total of 1164 such mine types distributed among the 15 supply regions. Table 2-5 aggregates these data by region and sulfur category for surface and underground mines.

F. MODIFICATION OF THE RESOURCES DATA BASE

While the reserve base characterization in Tables 2-4 and 2-5 certainly represents a significant increase in available detail, it was judged that the advanced coal extraction system price guidance requirement would be better served with a modified aggregation approach. Supply side data aggregated by region and coal type will allow the derivation of estimated market mine-mouth prices in the target years of 1985 and 2000; but the most helpful information for the present task would be data that allows a distinction of these regional coal supply estimates by the mine type characteristics that identify specific reserve blocks and their mining conditions. This would facilitate a more accurate assessment of the technological requirements of the new system on the basis of the particular portion of the coal mining market in which it is most likely to be competing. In addition, although the surface mines/reserves are important to the forecast of market prices in the target years, the study chose to focus on the characteristics of the underground mineable reserves, since these represent the universe of the new technology's potential market.

First, recall that the "mine type" characterization of the reserve block is done with the six element code contained in columns (3)-(8) in Table 2-4 above. Let the elements of this code be designated as:

$$(a_1, a_2, a_3, a_4, a_5, a_6)$$

where, for underground mines:

$$a_1 = \begin{cases} RP = \text{room and pillar mine} \\ LW = \text{longwall mine} \end{cases}$$

Table 2-5. Summary of Regional Reserves, million metric tons per year

Supply Region	Sulfur Category	Mine Type	Annual Reserves	Sulfur Total	Region Total
01	H	S	146.6	595.1	613.5
01	H	U	448.5		
01	L	S	8.4	18.4	
01	L	U	10.0		
02	H	S	303.0	1987.1	2207.6
02	H	U	1684.1		
02	L	S	12.6	220.5	
02	L	U	207.9		
03	C	S	118.7	738.2	1640.5
03	C	U	619.5		
03	H	S	35.4	196.9	
03	H	U	161.5		
03	L	S	114.1	705.4	
03	L	U	591.3		
04	C	S	9.0	15.9	130.7
04	C	U	6.9		
04	H	S	16.4	29.9	
04	H	U	13.5		
04	L	S	49.2	84.9	
04	L	U	35.7		
05	H	S	856.0	3992.0	4201.9
05	H	U	3136.0		
05	L	S	28.9	209.9	
05	L	U	181.0		
06	H	S	254.7	1185.2	1185.2
06	H	U	930.5		
07	H	S	10.7	39.9	105.1
07	H	U	29.2		
07	L	S	18.9	65.2	
07	L	U	46.3	65.2	

Table 2-5. (Cont'd)

Supply Region	Sulfur Category	Mine Type	Annual Reserves	Sulfur Total	Region Total
08	H	S	460.2	460.2	460.2
08	H	U	-		
09	H	S	359.1	359.1	1797.7
09	H	U	-		
09	L	S	1438.6	1438.6	
09	L	U	-		
10	C	S	394.8	1684.9	5616.3
10	C	U	1290.1		
10	L	S	232.1	3931.4	
10	L	U	3699.3		
11	C	S	263.5	1207.7	4025.6
11	C	U	944.2		
11	L	S	614.8	1218.0	
11	L	U	2203.2		
12	C	S	83.9	228.8	670.1
12	C	U	144.9		
12	L	S	233.4	441.3	
12	L	U	207.9		
13	C	S	61.1	1175.8	2936.1
13	C	U	1114.7		
13	L	S	167.6	1760.3	
13	L	U	1592.7		
14	C	S	13.5	298.3	1494.2
14	C	U	284.8		
14	L	S	145.9	1195.9	
14	L	U	1050.0		
15	C	S	126.1	2728.5	6821.2
15	C	U	2602.4		
15	L	S	189.0	4092.7	
15	L	U	3903.7		

TOTALS (all regions) million metric tons/year

C	8,078.1	S	6,766.2
H	8,845.4	U	27,139.8
L	16,982.5		
	33,906.0		33,906.0

a_2 = seam thickness

a_3 = pitch

a_4 = block size

a_5 = overburden depth

a_6 = entry (drift or shaft)

To keep the task (and the results) manageable, it was determined that the study would focus on seam thickness (a_2), block size (a_4), and overburden depth (a_5); and further that the EEA data would be divided such that each variable took only two values. This then yields a total of eight possible aggregated "mine types" identified by the values of the triplet (a_2, a_4, a_5).

The "pitch" and "entry" variables have been suppressed in order to focus on a manageable number of variables. With respect to entry, it was determined that the need for shaft rather than drift access impacted more on development cost than on the method of extraction (and hence operating cost) once the seam was reached. Since costs divorced from extraction mode are of less direct interest in terms of the technology development, it was deemed a reasonable abstraction. The suppression of pitch might seem somewhat more worrisome. As noted above, EEA was only able to use regional pitch in their reserve base estimations. While they recognized that there is significantly more variation in local pitch, the input data did not allow its estimation. As a result, in the 15 regional underground reserve base estimates, only regions 7, 12, and 14 contain any pitching reserves (i.e., over 10 degrees). Table 2-6 summarizes these data. Thus, given the extremely small percentage of total estimated regional reserves that could be classified as having any significant pitch, it was determined the study would focus on flat-lying seams.

Treatment of the dichotomization of the values of the remaining three geologic variables is perhaps less obvious. First, seam thickness (a_2) was considered. It was decided to divide all reserves into those with (relatively) "thin" seams, less than 46 inches in the EEA data base, and those with (relatively) "thick" seams, greater than 46 inches. These decisions correspond to $a_2 = 1$ in the former case, and $a_2 = y$ ($y = 2, 3$) in the latter case. Likewise, it was decided to focus on "small" (5 million tons) and "large" (≥ 20 million tons) block size reserves. This corresponds to $a_4 = 1$, and $a_4 = y$ ($y \geq 2$) in the EEA data base. And finally, it was decided to call mines with 0-500 feet of overburden "shallow," and those with over 500 feet, "deep" mines. These correspond to $a_5 = 1$, and $a_5 = y$ ($y \geq 2$) respectively.

Thus eight possible "mine types" have been defined by all possible combinations of the newly aggregative values of the triplet (a_2, a_4, a_5). The values of this triplet are then used to designate the mine types, which are summarized in Table 2-7.

Table 2-6. Estimates of Pitching Coal (Underground)

Region	Sulfur Type	Pitching Coal (U)*	Total Reserves (U)*	Pitching Coal
7	High Low	15.2 24.6	75.5	53%
12	Compliance Low	57.7 76.9	134.6	38%
14	Compliance Low	5.7 26.7	1334.8	2%
Total (1-15)	-	206.8	28,410	1%

*Million metric tons per year.

Table 2-7. Definition of Mine Types by Characteristics

Characteristics	Parameter Values	Mine Type							
		lll	lyl	lly	lyy	yll	yyl	yly	yyy
Seam, inches (a_2)	< 42	X	X	X	X				
Thickness, inches	≥ 42					X	X	X	X
Block, million metric tons (a_4)	6	X		X		X		X	
Size, million metric tons	≥20		X		X		X		X
Overburden, feet (a_5)	0-500	X	X			X	X		
Depth, feet	> 500			X	X			X	X

Table 2-8. Estimated Yearly Rate of Underground Reserves by Regions and Mine Type, million metric tons per year

Region	lll	lyl	lly	lyy	yll	yyl	yly	yyy	Total
1	24.2	40.7	0.3	127.8	33.6	46.5	0.6	184.8	458.5
2	74.4	291.6	0.9	542.4	72.9	169.8	0.3	739.7	1892.0
3	36.7	78.6	0.3	428.1	41.1	117.0	1.0	679.5	1392.3
4	3.4	7.8	0.3	18.2	2.4	5.4	0.6	18.0	56.1
5	3.7	162.9	27.8	251.7	6.6	597.2	26.3	2240.8	3317.0
6	0	73.9	0	654.7	0	21.6	0	180.3	930.5
7	3.2	5.6	9.5	30.1	6.5	0	1.9	18.7	75.5
8	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0
10	107.8	254.3	355.8	62.8	0	1309.5	0	2899.0	4989.4
11	0	201.3	0	328.6	0	994.6	0	1622.9	3147.4
12	0	18.0	1.3	39.1	0	115.0	8.7	170.7	352.8
13	0	49.5	0	635.8	0	148.5	0	1873.6	2707.1
14	21.4	20.0	54.9	189.1	50.7	115.4	67.2	816.1	1334.8
15	0	80.8	0	1545.4	0	243.9	0	4636.0	6506.1
TOTALS	274.8	1285.0	451.1	4853.8	213.8	3884.4	106.6	16098.3	27139.4

In keeping with the above definitions, the first four mine types listed in Table 2-7, reading across (lll, lyl, lly, and lyy), have $a_2 = 1$ and are therefore "thin" seam mine types with various block sizes and overburden depths. Likewise, the latter four have $a_2 = y$, and are therefore "thick(er)" seam mines. Reading down any column identifies the specific characteristics of that mine type.

Finally, Table 2-8 presents the estimation of the (yearly rate of production) reserve data contained in Table 2-5 broken down by study-revised mine type characteristics. Given the large quantity of estimated reserves relative to the present yearly rate of use, these values and their relative size mean little by themselves. However, as will be discussed in Section IV, such a breakdown will be valuable in constructing advanced coal extraction system price targets.

SECTION III

ESTIMATION OF MINING COSTS

The modeling problem next addressed was the estimation of the cost of actually bringing coal to the mouth of a mine. This estimation process is addressed in some detail below. It will also be most useful to discuss the particular "supply cost" concept utilized by EEA, and this discussion will be carried out in the remainder of this report.

A. THE MINIMUM ACCEPTABLE SUPPLY PRICE (MASP)

The methodology for attempting to estimate a probable future market price for a commodity incorporated estimating basic cost of production for various levels of output and then determining how much of this supply will be forthcoming at various market prices, as well as determining from which firms this supply will likely come. Thus, any particular firm would likely vary its desired level of supply depending upon the prevailing demand (or market) price. Hence, when the estimated level of demand (which also is a function of the market price) is combined with the aggregate supply plans of the industry and an equilibrating market price determined, only then is the particular level of production of a firm (and its prevailing supply costs) known.

In the case of the coal industry, the unique production and market conditions, which will be discussed in more detail below, call for a somewhat different task. In particular, instead of deriving a supply curve for a particular coal mine in a region (similar to that of Figure 3-1), the mine/reserve block-specific supply curves will be derived as shown in Figure 3-2.

The supply curve in Figure 3-1 indicates that as the selling price of the product increases, a "traditional" firm is willing to supply an increasing quantity of its product. This stems from its (generally) increasing periodic costs of production and its desire to maximize its profits. In Figure 3-2, the MASP curve indicates that the mine owners have calculated their Minimum Acceptable Supply Price to be p dollars per ton and are willing to supply any quantity of coal between zero and c tons at that average revenue or price per unit during the production year. That is, they are interested in recovering their total actual costs, amortized over the expected lifetime production of the mine, plus a "reasonable" return on their investment capital.

Given the special nature of the market for coal this is a defensible assumption. Specifically, the tremendous reliance on long-term contracts between a specific buyer and specific producer (mine) makes a predetermined period over which the reserve block is to be "mined-out" a realistic assumption. Likewise, these long-term contractual relationships make true market influenced price

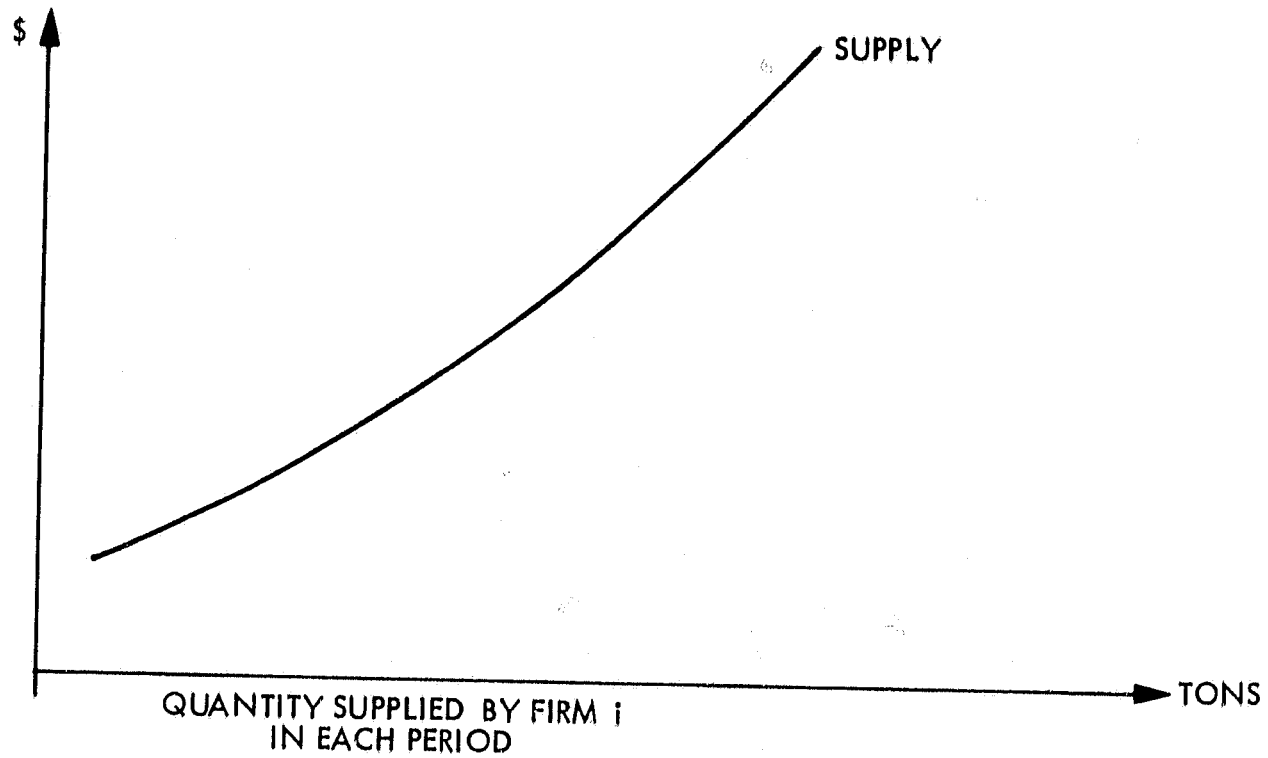

Figure 3-1. Traditional Supply Curve

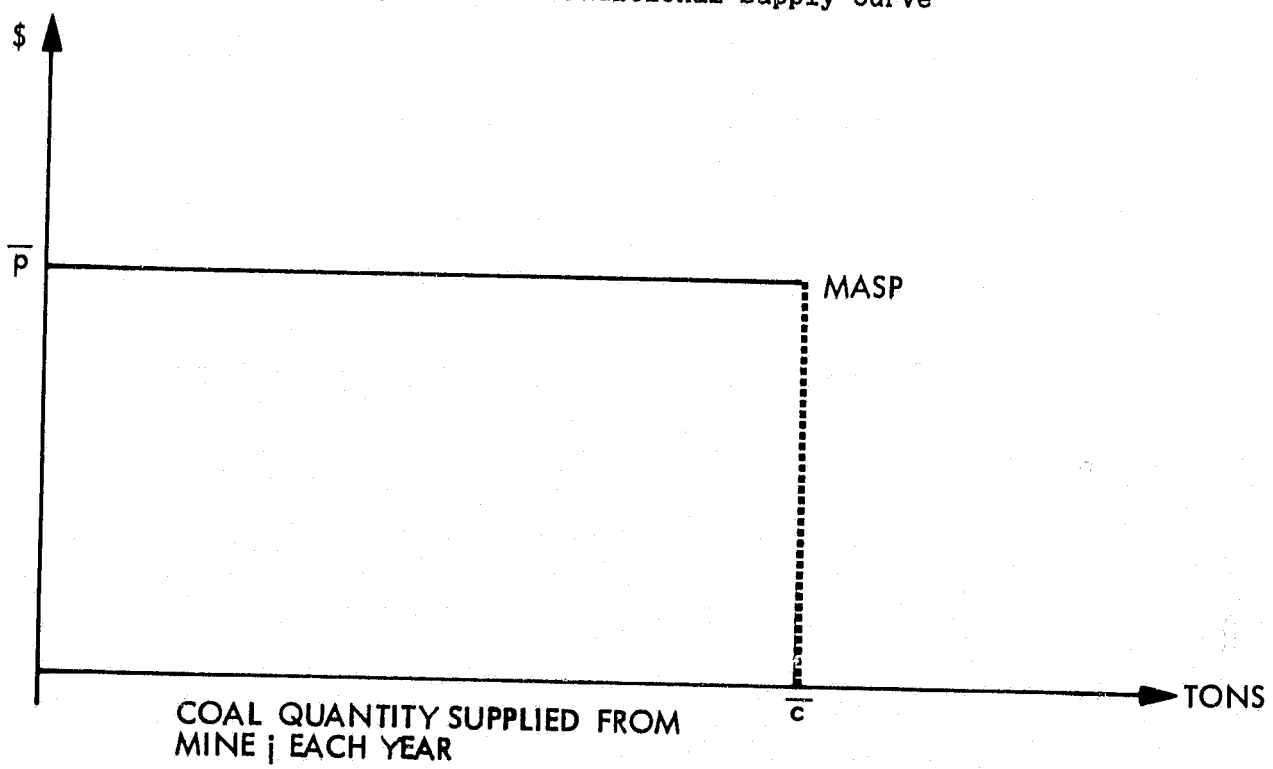

Figure 3-2. Minimum Acceptable Supply Price (MASP) Curve

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fluctuations (for the specific mine) difficult, leading instead to a reliance on cost-plus type contracts.

Thus, (in simplified notation), if we let:

t = length of time the reserve block is to be mined

ρ = estimated annual production possible from the reserve block

$t.\rho$ = total expected production over the life of the mine[8]

And, if:

TC = total cost of starting and operating the mine at the rate ρ over t

ROI = total return on the investment involved in generating TC

then we can define:

$$\text{MASP} \quad \frac{TC + ROI}{t \cdot \rho}$$

The potential impact of these and related assumptions made in the mine cost modeling on the derivation of target prices will be discussed further on in this section, and efforts to identify necessary sensitivity analysis in the construction of the cost guidance will be detailed.

B. MINE COST MODEL OVERVIEW

The objective of the cost model portion of the forecasting effort was to estimate a MASP for each of the 1164 mine types for the target years 1985 and 2000, and then to arrange them in increasing order by region and coal type to form the relevant supply curves. This was accomplished by developing separate mine cost models for underground, contour, and area mines which were then used to estimate the MASP as a function of the mine type characteristics (see columns 3-8 in Table 2-4), mine size,[9] and regional royalty and severance taxes.

The underground mine-cost model was essentially developed from scratch using Department of Energy and Bureau of Mining data for the basic cost information, while the surface models were adaptations of earlier models, (Contour = Oak Ridge National Laboratory model and Area = ERDA model) adjusted to reflect 1979 costs and the required Return on Investment (ROI) criteria.

All three of the models share the following common assumptions:

(1) Technology: The 1979 state of the art is reflected. Especially for the 1985 time period this is reasonable since no major improvements appear imminent. The JPL "moving baseline" alternative cost guidance will provide for the estimation of potential dynamic changes in the more distant future.

(2) Production Costs: No real change in capital and operating costs through 1985 is expected. Through 2000 real labor costs are assumed to increase 20 percent, while all tax rates and tax credits are held constant.

(3) Regulation/Legislation: Royalty, income tax, severance tax rates and the investment tax credit assumed unchanged through 2000.

(4) Unionization: No change in union/nonunion share of labor force through 2000.

Given the established focus of interest on underground production, reserves, and costs, the detailed elaboration shall be confined to that of the underground mine cost model structure.

C. UNDERGROUND MINE COST MODEL CONTENT

The underground mine model is the most detailed of the three mine cost models. Its operation consists of three interrelated steps:

(1) For a given mine type and base production size, inputs covering capital and operating costs are fed into the model. Other cost elements (e.g., depreciation) are calculated internally, some being dependent upon the productivity determination made in step (2) below.

(2) The mine's production level and costs are adjusted to reflect the miners' estimated productivity (in uncleaned tons/day). The productivity estimates depend upon mine size, geologic characteristics, and region.

(3) The amount of annual revenue required to amortize all costs is calculated. This magnitude is then divided by clean tonnage to complete the estimation of the MASP for that particular mine type and reserve block.

The major factor in determining the MASP of any particular mine type relative to another is the productivity estimate resulting from step (2). This is because mine costs, with the exception of some operating and labor costs, are fixed for a given mine, base size, and type. The productivity estimate is critical because it determines the total estimated coal production, and thus the number of tons of coal, over which coal costs can be spread. The prominent role of productivity warrants a deeper look at its determinants.

D. ESTIMATING MINER PRODUCTIVITY

The productivity estimates were developed through a four step process:

(1) Calculation of a base productivity, individually, for longwall, Appalachian room and pillar, and other room and pillar mines.

(2) Adjustment of the base estimate reflecting geological factors.

(3) A further adjustment to reflect raw or uncleaned production.

(4) A final adjustment to reflect expected gains in productivity through 2000.

In the process of developing this four-step estimation procedure, a number of assumptions naturally had to be made. Most involved relatively minor corrections to the productivity data used in the calculations and taken for the most part from Mine Safety and Health Administration statistics covering 1600 underground mines from the first quarter of 1978 to the first quarter of 1979. However, two of these assumptions are of such potential importance to the accuracy of the relative and absolute value of the forecast MASPs that further discussion is warranted:

Assumption 1. Smaller mines are more productive than larger ones (i.e., there exist diseconomies of scale), at least in Appalachia.

Assumption 2. The 1977-1979 increase in underground miner productivity will continue such that a trend is established. On this basis the associated productivities in the model were increased 5 percent for 1985, and 20 percent for 2000. No such assumption and adjustment is made with respect to surface miner productivity.

EEA's model structure Assumption 1, that small Appalachian underground mines are more productive than large ones, was based upon the perception of greater management efficiency and work force experience and cohesion in the former which leads in part, to fewer work stoppages and thus more production per employed worker.[10] Although this assumption would seem to be valid if one could expect that the same number of work stoppages in the same mines continue and that the same size work force would be kept on the payroll, this does not seem likely to occur. In fact such work stoppages have declined (EEA Briefing, pg. 35) and are expected to continue to fall.

Although to determine in any rigorous way the effects on forecast MASPs of this assumption the model will have to be rerun without it, the following statements can be made prior to this effort:

(1) Assumption 1 biases the cost of production of smaller mines in regions 1-4 downward relative to that region's larger mines. Thus the region-specific MASPs could be expected to rise if it is relaxed.

(2) In addition, because of the interconnected nature of the market determinants of the structure of 1985 and 2000 regional MASPs and production levels, it could be expected that predicted Appalachian production levels would tend to be biased upward relative to competing regions.

Assumption 2, underground labor productivity increasing 5 percent by 1985 and 20 percent by 2000, is based on an interpretation of the data illustrated in Figure 3-3. The assumption is that the declining productivity for the period 1968-1977 is outweighted by the 1977-1979 data showing an overall increase in productivity of 25 percent and individual increases as indicated in Table 3-1. Although this assumption too seems questionable, a more rigorous attempt can be made to estimate its impact on the predicted MASPs (because of the manner in which this productivity assumption enters the MASP calculation).

The MASP calculation can be broken into two terms,[11] a constant and a term which is inversely related to α, the assumed productivity change:

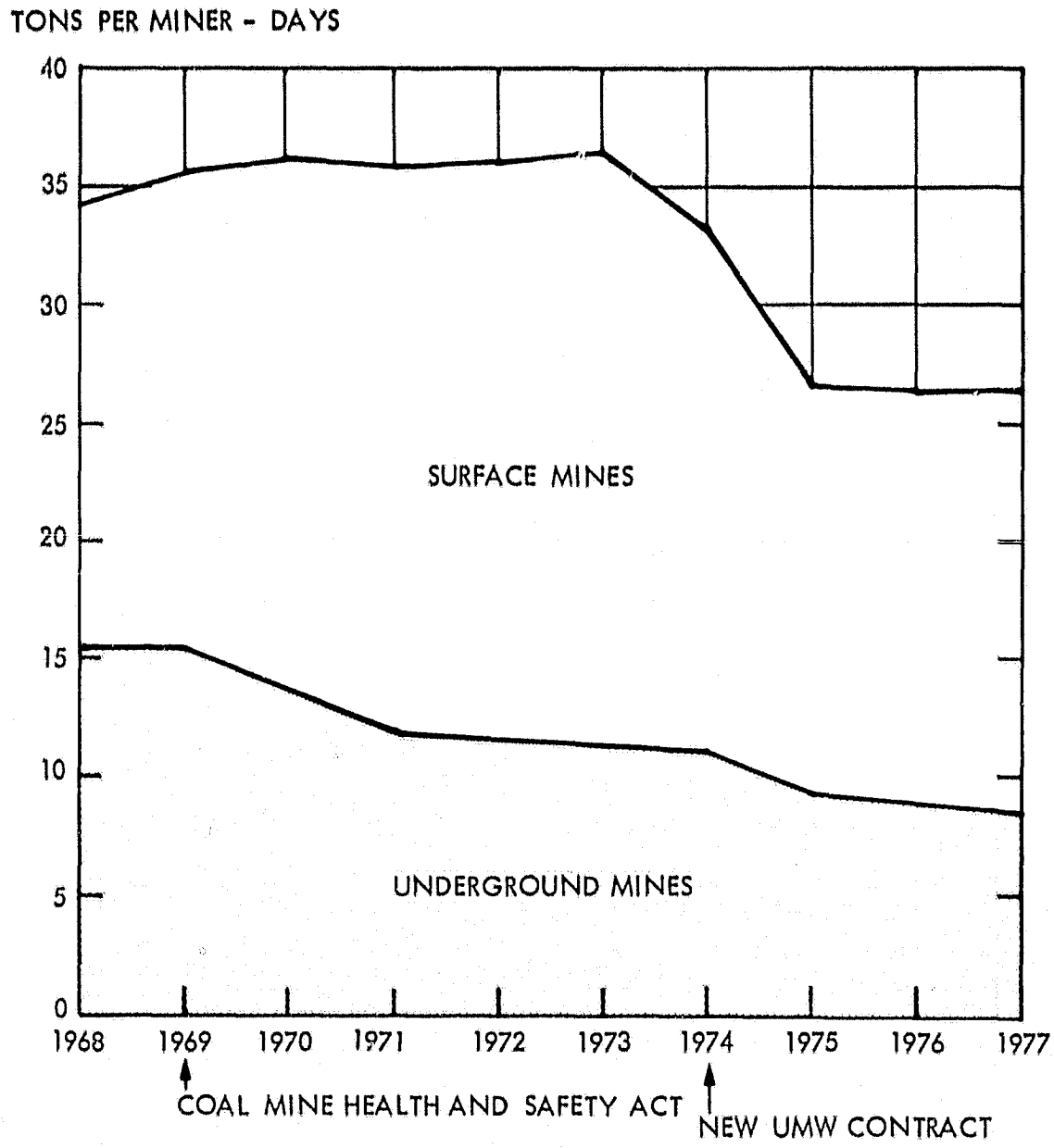
$$\text{MASP} = \frac{M_1}{1+\alpha} + M_2$$

If there is no productivity improvement in 1985 (2000), then the first term will be 5 percent (20 percent) larger in 1985 (2000). Hence, the quantitative effect of the productivity assumption depends upon the relative size of M_1 and M_2. M_1 is is estimated to be approximately three times as large as M_2.[12] The precise relationship of M_1 to M_2 will vary depending upon characteristics such as mine size, seam thickness, and mine type. This procedure may be utilized to calculate the correct M_1 to M_2 ratio for any combination of mine characteristics.

Utilizing the estimation of a 3 to 1 ratio for M_1 to M_2, the estimated impact on MASP of the productivity assumption can be derived. Without the assumption of a 5 percent productivity increase in 1985 and a 20 percent increase in 2000, the affected MASPs would be 3.8 percent higher in 1985 and 15 percent higher in 2000. Thus the prediction of underground (versus surface) production may be biased upward by unduly reducing the relative price of underground coal. To the extent further work indicates a necessity to be more specific, the model may be rerun, incorporating a modification to this productivity assumption.

E. MINE COST ADJUSTMENTS

The final output of the mine cost models is a single MASP for each coal reserve block. However, it is clear that the actual cost of mining any given reserve block can vary significantly and thus it was determined that an additional adjustment was warranted. The causes of these variations include:



SOURCE: USBM MINERALS YEARBOOK

Figure 3-3. U.S. National Average Productivity

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Table 3-1. Underground Mine Productivity and Mine Size

Area	Approx. Average Mine Size 1979, tons per year	Change in Productivity, percent (1977-79)
Ohio	540,000	19
Alabama	350,000	16
Pennsylvania	310,000	28
W. Virginia	110,000	14
Virginia	65,000	25
Tennessee	60,000	20
E. Kentucky	50,000	30

Source: EEA data

(1) Sunk costs in established mines such that recovery of only variable costs is acceptable.

(2) Reopened mines and concomitant reductions in required initial investments.

(3) Variability in management and labor efficiency.

(4) The possible use of used equipment and the accompanying reduction in capital costs. Since this tends to be true mainly in Regions 1-5, adjustments were limited to mines in these supply areas.

The adjustments for surface and underground mines, respectively, were:

(1) For contour mines, base cost was figured and taken as a lower bound. "Medium" and "high" production cost mines were created by adding 10 and 20 percent, respectively, to base costs.

(2) For underground mines, base cost was taken as an upper bound. "Medium" and "low" cost mines were created by subtracting 10 and 20 percent, respectively, from base costs.

Following these adjustments, one-third of each reserve block/mine type was assigned to each of the high, medium, and low cost mine categories. These assumptions may have the tendency to introduce a further source

of variability into the calculations. The study's continuing efforts to test the sensitivity of the target price and market guidance to questionable assumptions thus will include this feature as well.

F. THE COAL SUPPLY CURVES

The surface and underground mine cost models, and the various adjustments to their raw estimates just discussed, thus generate a sequence of MASPs for each region and coal type. Specifically, they generate a MASP for each underground mine-type/reserve block within each category summarized in Table 2-5 (pages 2-13 to 2-14). The total supply curve for each region/coal type has not been presented, but the actual graphical form of the mine cost output has instead been limited to the set of relevant production levels of underground mines.

SECTION IV

DERIVATION OF PRICE TARGETS

Thus far an estimation and characterization of the reserve base has been presented in terms of its major geologic parameters, and the structure of the various mine cost models which were used to estimate the region-specific mine-mouth supply prices has been described. Section IV provides the remaining components of the forecasting model which generate the predicted market prices and production levels of coal in the target years of 1985 and 2000. These in turn form the basis for the derivation of the price targets for Advanced Coal Extraction Systems (ACES) development.

The reason for the focus on price targets for ACES is as follows. Any effort to determine market prices requires knowledge of supply and demand. It would be ideal if the market price for an ACES project could be determined. But since ACES technology is undefined, the supply side of the model is entirely missing. Thus the focus of this report is on the demand for ACES. In particular, it would be useful to determine the amount that coal producers would be willing to pay to obtain ACES.

In the subsequent text, the total and regional demand for coal in the target years is first estimated and its variability evaluated. Next, the estimation process and results of the transportation cost forecasts between the supply and demand regions are delineated. The optimization model that actually yields the forecasts of market prices in the target years is then described and its results presented. Finally, the most appropriate use of the forecast price and production data is investigated to derive an initial set of price targets.

A. THE DEMAND ESTIMATION METHODOLOGY

This section describes and evaluates the methodology used by EEA to estimate the regional demand for coal necessary to determine the 1985 and 2000 forecasts of market coal prices and production levels. Specifically, EEA's plan of attack was to:

(1) Divide the county into 15 demand regions.

(2) Estimate the associated regional demands for coal in the target years by major demand sector.

(3) Calculate the total demand for sulfur category coal which must be supplied (from the previously identified supply regions).

The demand regions used by EEA are set forth in Table 4-1 (along with the numerically corresponding supply regions for comparison). These are of particular importance because of the associated accuracy

Table 4-1. Component States of Regions

Region	Demand	Supply
1	New England, New York	Ohio
2	New Jersey, Delaware, Maryland	West Virginia (North), Pennsylvania, Maryland
3	Pennsylvania	West Virginia (South), E. Kentucky, Virginia, Tennessee (North)
4	Ohio	Tennessee (South), Alabama
5	Virginia, North Carolina	W. Kentucky, Indiana, Illinois
6	South Carolina, Georgia, Florida	Kansas, Missouri, Nebraska, Iowa
7	Alabama, Mississippi	Oklahoma, Iowa (Bit.)
8	Texas, Louisiana	Texas, Louisiana
9	Tennessee, Kentucky	North Dakota, Montana
10	Kansas, Nebraska, Iowa, Minnesota, Missouri	Montana*
11	Oklahoma, Arkansas	Wyoming*
12	Wisconsin, Indiana	S. Wyoming
13	Montana, Wyoming, North Dakota, South Dakota	Colorado (N.W.), Utah (North)
14	Arizona, Colorado, Utah, New Mexico	Colorado (South), Utah (South)
15	California, Oregon, Washington, Idaho, Nevada	Arizona, New Mexico

*Powder River Basin portion only.

of the transportation costs which must be considered in the estimation of market (as opposed to mine-mouth) prices in the target years.

Contiguous states were aggregated into demand regions by considering the states' location relative to coal supply regions. There are two general situations: Either a collection of states is likely to be supplied by only one supply region or the states are located between two or more competing supply regions. In the former case, since transportation costs from the supply region to each of the states within the area will be roughly the same, those states can be grouped together without risking any reduction in model accuracy. In the latter case however, more care must be given to grouping of the states. When there are "competing" supply regions, transportation costs (see subsequent text) become a critical factor.

Next, EEA estimated the regional demands from the major demand sectors: utilities, industrial boilers, metallurgical, synthetic fuels, and export. The EEA model utilizes a given demand scenario, and emphasizes the two coal markets, electric utility and industrial coal, which accounted for 83 percent of coal demand in 1978. The electric utility projection relies on two assumptions:

(1) For the short term (1985), utility coal demand is accurately estimated by relying primarily on the utilities' own projections of coal requirements.

(2) For the year 2000, all electricity not generated by nuclear power will be coal generated.

EEA's Industrial Fuel Choice Analysis Model (IFCAM) was used to develop the industrial demand projection. IFCAM forecasts are based on assumptions of industrial growth rates, tax structure, energy and environmental regulations, and relative fuel prices.

Because there is uncertainty concerning the elasticity of supply and demand, some sensitivity analysis is imperative. The fact that the EEA model utilizes exogenously determined demands for coal makes it easier to do sensitivity analyses of scenarios which are likely to shift the demand for coal.

An attempt can be made to place the EEA estimates in perspective by comparing them, where possible, with those made by other groups and studies. This is done in Tables 4-2 and 4-3. Perhaps the most striking feature of these tables is the narrow band into which the estimates fall. It may be of comfort to realize that the EEA forecast lies near the middle of the range of forecasts. But it must also be recognized that these forecasts all fail or succeed together; no one forecast lies so far away from the others as to have different predictive content. The reason for the narrow band could either be attributed to the powerful forecasting techniques available to the modern analyst or to the risk averse nature of the forecaster.

Table 4-2. Predicted Coal Production, million metric tons

Group	1985	2000
EEA	1092	2145
DRI	1081	1910
NCM	1027-1034	--
Bechtel	1127	--

Table 4-3. Predicted Sectoral Coal Demand Growth, quads

	1985		2000		Annual Growth	
Sector	EEA	DRI	EEA	DRI	EEA	DRI
Electric	17.3	15.7	29.6	26.3	3.4	
Industrial	2.7		9.5		8.7	
		5.8		9.2		
Metallurgical	2.2		2.6		1.1	
Exports	1.3	1.7	1.8	2.3	2.2	
Syn Fuels	-	-	2.5	3.2	-	
TOTAL	24.0	23.6	46.0	41.3	4.4	

The use of exogenously given utility demand for coal requires some careful analysis. Such an assumption in the derivation of equilibrium may be warranted under any of the following three conditions:

(1) The price implicitly assumed in the demand scenario happens to equal the equilibrium price.

(2) Demand is perfectly inelastic.

(3) Supply is perfectly elastic.

While the first condition is outside the bounds of reasonable probability, a case could be made for the last two. If coal is significantly less expensive than other alternative fuels, demand could show strong inelasticity over a range. Because of the tremendous supply of coal reserve, it might be argued that the supply curve could exhibit high elasticity.

The JPL study proposes that, for the purposes of determining an advanced system's cost guidance and target markets, an effective strategy would be to make some relatively simple assumptions of percentage shifts and totals in regional production. Specifically:

(1) When the search for the target region(s) and mine type(s) has narrowed to a small number of candidates, then look at the sensitivity of the choice of each to posited changes in demand (production) from that region and mine type.

(2) Rerun the EEA model with a revised sequence of sectional and regional demand growth rates and check to see if there is a change in the optimal choices.

A more complex and potentially critical portion of the EEA demand projection methodology occurs where demand is disaggregated to the regional level. Any error in the allocation of the overall demand for coal has the potential to tremendously bias the picture in which supply regions and mine types should be the "target market" for the new technology. Unfortunately, it is a relatively complex task to do this type of sensitivity analysis.

B. TRANSPORTATION COST ESTIMATION

The product of the transport cost estimation step of the EEA forecast process is a matrix of minimum estimated cost-per-ton transportation costs between the supply and demand regions. EEA used 1979 rate structures for the set of competing modes of transportation; rail, barge, slurry pipeline, and appropriate combinations thereof, and calculated the actual costs from sample shipping points to sample receiving points. This approach avoided many of the pitfalls inherent in use of the older, alternative "centroid" approach.

More specifically, the major components of the EEA rate estimation methodology were:

(1) Baseline rate determination:

(a) For existing rail and barge movements, actual July 1979 rates were used.

(b) For currently non-existent rail and barge movements, rates were estimated from comparable existing movements.

(c) Slurry pipeline rates estimated from 1979 projections.

(2) Rates were calculated or reduced in real terms to reflect constant dollars.

(3) Where multiple transportation options were available, the least expensive link was selected.

Finally, the specific major assumptions made in estimating the 1985 and 2000 transportation rates are:

(1) In the western United States the rates are not expected to increase over the next 20 years, as the recently established western rates account for future conditions, including:

(a) Relatively new equipment and track and anticipated additional investment.

(b) Large volumes of coal needed to be shipped per year.

(c) Distances to eastern markets.

(d) Competitive position with eastern coal.

(2) In the eastern United States the rates are projected to increase 18 percent in real terms by 1985 and then remain constant through 2000. This assumption reflects:

(a) Major investments in eastern railroads will need to be made in new equipment and renovation.

(b) Contacts with ICC and recent ICC decisions.

(c) DOE projections.

(3) Barge rates are assumed to increase 18 percent in real terms by 1985, reflecting the federal fuel tax and an effort to take advantage of eastern rail rate increases, and then to remain constant through 2000.

(4) Slurry pipelines will not be operational until 1985. Pipeline rates will decline in real terms relative to rail and barge rates between 1985 and 2000 because their large fixed cost limits inflationary impacts.

Study concern with EEA's assumptions and their impact on transportation rates is derived from the latter's reliance on the regional coal supply estimates to fill the exogenously given demands. To visualize the potential for changes in the predicted regional production levels one must consider the way in which Table 4-4 shows that the decreasing per mile cost of some modes of transportation can make significant interregional competition possible.

Although the results of the EEA estimates of transportation costs are perhaps more realistic than any other such input data used in coal supply forecasts, there remains natural uncertainty over their validity for the year 2000. Relatively small changes in rate schedules and, more importantly, rail links between the vast western coal fields and major growth markets (demand regions) might significantly alter the regional cost and production forecasts based upon them. The JPL study is aware of this and plans to both monitor the possibility of such events, as well as to assess the potential impact on the study's price targets.

C. GENERATION OF MARKET PRICES AND PRODUCTION

The optimization model used by EEA is one which minimizes the cost of satisfying the given estimated regional demands by allocating them among the supply regions, and therefore among the mine-type reserve blocks within each supply region, such that the combined costs of producing and transporting the coal is minimized. The summarized results of this production forecast, segregated by region, sulfur category and surface or underground mine are displayed in Table 4-5. The companion predictions of the 1985 and 2000 market mine-mouth prices (MASP, in 1979 dollars) are displayed in Table 4-6.

For both 1985 and 2000 the model forecasts similar patterns: production growth in compliance and low sulfur coal regions. This illustrates the central importance of federal environmental regulations and the dry-scrubbing technology. The heavy demand for compliance coal comes from utility plants operating under the original New Source Performance Standards (NSPS). The low sulfur demand largely represents utilities under NSPS II minimizing their pollution control costs by dry scrubbing low sulfur coal; in fact, this combination is so cost-effective that the model projects very little wet scrubbing of high sulfur coal. Another regulatory factor is the Fuel Use Act which attaches a cost penalty to the use of oil or gas in new industrial boilers and thus further encourages demand for low sulfur and compliance coal.

The major supply regions that stand to gain from these demand factors are the areas with low sulfur reserves: the West generally,

Table 4-4. Comparison of All-Rail Estimated 1985 Unit-Train Rates

	$/Ton	Mileage One-Way	Ton/Mile
To Mobile, Ala. from:			
Union, Pa.	19.47	1,076	.018
Kansas City, Mo.	20.08	1,110	.018
Starlake, N. Mex.	21.73	1,630	.013
To Houston, Tex. from:			
Kansas City, Mo.	17.44	964	.018
Rock Springs, Wyo.	16.51	1,497	.011
To Chicago, Ill. from:			
Uniontown, Pa.	14.41	555	.026
Kansas City, Mo.	11.71	451	.026
Gillette, Wyo.	14.20	1,137	.012
Rock Springs, Wyo.	16.35	1,303	.013
Grand Junction, Colo.	16.35	1,309	.013
To Tulsa, Okla. from:			
Gillette, Wyo.	13.01	1,149	.011
Rock Springs, Wyo.	13.14	1,161	.011
To Des Moines, Iowa from:			
Rock Springs, Wyo.	10.83	957	.011
Grand Junction, Colo.	10.98	970	.011

Table 4-5. Coal Production Forecast by Region, millions of tons per year

Region	Year	Mine Type			Coal Sulfur Category		
		Deep	Surface	Total	Compl.	Low	High
1. (Ohio)	1976	17	30	47	-*	-	-
	1985	15	26	41	0	6	35
	2000	31	21	52	-	12	39
2. (N. Appalachia)	1976	88	55	143	-	-	-
	1985	58	27	85	-	36	49
	2000	141	20	162	-	105	57
3. (C. Appalachia)	1976	113	77	190	-	-	-
	1985	128	119	247	128	93	26
	2000	256	144	400	174	180	46
4. (S. Appalachia)	1976	10	16	26	-	-	-
	1985	20	43	64	11	38	15
	2000	42	53	95	13	60	22
5. (Illinois Basin)	1976	55	81	136	-	-	-
	1985	4	103	107	-	20	87
	2000	59	108	167	-	79	88
6. (Central Midwest)	1976	0	18	18	-	-	-
	1985	0	91	91	-	-	91
	2000	0	113	113	-	-	113
7. (Oklahoma)	1976	0	4	4	-	-	-
	1985	0	27	27	0	18	9
	2000	0	29	29	-	18	11

*A dash signifies no production of this type.

Table 4-5. (Cont'd)

Region	Year	Mine Type: Deep	Mine Type: Surface	Mine Type: Total	Coal Sulfur Category: Compl.	Coal Sulfur Category: Low	Coal Sulfur Category: High
8. (Texas Lignite)	1976	0	14	14	-	0	0
	1985	0	62	62	-	-	62
	2000	0	229	229	-	-	229
9. (Mont./N. Dak. Lignite)	1976	0	21	21	-	-	-
	1985	0	47	47	-	33	15
	2000	0	103	103	-	62	41
10. (Powder River Basin--Montana)	1976	0	19	19	-	-	-
	1985	0	50	50	50	-	-
	2000	0	180	180	100	80	-
11. (Powder River Basin--Wyoming)	1985	0	138	138	120	18	0
	2000	0	178	178	169	9	0
12. (S. Wyoming)	1976	1	12	13	-	-	-
	1985	0	0	0	0	0	0
	2000	0	0	0	0	0	0
13. (Uinta)	1976	10	14	24	-	-	-
	1985	63	2	66	55	11	-
	2000	215	29	244	110	134	-
14. (4 Corners)	1976	0	5	5	-	-	-
	1985	0	35	35	34	1	-
	2000	0	94	94	66	28	-
15. (San Juan)	1976	1	5	6	-	-	-
	1985	0	35	35	34	1	-
	2000	0	94	94	66	28	-
TOTAL USA	1976	295	385	680	-	-	-
	1985	288	804	1,092	405	301	389
	2000	744	1,335	2,079	639	794	646

Note: Totals may be affected by rounding.

Table 4-6. Market Mine-Mouth Prices Forecast by Year, Region and Coal Type, 1979 dollars

	1985			2000		
Region	Compliance	Low	High	Compliance	Low	High
1.	--*	28.95	23.20	--	32.93	22.90
2.	--	31.10	27.22	--	34.67	27.05
3.	29.59	27.81	27.81	32.24	32.24	31.29
4.	34.75	28.46	28.46	39.52	32.10	31.24
5.	--	24.68	21.08	--	25.92	21.60
6.	--	--	16.21	--	--	16.61
7.	--	18.90	18.56	--	19.47	19.47
8.	--	--	11.07	--	--	11.98
9.	--	5.41	5.41	--	5.62	5.62
10.	8.38	--	--	8.81	8.81	--
11.	7.39	7.36	--	7.73	7.70	--
12.	--	--	--	--	--	--
13.	24.23	24.15	--	25.85	25.85	--
14.	12.10	11.84	--	12.54	12.30	--
15.	15.14	15.14	--	16.22	15.74	--

*A dash signifies no production of this coal type.

and southern and central Appalachia. Overall, total production is forecast to rise from 680 million tons in 1976 to 1.092 billion tons in 1985 and 2.079 billion tons in 2000. In all three cases most production is accounted for by surface mining, with surface mining accounting for 65 percent of the total in 2000. However, the model does show a resurgence of underground mining (primarily drift) in Appalachia (Regions 2-4).

Note that the prices forecast to prevail in 1985 and 2000 do not significantly increase in real terms (i.e., in 1979 dollars). This is largely attributable to the large size of the reserve base and the model's embodiment of the "general industry competitiveness" and "increasing miner productivity" assumptions discussed in Section III.

The results of the optimization model are actually available in a much more disaggregated form. Specifically, when demand from one region is "filled" by, or allocated to, a specific supply region on the basis of least delivered cost, a specific reserve block/mine type is chosen. Each of these "actively producing" mine types is identifiable in the data, along with the order in which they became active within the region. Since these mine types are identified with the geologic characteristics discussed in Sections II and III, they lend themselves to more intensive scrutiny and analysis than the aggregated results presented in Tables 4-5 and 4-6. Advantage is taken of this aspect of the data base to parallel the development summarized in Tables 4-5 and 4-6 in the following text.

D. PRICE TARGET DERIVATION: THE DATA

Utilizing the EEA-derived estimates for the year 2000 by region and coal type, the supply cost and production data (actual and potential) were identified and partitioned according to the eight previously defined mine-types. Table 4-7 summarizes the division of the estimated underground production for the year 2000 into the output of the eight mine types of region. A plurality of underground production is seen from "yyy" type mines, i.e., from those with relatively thick seams, larger block sizes, and deeper over-burden. Further, it is noted that two-thirds of this production (and 30 percent of total underground) is from Region 13 (the Uinta Basin). On the other hand, about 60 percent of total underground production is expected to come from the three regions (2,3,4) which together comprise Appalachia.

However, knowledge of the probable levels of production at the time of potential new technology adoption is not sufficient. For example, it may be that the new technology will be more attractive to mine owners who are considering opening <u>new</u> mines. Therefore the reserves remaining to be mined in 2000 are of special interest. Table 4-8 presents a reaggregation of the EEA allocations of these remaining reserves among the aggregated mine types and region by coal type. These data indicate the possibility of an entirely different post-2000 regional production picture in that Appalachia now has only about

Table 4-7. Estimated Underground Production for Target Year 2000 by Region and Mine Type, million metric tons

Mine/ Region	lll	lyl	lly	lyy	yll	yyl	yly	yyy	Total
1.	1.1	0.2	0	0	22.9	0.8	0.6	4.7	30.3
2.	5.0	24.6	0	14.7	51.1	11.2	0.3	29.3	136.2
3.	36.7	78.6	0.3	69.8	41.1	36.8	1.0	0.2	264.5
4.	2.3	7.2	0.3	2.3	2.4	5.4	0.6	17.8	38.3
5.	0	0	0	0	1.9	18.8	0.2	37.6	58.5
6.	0	0	0	0	0	0	0	0	--
7.	0	0	0	0	0	0	0	0	--
8.	0	0	0	0	0	0	0	0	--
9.	0	0	0	0	0	0	0	0	--
10.	0	0	0	0	0	0	0	0	--
11.	0	0	0	0	0	0	0	0	--
12.	0	0	0	0	0	0	0	0	--
13.	0	0	0	0	0	0	0	214	214
14.	0	0	0	0	0	0	0	0	--
15.	0	0	0	0	0	0	0	0	--
TOTALS	45.1	110.6	0.6	86.8	119.4	73.0	2.7	303.6	741.8
%	(6)	(15)	-	(12)	(16)	(10)	-	(41)	--

Table 4-8. Remaining Reserves for Target Year 2000 by Region, Coal and Mine Type, million metric tons

Region	lll	lyl	lly	lyy	yll	yyl	yly	yyy	Total
1 (H)	22.9	40.3	0.0	127.8	10.7	45.7	0.0	179.7	427.1
1 (L)	0.2	0.2	0.3	0.0	0.0	0.0	0.0	0.4	1.1
1	23.1	40.5	0.3	127.8	10.7	45.7	0.0	180.1	428.2
2 (H)	66.9	267.0	0.9	465.0	21.8	153.0	0.0	665.9	1640.5
2 (L)	2.5	0.0	0.0	62.7	0.0	5.6	0.0	44.5	115.3
2	69.4	267.0	0.9	527.7	21.8	158.6	0.0	710.4	1755.8
3 (H)	0.0	0.0	0.0	42.9	0.0	9.6	0.0	81.7	134.2
3 (L)	0.0	0.0	0.0	153.6	0.0	34.6	0.0	291.9	480.1
3 (C)	0.0	0.0	0.0	161.8	0.0	36.0	0.0	305.7	503.5
3	0.0	0.0	0.0	358.3	0.0	80.2	0.0	679.3	1117.8
4 (H)	0.3	0.6	0.0	4.2	0.0	0.0	0.0	0.2	5.3
4 (L)	0.8	0.0	0.0	9.9	0.0	0.0	0.0	0.0	10.7
4 (C)	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	1.8
4	1.1	0.6	0.0	15.9	0.0	0.0	0.0	0.2	17.8
5 (H)	3.0	156.3	26.6	221.7	4.2	567.9	25.2	2129.6	3134.5
5 (L)	0.7	6.6	1.2	30.0	0.5	10.5	0.9	73.6	124.0
5	3.7	162.9	27.8	251.7	4.7	578.4	26.1	2203.2	3258.5
6 (H)	0.0	73.9	0.0	654.7	0.0	21.6	0.0	180.3	930.5
6	0.0	73.9	0.0	654.7	0.0	21.6	0.0	180.3	930.5
7 (H)	1.5	2.2	4.1	11.3	2.2	0.0	0.7	7.2	29.2
7 (L)	1.7	3.4	5.4	18.8	4.3	0.0	1.2	11.5	46.3
7	3.2	5.6	9.5	30.1	6.5	0.0	1.9	18.7	75.5
8	--	--	--	--	--	--	--	--	--

Table 4-8. (Cont'd)

Region	lll	lyl	lly	lyy	yll	yyl	yly	yyy	Total
9	--	--	--	--	--	--	--	--	--
10 (L)	75.5	222.0	146.5	0.0	0.0	1106.8	0.0	2148.5	3699.3
10 (C)	32.3	32.3	62.8	62.8	0.0	202.7	0.0	750.7	1290.1
10	107.8	254.3	209.3	62.8	0.0	1309.5	0.0	2899.2	4989.4
11 (L)	0.0	140.9	0.0	230.0	0.0	696.3	0.0	1136.0	2203.2
11 (C)	0.0	60.4	0.0	98.6	0.0	298.3	0.0	496.9	944.2
11	0.0	201.3	0.0	328.6	0.0	994.6	0.0	1622.9	3147.4
12 (L)	0.0	10.8	0.9	23.5	0.0	69.0	0.8	102.9	207.9
12 (C)	0.0	7.2	0.4	15.6	0.0	46.0	7.9	67.8	144.9
12	0.0	18.0	1.3	39.1	0.0	115.0	8.7	170.7	352.8
13 (L)	0.0	29.7	0.0	381.5	0.0	89.1	0.0	993.9	1494.2
13 (C)	0.0	19.8	0.0	254.3	0.0	59.4	0.0	664.7	998.2
13	0.0	49.5	0.0	635.8	0.0	148.5	0.0	1658.6	2492.4
14 (L)	17.3	16.0	44.1	151.0	39.9	92.9	54.1	634.7	1050.0
14 (C)	4.1	4.0	10.8	38.1	10.8	22.5	13.1	181.4	284.8
14	21.4	20.0	54.9	189.1	50.7	115.4	67.2	816.1	1334.8
15 (L)	0.0	48.3	0.0	927.3	0.0	146.3	0.0	2781.8	3903.7
15 (C)	0.0	32.5	0.0	618.1	0.0	97.6	0.0	1854.2	2602.4
15	0.0	80.8	0.0	1545.4	0.0	243.9	0.0	4636.0	6505.1
TOTALS									
High	94.6	540.3	31.6	1527.6	38.9	697.8	25.9	3244.6	6201.3
Low	98.7	477.9	198.4	1988.3	44.7	2251.1	21.0	8219.7	13299.8
Comp.	36.4	156.2	74.0	1251.1	10.8	762.5	57.0	4311.4	6659.4
Total	229.7	1174.4	304.0	4767.0	94.4	3811.4	103.9	15775.7	26260.3
% Total	1	4	2	18	--	14	--	60	100

10 percent of the "mine-assigned" remaining reserves (on a yearly rate of production basis) and the Uinta Basin only about 9 percent, while Region 15, San Juan, has about 25 percent. It should be noticed, however, that the reserve production from the "yyy"-type mines still dominates, now accounting for about 60 percent of actually recoverable reserves, on a yearly production rate basis.

Of course, neither of these pictures "captures" the environment sufficiently for a unilateral decision with respect to the "best" market areas and geologic conditions for the new underground extraction technology. Specifically, for a technology to be commercially attractive requires that:

(1) The hardware developed must be competitive in terms of net revenue generated (over costs and including ROI) with that likely to exist in the absence of the new system.

(2) The hardware itself must be developed with attention to the specific probable market that must in turn be carefully chosen in order to have a significant, if not maximum, impact on the industry-wide price of coal and the accompanying changes in the health, safety, environmental, and conservation parameters, the incorporation of which have contributed to the uniqueness of this project.

Thus, it will not do to merely build a "better continuous miner" with limited applicability, even though it does, in fact, increase productivity, say by 50 percent, and therefore lowers production costs. An example will be useful to indicate the care that must be exercised in the use of the data contained in the regional supply curves and in Tables 4-7 and 4-8. As is evident from these data, the supply regions showing the greatest growth in production levels are those with large reserves of compliance and low sulfur coal. These include central and southern Appalachia, the Powder River Basin, Uinta, and San Juan reserves. This is largely a result of the toughened air pollution standards. Since these standards are not likely to be eased, greater total production in the future will tend to mean even greater increases in the need for compliance coal.

Table 4-6 shows that the central and southern Appalachia MASPs for compliance coal are significantly higher than those of the other regions producing compliance coal. Since it may seem easier to reduce higher costs than lower ones, it might be tempting to key on the compliance production of Regions 3 and 4 as "target markets." However, a look at the Region 4 data in Table 4-8 shows that all but 1.8 million tons per year of compliance reserves are forecast to be in production by 2000. This is of course a relatively small "market segment." Thus to simply focus on the MASP will not be a proper decision criterion. But, it is shown that for Region 3 there are approximately 500 million tons of compliance coal per year not forecast to be in production by 2000. Here the problem is that only 18 million tons of this reserve presently has an estimated MASP of less than $40.00, with 467.5 million tons of yearly production

"priced" at $48.60 per ton or more. The high MASP should by itself induce an attempt to develop a technology to exploit the reserve. The key is to weigh the cost of the technology against the value of being able to bring the resource into production. The fact that there is a large volume of revenue is attractive, but a need exists to be sure that the costs of exploiting the resource can be brought to a competitive level.

Another caveat is that it is easy to let the data point to the development of a technology that has a significant potential market size and has the potential to reduce the cost considerably but with cost-effectiveness not being reached, for instance, until the year 2050. Developing such a technology, while desirable, does not satisfy the goal of this project. That is, such a huge reserve base exists that the likely timing of its entry into production is crucial to this project. This is a complex problem, but must and can be addressed in the generation of the cost guidance for the development of advanced extraction systems.

Finally, a return to the example of Region 3 versus Region 13 as choices for "target markets" indicates that the choice of a target mine-type is not independent (in general) from the choice of the target region. In Region 3 in the year 2000, the remaining cheapest-to-mine (i.e., lowest MASP) compliance mine was a "yyl" type that could produce 18.1 million tons per year at $35.21 per ton. In Region 13, the compliance mine-type which was most attractive was a "yyy" type which could produce 204.1 million tons at $28.75 per ton. The major difference between these two mine-types is that the "yyy" mine has a deeper overburden than the "yyl" mine. Thus it may or may not be feasible and cost effective to design a technology which could be used in either type mine. In addition, the assignment of such mine type codes is a necessary oversimplification even within a single region. However, between regions even two mines identical in the five digit (a_2, a_3, a_4, a_5, a_6) vector (see Section II) are not necessarily "identical" for the purposes of technology development. This is due to regional differences in such characteristics as roof and floor quality, capability, seam regularity, etc. Thus, although some judgments about mine types may be valid across regions, in general there is a sufficient number of confounding factors to require that the "target supply region" and "target mine type" be jointly considered.

Next, it is noted that the actual and potential penetration of the longwall (LW) mining technology in the U.S. market is of direct interest to the present project for at least two reasons:

(1) It is a technology that competes, at least potentially, with others still being developed and thus its market penetration could significantly alter the target market and cost guidance developed for an advanced system.

(2) It is an "innovation" in terms of mining technology and as such may yield important and instructive guidance with respect to "acceptability" on the part of the coal industry.

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A LW system has characteristics that may yield significant advantages over Room and Pillar (RP) mines. Specifically, it has been asserted that:

(1) LW mines are safer.

(2) LW mines require less labor.

(3) LW mining is more productive (30-40 tons per day per person versus 10-20 for RP).

However, although it has been predicted that LW would account for 25 percent of underground production by the 1980's, in 1976 it held only a 4 percent market share, and a recent study (Kuti, Nov. 1979, Reference 6) reduces the estimated LW 1985 market share to only 12 percent. The major reasons conjectured for this reduction are mine owner/operator resistance to the significant operational and organizational changes associated with LW, and the barriers posed by regulatory requirements (e.g., multiple entries) which reduce its expected profitability.

These facts and predictions are noted here because any new system may have to face some of the same exogenous (with respect to the efficiency of the technology) considerations. Thus, should a new system turn out to be a significant change from status quo procedures and cost shares, it may replace LW as the "most resisted" innovation. This would tend to cause the industry to embrace LW, by then a more familiar (and acceptable) technology, and to shun the new technology, in spite of its cost effectiveness. Although this statement is limited to a hypothetical one at this point, it clearly is a consideration which will be kept in mind by the project staff.

More concretely, Table 4-9 indicates that the EEA model forecasts that LW technology will prevail for the year 2000 (Region 13). In this basin, a total of 215 million tons of coal is expected to be produced at a maximum MASP of $25.85 (see Table 4-7). This represents almost 29 percent of the total U.S. underground production of 741 million tons and 10 percent of the total production of 2,079 million tons. The 63 million tons of predicted production from the same mines in 1985 likewise represents about 22 percent of underground, and about 6 percent of total production. Furthermore, the 5,091.3 million tons of underground reserve capacity per year assigned to LW in the other 31 reserve blocks comprise over 43 percent of the remaining reserves in Regions 12-15, and about 19 percent of the total U.S. remaining (assigned) reserves.

Thus, the possibility of greater than forecast LW penetration must be investigated, especially when the long run possibility of a more direct transportation link between these supply regions and the major markets significantly increases the competitiveness. There are innumerable ways to do sensitivity analysis on additional LW market penetration (i.e., to reserve blocks not presently assigned to LW). However, these possibilities must remain suggestions for the time

being, since almost all of these methods require either computerizing the EEA result data base and/or rerunning the EEA model with a resulting change in the mine type assignments and cost calculations.

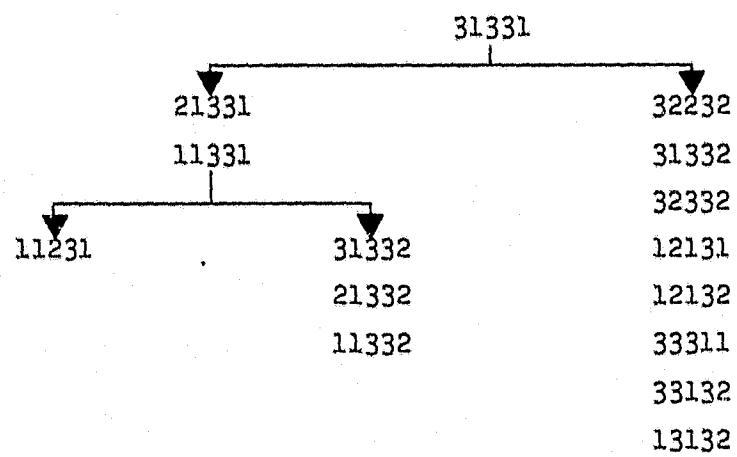
First, an analysis can be made of both the mine code vector listed for each LW assignment, under the column "EEA" in Table 4-9, as well as of the revised aggregate mine codes. A comparison of the results of "matching" candidate subsets of the (a_2 - a_6) LW vector, with reserve blocks presently assigned to RP mines, will generate estimates of regional and coal-type specific LW penetration rates.

For example, Table 4-9 shows that there are 11 thin seam reserve blocks presently assigned to the LW technology category. Thus, if <u>all</u> the reserve blocks (in the 1164 total) are checked with, say, codes of:

$$(1, x, y, y, x)$$

where $x > 0$, $y \geq 3$, a set of reserve blocks will be generated for which LW <u>may</u> be feasible. As can be seen, the possible variations on this theme are many.

In the same spirit, a statistical analysis could be made of whether there are feasible "LW assignment patterns" not obvious a priori, and a determination could be made of which patterns (mine codes) dominate. As an example, using only the data from Table 4-9, the following hierarchical structure in terms of mine code can be derived:



The arrows indicate lower preferred assignable reserve blocks in terms of predicted MASPs. Thus, reserve blocks coded (31331) are likely to be "better" (lower cost) for LW assignment than either of the ones coded (21331) or (32232), which in turn "dominate" a series of (transitive) reserve block types. However, on the basis of Table 4-9 data, there is not sufficient information to similarly choose between the (21331) and (32232) types. This requires more data, if at all possible, or a subjective assignment.

Table 4-9. Estimated Longwall Reserve Block Assignments

Region (Coal Type)	EEA	yvy	lyy	lly	Other	Production (Reserves)	2000 MASP
12. (L)	31332	X				(4.9)	$28.90
	32332	X				(2.5)	28.90
	12132			X		(0.6)	31.84
	33311				yyl	(4.8)	38.66
	33132				yly	(0.8)	44.08
	13132		X			(0.3)	54.05
	6					(13.9)	
12. (C)	32232	X				(1.6)	27.88
	31332	X				(3.3)	28.90
	12132			X		(0.4)	31.84
	33311				yyl	(3.2)	38.66
	33132				yly	(0.5)	44.08
	5					(9.0)	
Totals	11					(2219)	
13. (L)	31331	X				52.5	24.15
	21331	X				46.0	25.8
	11331		X			(49.2)	28.50
	3					98.5/(49.2)	
13.	31331	X				78.8	24.15
	21331	X				37.7	25.85
	11331		X			(32.2)	28.50
	3					116.5/(32.2)	
Totals	6					215.0/(81.4)	

Table 4-9. Estimated Longwall Reserve Block Assignments (Continuation 1)

Region (Coal Type)	EEA	yyy	lyy	lly	Other	Production (Reserves)	2000 MASP
14. (L)	31331	X				(10.1)	24.13
	21331	X				(29)	25.85
	11331		X			(8.1)	28.51
	31332	X				(9.1)	28.91
	21332	X				(200.0)	31.17
	71332		X			(72.8)	34.34
	6					(329.1)	
14. (C)	31331	X				(2.5)	24.13
	21331	X				(7.3)	25.85
	11331		X			(2.0)	28.51
	31332	X				(22.7)	28.91
	21332	X				(50.0)	31.17
	11332		X			(18.2)	34.4
	6					(102.7)	
Totals	12					(431.8)	
15. (L)	31331	X				(1093.3)	31.44
	21331	X				(956.6)	33.67
	11231		X			(683.3)	37.13
	3					(2733.2)	
15. (C)	31331	X				(728.8)	
	21331	X				(637.7)	
	11231		X			(455.5)	
	3					(1822)	
Totals	6					(4555.2)	
Grand Totals	35					215/(5091.3)	

Prior to providing some direct suggestions of ways in which specific cost guidance for advanced underground extraction systems might be structured, a final element of necessary caution should be noted about the use of the data base just described. The EEA model does not explicitly consider the depletion of the identified reserve blocks as a result of the yearly production flow. However, the model assumes (for the most part) a 20-year life span for mines and reserve blocks and, as noted in Section III, the derivation of the MASPs are modeled on this basis. Since the new extraction system may affect the rate of recovery, and since this recovery rate and the total yearly mine life and the resulting depletion may well significantly impact the pattern of the remaining reserves, the construction of the cost guidance and the derivation of the target market must show a sensitivity to alternative "depletion" and "recovery rate" assumptions.

E. STRUCTURING COST GUIDANCE: SUGGESTIONS

To reiterate, the basic questions to be answered prior to attempting to estimate cost guidance for any specific hardware development are:

(1) Which regions are likely to contain the best markets for ACES?

(2) Which mine types within these regions should be selected as targets for the technology?

A complete analysis of the above two issues requires knowledge of both the supply of and demand for ACES hardware. Since this hardware has not yet been developed, it is not feasible to model the supply side. However, some demand information can be derived, namely the amount various potential users would be willing to pay for a new technology. Another example follows, in order to better illustrate the challenge. Assume that:

(1) The EEA estimates of the total and regional demands and supplies and MASPs are exactly correct.

(2) The total feasible market for ACES is defined by the "remaining reserves" identified in Table 4-8 by region, mine and coal type.

(3) The costs of the best competitive extracting system in each case is represented by the sequence of estimated MASPs.

(4) The sequence of pilot tests to be associated with the refinement of ACES hardware in the 1990's will have significantly reduced or removed the need for a "risk premium" to the coal company adopting ACES, given that they are shown cost data indicating that they can reduce their costs with ACES.

Abstracting for the moment from the interregional and coal-type features of the problem, suppose that the year 2000 actual coal production level in a region is as shown in Figure 4-1 and is forecast to be q_o million tons at an average price of P_o dollars, using conventional technologies (at that time). In order to increase regional production above q_o million tons, the price per ton must rise to p_1. At this price, a total annual production increase of $(q_1 - q_o)$ million tons are available at p_1 dollars per ton. Analogous statements hold for the pairs (q_2, p_2) and (q_3, p_3). In Figure 4-1 the line segments AB, CD, EF therefore form a portion of the supply curve for coal from this region.

Now, suppose that the yearly demand for coal post-2000 increased from q_o to q_2, and that the increased production $(q_2 - q_o)$ was to be sold at the uniform price p_2. Then the owners of the newly opened mine(s) producing the first $(q_1 - q_o)$ million tons of increased production would be making a "pure" (i.e., over the normal return on investment) profit of $(p_2 - p_1) \cdot (q_1 - q_o)$, while the owners of the newly opened mine(s) producing $(q_2 - q_1)$ million tons of increased production would just be recovering their actual costs plus a normal return on investment.

Assume that the newly developed advanced extraction system was applicable to <u>only</u> the type of mine (e.g., "yyy") producing the additional $(q_1 = q_o)$ <u>million</u> tons of coal per year, and that this additional production would cost $\$(p_1 - \Delta)$ per ton, again including required return on investment. Then the shaded area of Figure 4-1 represents the total savings to the owners of this reserve block/mine accruing from the adoption of the new technology. The quantity $(q_1 - q_o)$, or $(q_1 - q_o)$ divided by the annual production capacity of a unit of the new hardware, is a measure of the market size for the new technology. The appropriate target price in this instance is thus p_1.

However, consider the following modified scenario. Suppose that the new technology is applicable to <u>neither</u> of the reserve blocks associated with the supply schedule segments AB and CD, but rather used in mine types such as those from which $(q_3 - q_2)$ would be a factor. Although the magnitude $[p_3 - (p_1 - \Delta)]$ is an accurate measure of the <u>unit savings</u> attributable to the introduction of the new technology, it is <u>not</u> a measure of the increased profitability. The index of merit for ACES in a market economy is the difference between the market price and the MASP given that ACES is used, not the difference between MASP before ACES and MASP after ACES.

The point of the example is simple: care must be taken to identify the most appropriate targets for cost and marketability comparisons. In the example given above, if the <u>cost</u> reduction for the mine-type producing segment EF was considered as a measure of the potential marketability one could easily be led astray. The choice of the target region and mine type depends heavily on the next best <u>alternative</u>.

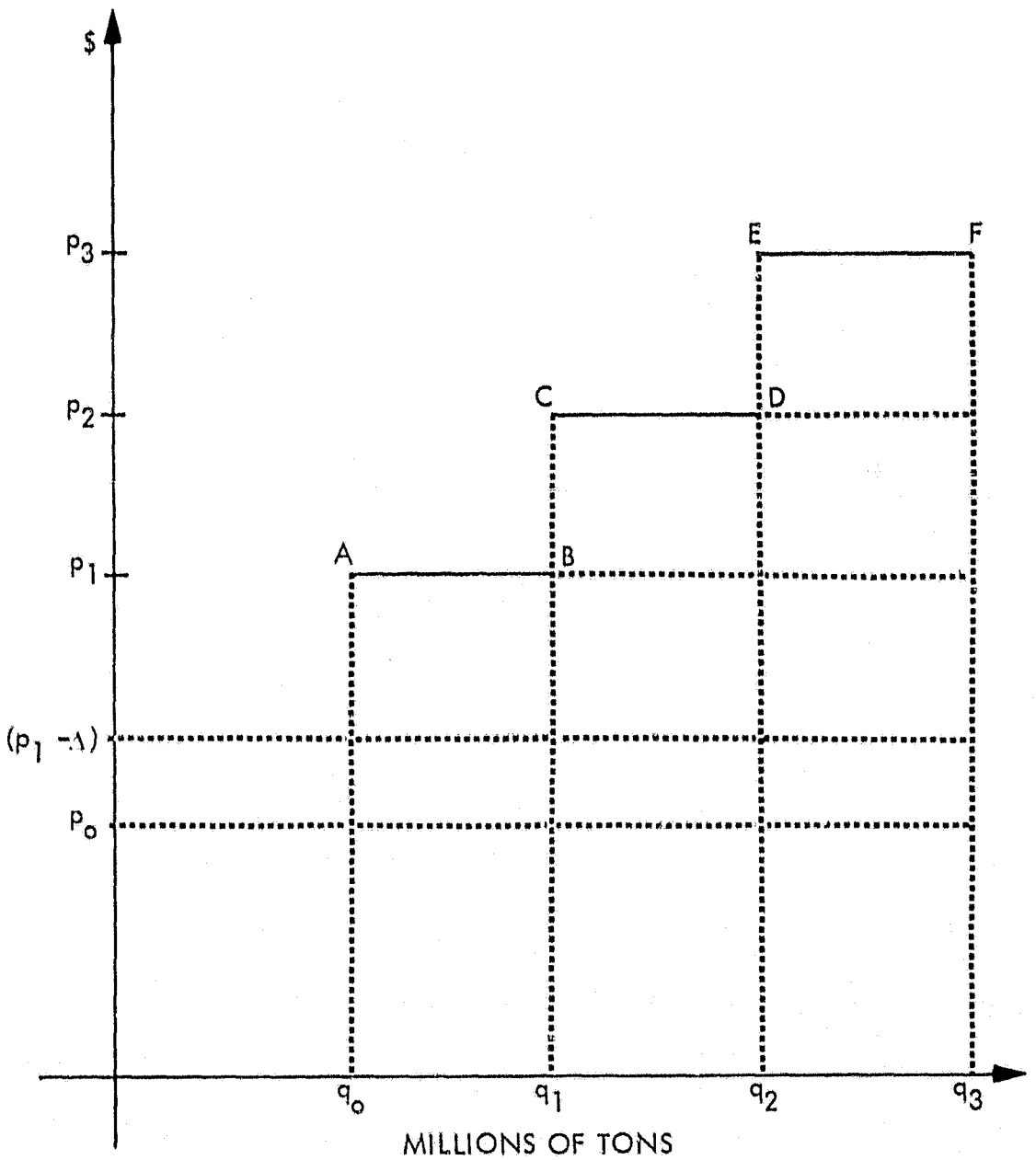


Figure 4-1. Actual Coal Production Level

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SECTION V

QUALIFICATIONS AND RECOMMENDATIONS

Because of the uniqueness of this study and the accompanying need for simplifying assumptions, the study has purposely refrained from identifying the forecasts presented herein as definitive. However, these forecasts may certainly be viewed as providing a foundation for setting target prices and identifying target market locations and sizes, estimates which are required to guide the development of advanced extraction technology. The potential sensitivity of such guidance to the assumptions and methodology embodied in the preceding pages requires a word of caution. Although these cautionary notes are contained in the subsections above, they will be summarized here for ease of reference. They are listed in order of decreasing importance, i.e., in terms of the probability of having an impact on the present target prices and target market characteristics.

(1) The exclusion in the present results of the possibility that specific reserve blocks might be depleted, or at least be nearing depletion by the year 2000, may cause the estimated market MASPs to be too low, and the most attractive new markets for an advanced extraction system to be inaccurately characterized.

(2) The use of only a subset of the geologic parameters to define the mine types that are to provide the basis for the choice among target markets as well as the structure for the regional price targets may be a source of substantial bias.

(3) The assumptions regarding relative productivity of surface (versus underground) mining may well turn out to be consistent with the JPL companion work of constructing a "moving baseline" technology; nonetheless, these assumptions have the capacity to significantly alter relative regional price targets and target market choices.

(4) The defensible, but arguable, assumptions made to define "low," "medium" and "high" cost mines in Appalachia could have had an inappropriate impact on Appalachian versus other region's estimated MASPs and production levels, and on forecast surface versus underground production as well.

(5) Although the estimated transportation costs used in the forecast of "delivered" coal prices to the demand regions were developed in such a way as to be the most up-to-date and accurate, the possibility of future new transportation links between the coal-rich western supply regions and major demand centers may well understate actual future western production.

(6) The MASP concept appears reasonable, but may obscure some basic supply price implications, especially for mines which might open in extremely large reserve blocks and operate at less than full production. This potential non-linearity of average costs in specific reserve blocks may have a significant impact on predicted market prices, and thus on the cost guidance furnished in this report.

(7) Although the market price/production forecasting process assumes that the coal industry structure is essentially competitive (Kaplan, Reference 5) a closer look at the U.S. coal supply sector suggests that there may be significantly less effective competition than the raw number of coal suppliers (3,000+) and coal mines (6,000+) might indicate (Office of Technology Assessment, Reference 7). Indeed, a recent study by the Office of Technology Assessment indicates that long-term contracts cover about 86 percent of the coal produced. Since the contract length tends to be set equal to the expected (or desired) life of the mine, the existence of these contracts may have significant implications for the marketability of a new technology.

(8) The resource base estimates included "inferred reserves" as well as those "measured" and "indicated." Although the scope and time frame of the project makes this extension of the usual "reserve" base to a "resource" base appropriate, the unavoidable uncertainty surrounding such estimates, given the detailed level of their use, may have an unknown impact on predicted MASPs and target market derivations.

(9) Although the study team is convinced that the aggregate and regional demand estimates are reasonable given the present expectations for exports and synfuel use, the existence of increasingly credible forecasts of a dramatic shift to coal as a substitute fuel may well lead to non-marginal increases in aggregate demand, and significantly affect predicted target prices and markets.

(10) The stability of forecast MASPs and production levels may be sensitive to possible variations in the assumed required ROIs and risk premiums associated with the adoption of a significant new technology in a major industry such as coal.

(11) A variation in the "longwall assignment" algorithm could lead to a significant increase in predicted market penetration, and therefore to a modification in the regional price targets and target market size estimates.

It is recommended that effort be devoted to quantifications of the probable size of the most important of those qualifications listed

above. Further, it would appear very valuable to develop a "scalar measure" of target market size as discussed previously. To the extent such a construct can be obtained, the task of narrowing market choices (and price guidance) to a small number of possibilities will be greatly simplified. This effort requires both the development of an internally consistent candidate measure and its testing, using the available data base described here. It is believed that the integration of the results of such an effort with those of the JPL moving baseline will greatly strengthen the effort to develop an advanced coal extraction system with large commercial appeal.

FOOTNOTES

[1]"Coal Models and Their Use in Government Planning," JPL-sponsored seminar, Carmel, California, July 16 and 17, 1979.

[2]This distribution was determined by comparing the cumulative tonnage in each sulfur category (as estimated by the USBM) to the average Btu content by region. The low sulfur category includes 2.1 - 2.4 lb SO_2/million Btu coal because this coal can be blended/mixed with the 1.3 - 1.9 lb SO_2/million Btu coal to achieve an "average 2.0" product. The "compliance" category is that coal less than 1.2 lb SO_2/million Btu, while "high" indicates more than 2.5 lb SO_2/million Btu.

[3]"Measured" reserves are based on such extremely localized sample data that their computed tonnage is judged to be within 20 percent of the true value. "Indicated" reserves are based on sample points as much as 1½ miles apart, while "inferred" reserves generally lie more than 2 miles from the sample (borehole) point and assume continuity of "measured" and "indicated" resources.

[4]See the remarks of Robert Major contained in the "Discussion of Part I Papers" in Coal Models and Their Use in Government Planning (Reference 8).

[5]Details of the algorithm used are available in Section 6.5 (pages 6-7 to 6-22) of EEA's Final Report to JPL (Reference 3).

[6]For further details regarding the specific state content of the demand regions see pages 5-15 to 5-17 of the EEA Final Report (Reference 3).

[7]That is, weighted by the numbers and origins of the shipments.

[8]Although $t \cdot \rho$ is approximately equal to the expected lifetime production from the mine, it is not necessarily equal to the raw (unadjusted) block size. Recall that a number of adjustments to the actual, recoverable, size of specific reserves were detailed in Section III. Thus, in general, $t \cdot \rho$ will be less than the block size.

[9]The assignment of a mine size is determined as follows:

(a) Area mines: divide block size by 20 (years) and multiply by 90 percent (recovery factor).
(b) Contour mines: fixed at a typical size, 150,000 tons per year.
(c) Longwall mines: fixed at a typical size, 1.5 million tons per year.
(d) Room and pillar: divide block size by 20 (years) and multiply by 50 percent recovery factor.
(e) Room and pillar, thin seam: fixed at typical sizes; 125,000 and 250,000 tons per year.

[10]Although there is some empirical work to substantiate this Assumption 1, it is not clear whether in that analysis the traditional definition of productivity was used.

[11]See Appendix A for the derivation.

[12]This is based upon the application of corrected MASP calculations to the example contained in the EEA Briefing Paper, (Reference 2).

[13]See "Report of the World Coal Project," an article appearing in Science, 30 May 1980, which predicts that the production of coal for export as well as for domestic use will increase dramatically over the next 20 years.

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7. Office of Technology Assessment, The Direct Use of Coal, Washington, D.C.

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APPENDIX A

CALCULATION OF THE EFFECT OF PRODUCTIVITY ON DEEP MINE MASP*

A. PRODUCTION CALCULATIONS

Let:

X	=	Production in tons of cleaned coal per person/day
α	=	Productivity gain
a_2	=	Clean tonnage correction factor
R	=	Raw coal production
C	=	Clean coal production
a_1	=	Number of mine employees
W	=	Union welfare contribution
a_3	=	Number of unionized employees
T	=	Cleaning costs

The following relationships are given:

$$R = (1+\alpha)\ (220 \text{ days})\ a_1\ a_2\ x$$

$$C = .85\ R = (1+\alpha)\ 187\ a_1\ a_2\ x$$

$$T = 1.75\ R = (1+\alpha)\ 385\ a_1\ a_2\ x$$

$$W = 2.05\ R + .94\ (8 \text{ hr})\ (220)\ a_3$$

or

$$= (1+\alpha)\ 451\ a_1\ a_2\ x + 1{,}654\ a_3$$

B. CAPITAL INVESTMENT

(not a function of productivity in the EEA model)

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*This utilizes the components of the "Deep Mine Model" used by EEA to estimate 1985 and 2000 production and price levels. See pp. 7-28 to 7-31 of the EEA Final Report for the model structure and pp. 7-12 to 7-27 for narrative descriptions of the input.

C. OPERATING COSTS

Let:

Q	=	Total operating costs
C_2	=	Operating supplies cost
C_5	=	Taxes and insurance
C_1	=	Direct labor cost
B	=	Base mine production
C_3	=	Other costs
C_4	=	Power and water

APPENDIX B

CALCULATION OF THE PROPORTION OF MASP WHICH IS TECHNOLOGY-DEPENDENT

To calculate technology-dependent capital costs as a percentage of MASP the following procedure was applied. Since capital cost changes will not affect the clean tonnage calculation, the percentage change in MASP is equal to the percentage change in the revenue calculation. That is:

$$\frac{MASP'}{MASP} = \frac{REV'\ CLEAN}{REV/CLEAN} = \frac{REV'}{REV}$$

where the prime superscript indicates the amount of MASP that is technology-dependent capital costs.

For situation 1 REV_1 is:

$$REV_1 = \frac{CASH + 0.15\ TOTOP - 0.5\ DPCN}{0.55 - 0.5r - 0.5s}$$

Maximum technology-dependent capital costs are the sum of <u>deferred</u> and <u>other initial</u> capital costs. These costs affect the terms, CASH, TOTOP and DPCN, above as follows:

$$CASH' = TOTL'/6.533$$

$$TOTL' = 1.075\ INIT' + DEFRI$$

$$INIT' = OTHRI^* \quad \text{(adjusted original OTHRI)}$$

$$TOTL' = 1.075\ OTHRI^* + DEFRI$$

$$CASH' = (1.075\ OTHRI^* + DEFRI)/6.533$$

$$TOTOP \begin{cases} = .02\ INIT' \\ = .02\ OTHRI^* \end{cases}$$

Therefore, letting (MAX PRO - C) be the "maximum" technology dependent capital costs as a percentage of MASP we have:

$$(MAX\ PRO - C)^1 = \frac{CASH' + 0.5\ TOTOP' - 0.5\ DPCN'}{CASH + 0.5\ TOTOP - 0.5\ DPCN} =$$

$$\frac{(1.075\ OTHRI^* + DEFRI)/6.533 - 0.025\ OTHRI^*}{CASH + 0.5\ TOTOP - 0.5\ DPCN}$$

Likewise for situation "2" REV_2 is:

$$REV_2 = \frac{CASH + 0.75\ TOTOP - 0.25\ DPCN}{0.75 - 0.75\ (r + s)}$$

Such that

$$(\text{MAX PRO} - C)^2 = \frac{1{,}075\ \text{OTHRI*} + \text{DEFRI})/6.533 - .0025\ \text{OTHRI*}}{\text{CASH} + .75\ \text{TOTOP} - .25\ \text{DPCN}}$$

Where the following relationships hold:

$$Q = 1.55\ c_1 + (1+\alpha)\ 253\ \frac{c_2}{B}\ a_1\ a_2\ x + c_3 + c_4 + (1+\alpha)\ 385\ a_1\ a_2\ x + c_5 + (1+\alpha)\ 451\ a;\ a_2\ x + 1{,}654\ a_3$$

$$Q = (1+\alpha)\ a_1\ a_2\ x\ [253\ \frac{c_2}{B} + 836] + 1.55c_1 + c_3 + c_4\ c_5 + 1{,}654\ a_3$$

or:

$$Q = (1+\alpha)\ K_1 + K_2$$

where:

$$K_1 = a_1\ a_2\ x\ [253\ \frac{C_2}{B} + 836]$$

$$K_2 = 1.55\ c_1 + c_3 + c_4 + c_5 + 1{,}654\ a_3$$

D. REVENUE: ALTERNATIVE 1 (REV^1)

Let:

r = Royalty tax rate

s = Severance tax rate

R_1 = Cash flow requirement

R_2 = Depreciation

R_3 = $1.1 - r - s$

The following relationships hold:

$$(.55 - .5r - .5s)\ REV^1 = R_1 + .5\ Q - .5\ R_2$$

$$= .5\ [(1+\alpha)\ K_1 + K_2] + R_1 - .5\ R_2$$

which reduces to:

$$REV^1 = [(1+\alpha)\ K_1 + K_2 + 2\ R_1 - R_2]/R_3$$

Define:

$$MASP^1 = \frac{REV^1}{C}$$

$$MASP^1 = \frac{(1+\alpha)\ K_1 + K_2 + 2\ R_1 - R_2}{R_3\ \ (1+\alpha)\ \ 187\ a_1\ a_2\ x}$$

$$MASP^1 = \frac{m_1^1 + m_2^1}{1+\alpha}$$

where:

$$m_1^1 = \frac{K_2 + 2R_1 - R_2}{187\ a_1\ a_2\ x\ R_3}$$

$$m_2^1 = \frac{1.35\ \frac{C_2}{B} + 4.47}{R_3}$$

E. REVENUE: ALTERNATIVE 2 (REV^2)

Here, because of differing magnitude of the federal depletion allowance we have:

$$(.75 - .75\ r - .75\ s)\ REV^2 = R_1 + .75\ Q - .25\ R_2$$

or:

$$REV^2 = \frac{(1+\alpha)\ \ K_1 + K_2 + 1.33\ R_1 - .33\ R_2}{R_4}$$

where: $R_4 = (1 - r - s)$

Such that:

$$MASP^2 = \frac{K_2 + 1.33\ R_1 - .33\ R_2}{(1+\alpha)\ \ 187\ a_1\ a_2\ R_4} + \frac{253\ \frac{C_2}{B}}{187\ \ R_4} + \frac{836}{}$$

or:

$$MASP^2 = \frac{m_1^2}{(1+\alpha)} + m_2^2$$