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Analysis of the Economic Feasibility of the Kloswall Longwall Mining System

Final Technical Report—Volume 1

December 1978

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Prepared For
U.S. Department of Energy
Assistant Secretary for Energy Technology
Division of Solid Fuels Mining and Preparation

Under Contract No. HCP/T77-C-01-8915-01(7)

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ABSTRACT

This study was performed to evaluate the economic feasibility of the Kloswall longwall mining system. The Kloswall system utilizes a deep web mining concept. It was studied both to determine its own economic efficiency and to compare it to the economic efficiency of conventional longwall and continuous mining systems.

A broad-range of mine scenarios and equipment configurations was studied for each mining system. The principal economic factor used in the analysis was Rate of Return on Investment. This factor was derived through a yearly discounted cash flow analysis. An estimated value for yearly Cost per Ton has also been provided.

The Kloswall system is shown to be a feasible concept from an economic point-of-view and to provide an economic advantage over conventional longwall systems in seam heights in the range of 6 to 9 feet. This is predicted to be true even if there are relatively large errors in initial cost estimates for the Kloswall equipment.

Additionally, by simultaneously considering the nature of equipment cost variations and production rates, the study was able to ascertain optimal longwall mine layouts for the scenarios studied.

EXECUTIVE SUMMARY

Background and Justification

The first feasibility study of the Kloswall Longwall Mining System¹ has been performed by Foster-Miller Associates (FMA), under contract to the Bureau of Mines. FMA's final report addresses the engineering feasibility of the Kloswall system and compares its productivity and cost with those of conventional longwall systems. The analysis of the economics, however, is neither comprehensive in the scenarios studied nor in its comparisons to current mining equipment systems. This study is designed to fill this gap by providing a comprehensive analysis of mining economics for Kloswall, conventional longwall and continuous mining systems under a wide range of mine scenarios.

Synopsis of Study

This study is designed to evaluate the economic feasibility of the Kloswall mining system. It achieves this by forecasting expected rate of return on investment for the Kloswall system and comparing this to the expected return on investment for alternate mining systems in a similar environment.

The study assumes a large number of mine scenarios and mining system specifications. Expected return on investment for each combination of mine scenario and system specification is calculated and the results of the total study are analyzed. From this analysis, conclusions and recommendations concerning the Kloswall system are derived.

The longwall mining scenarios studied cover a range of face lengths from 100 feet to 1,000 feet and seam heights of 6 feet to 12 feet. Additionally, the economic effect of one, two and three shift operation is studied. Within each scenario, the effects of changes in system capacity and reliability are studied. Conventional longwall systems are hypothesized to have capacities of 750, 1000 and 1200 tons per hour. Shearer

¹

United States Bureau of Mines Contract No. JO-265028.

speeds are limited to a maximum of 22 feet per minute. These system specifications are derived from consultations with equipment manufacturers and internal engineering discussions.

The Kloswall system is hypothesized to always have a 1,200 ton per hour capacity, being the capacity of its conveyor. Its reliability expressed in total cutting time per shift is assumed to be either the same as the conventional longwall systems, i.e., 148.5 minutes, or a Foster-Miller estimate of 162.2 minutes.

The economic efficiency of continuous mining systems is studied for a range of production rates. We have not been able to find nor derive an acceptable model to correlate these production rates to particular seam heights. An approximate regression relationship is provided in the main body of the report. This lack of a continuous mining production model has no impact on the economic analysis. The reader can make his own judgment as to the mining scenarios in which the production rates can be achieved.

Cost data for conventional longwall equipment are derived from consultations with equipment manufacturers. The Kloswall system costs are updated estimates supplied by Foster-Miller Associates.

Current operating and supply costs, as well as mine development costs, are obtained from consultants within the mining industry and from internal engineering discussions. This technique is also used to determine a realistic FOB mine price for clean coal. Estimates are made of the way in which these costs will vary over the time period studied. Algorithms to describe the expected cost behavior are developed and included in a proprietary cost model.

This cost model, KETRON's Mining Cost Analysis Model (MCAM), is exercised for each mine scenario and equipment configuration. The resulting data are analyzed and summarized in Volume I of this report. The expected economic results from each scenario studied are provided in Volume II.

The analysis shows that all the mining systems studied are economically viable. Calculated rates of return on investment for longwall systems range from 42% to 106%. The return on investment for continuous mining systems is found to be extremely sensitive to production rates, with predicted values ranging from below zero to 217% in the production range studied.

The Kloswall system is shown to provide an economic advantage over conventional longwall systems in seam heights around 7.5 feet. This is due to its higher system capacity at lower shearer speeds. The Kloswall system provides an economic advantage over conventional longwall systems under nearly all conditions, if, in addition to its high capacity, it is hypothesized to have a higher reliability. An additional contributor to this economic advantage is the estimated lower cost for Kloswall shields. An analysis of the sensitivity of the Kloswall advantage to errors in equipment cost estimates reveals that price corrections of 10% to 65% will reduce, but not eliminate the advantage. The sensitivity varies with the scenario studied.

The predicted large return on investment for continuous mining systems is unexpected. We have, however, verified that the cost inputs are reasonable and -- given those -- we feel the results to be true. These results indicate that continuous mining systems, given sufficient production rates, are worthy of careful consideration.

As an additional output, the analysis provides a viable technique for determining economically optimum longwall mine layouts. For this study, panel length and certain other variables were fixed and optimum face length determined. In general, however, the technique may be applied with any or all pertinent mine parameters as variables.

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Joy Manufacturing, Franklin, PA
NMS Company, Pittsburgh, PA

There are many others who assisted in the program who, although we cannot name them individually, certainly deserve our thanks. We particularly thank those within KETRON who lent their experience for the collaboration of the data and of the techniques employed.

1.0 INTRODUCTION

1.1 Background and Justification

The U. S. bituminous coal industry is faced with the challenge of achieving a production potential of over 1 billion tons per year by the mid-1980's. Current estimates are that 65% of this production will come from expanded surface mining. However, surface mining encounters severe environmental constraints. It is anticipated that these parameters will exert a positive influence on the effort to increase productivity from underground mining.

Longwall mining provides an attractive system for meeting this production challenge. The U. S. Department of Energy (DOE) has shown increased interest in longwall mining. Since 1974, approximately thirteen (13) contracts have been awarded by the U. S. Government to examine various aspects of automated longwall mining.

Foster-Miller Associates (FMA), under contract to the Bureau of Mines, undertook the first feasibility study of the Kloswall Longwall Mining System.¹ FMA's final report addressed the engineering feasibility of the Kloswall system and compared its productivity and cost with those of conventional longwall systems. The analysis of the economics, however, was neither comprehensive in the scenarios studied nor in its comparisons to current mining equipment systems. This study was designed to fill this gap by providing a comprehensive analysis of mining economics for Kloswall, conventional longwall, and continuous mining systems under a wide range of mine scenarios.

1.2 Objective

The objective of the study was to perform a broad ranged economic analysis of the Kloswall system and determine its cost-effectiveness in comparison with conventional longwall and continuous mining systems under a broad range of mine scenarios.

¹

United States Bureau of Mines Contract No. JO-265028.

1.3 Scope

The scenarios investigated cover the following ranges:

- o Face lengths ranging from 300 feet to 1,000 feet for the longwall systems
- o Additional face lengths ranging from 100 to 300 feet were studied to complete the economic analysis
- o Seam heights ranging from 6 feet to 12 feet for the longwall systems
- o Production rates ranging from 125 to 600 ROM tons per shift for the continuous mining systems
- o One, two and three shift operations
- o Short, mid- and long-term economic changes.

Within these limits, KETRON has studied the effects of various cost factors on the economic viability of the mining systems. The factors studied are:

- o Capital Equipment Costs
- o Expected FOB Mine Coal Prices
- o Operating and Support Costs
- o Cost per Ton
- o Return on Investment

1.4 Approach

KETRON's approach consisted of six (6) distinct phases:

PHASE 1	--	Visits to equipment manufacturers to collect current cost data and to acquire recommendations for optimum equipment usage for the conditions to be studied.
---------	----	---

- PHASE 2 -- Collection of empirical data on mine operations:
- o Literature search
 - o Analysis of KETRON's underground mining production data base
 - o Consultation with industry experts in finance and mine operations
- PHASE 3 -- Development of mine scenarios to encompass the range of mining conditions. This range is designed to satisfy the Statement of Work and to assure a complete analysis of economic effects.
- PHASE 4 -- Modification of KETRON's proprietary cost model (MCAM) to specifically address the operating and support costs of the mining industry.
- PHASE 5 -- Application of the cost model to all scenarios for varying equipment configurations
- PHASE 6 -- Data Analysis.

Section 2 of this report describes the cost model used for this analysis. In Section 3, the mine scenarios and the model input data are discussed. Section 4 provides a summation and discussion of the results of the analysis. The conclusions are presented in Section 5.

Summary data tables are provided in the Appendices to Volume I. Detailed yearly cash-flow analysis for each scenario studied are presented in Volume II.

2.0 MINE COST ANALYSIS MODEL (MCAM)

The basic technique used by the MCAM model is a cash flow analysis using rate of return on investment as the evaluation criteria. This basic technique is discussed in Section 2.1.

MCAM consists of the following elements:

- o Production Model
- o Coal Price Model
- o Estimation of Labor Rates
- o Equipment Maintenance Expense Model
- o Operating Supplies Expense Model
- o Coal Charges Model
- o Interest Expense Model
- o Depreciation Model
- o Depletion Model
- o Mine Development Cost Model

Each element is discussed, in detail, in this section. Other pertinent cost factors such as Federal Income Tax and Investment Tax Credit are also discussed.

2.1 Basic Technique

Of the many methods used to measure economic efficiency, only the Rate of Return and Present Value techniques provide a complete picture of the economic feasibility of capital investments. The advantages of the present value and rate of return techniques are briefly summarized as follows:

- o They consider the effect of the investment over its entire life.
- o They permit evaluation of the investment in terms of the "risk" involved.
- o They permit comparison of alternate investments on equal terms.

Two other methods commonly used for cost analysis are cost per ton and payback period. All four techniques are briefly discussed in this section to serve as background material; however, only Rate of Return on Investment and Cost per Ton are provided for analysis.

2.1.1 Rate of Return on Investment

The Rate of Return on Investment (ROI) technique evaluates the rate of return that results from a capital investment, based upon predicted annual (net) cash flows. This may be interpreted as the interest rate that the investor would have to charge on a capital loan of equivalent risk, in order to be indifferent between the investment and the loan.

This calculated "interest rate" can be used by a decision-maker for two purposes:

- (1) to determine if the investment provides a sufficient rate of return to compensate him for his cost of capital and for the degree of "risk" involved in the investment, and
- (2) to permit meaningful comparisons of alternate investments. From a purely economic point-of-view, the investment with the highest ROI would be selected.

The Rate of Return on Investment is evaluated by solving the following equation for r :

$$P = \frac{S_1}{(1+r)} + \frac{S_2}{(1+r)^2} + \dots + \frac{S_n}{(1+r)^n}$$

where:

P = Initial Capital Investment

$S_1, S_2, \dots, S_n$ = Expected Cash Flow per Year
1, 2, ..., n

r = Rate of Return on Investment

2.1.2 Present Value

The Present Value (PV) technique is similar to the ROI technique. Rather than calculating the actual ROI, however, it evaluates whether an investment will return at least a pre-selected, minimum acceptable, rate

of return. The selected rate of return should reflect both cost of capital and risk considerations.

The Present Value is obtained from the cash flow equation in the following manner:

$$PV = \frac{S_1}{(1+i)} + \frac{S_2}{(1+i)^2} + \dots + \frac{S_n}{(1+i)^n}$$

where:

PV = Present Value

$S_1, S_2, \dots, S_n$ = Expected Cash Flow per Year

i = Pre-selected "discounting" Rate

As stated, the factor i , is the minimum acceptable rate of return that a decision-maker is willing to accept for his initial capital investment, given the degree of risk involved. For example, by choosing $i = 0.15$, the decision-maker demands a rate of return on investment of at least 15%. If the present value calculated with this value of i is greater than the initial capital investment, then the criteria is met.

Alternate investments which are otherwise equivalent can be evaluated by comparing their excess Present Value over their required capital investment; the investment with the highest excess Present Value would be selected.

Both Present Value and Rate of Return techniques take into account the time value of money and are equally valid for evaluating investments. KETRON has selected the Return on Investment techniques for the evaluation process in this study.

2.1.3 Cost per Ton

The cost per ton technique divides the total operating and support cost per year by the number of tons produced that year. There are two principal reasons why this figure should not be used for measuring the effectiveness of an investment. These are:

- o The "cost" is a totally artificial one because it includes the non-cash "expenses" of depreciation and depletion. For purposes of minimizing income taxes, it is normally a company objective to have these non-cash "expenses" as high as possible and, therefore, cost per ton artificially high.

- o The technique does not permit accounting for the time value of money.

However, KETRON has included a cost per ton calculation in this report for readers who may be interested. Additionally, an average cost per ton for the ten-year period studied is included in the summary tables of Section 4 and Appendix B.

2.1.4 Payback Period

The Payback Period technique does not consider the entire economic life of the equipment. This method evaluates only the cash flow for a sufficient period of time to "payback" the initial investment. This technique does not measure the total economic worth of an investment, since all cash flow beyond the "payback" period is disregarded. The method does provide a quick means for ascertaining whether funds invested in a given project will be recovered quickly or over a long period. The principal drawback to this method is that the investments are not evaluated thoroughly. The highest initial cash flow investment is always favored over investments which are potentially more attractive in the long run.

2.2 Model Elements

2.2.1 Production Model

2.2.1.1 Longwall Production

The model developed in the Foster-Miller Kloswall report was utilized to estimate the per shift production for the Kloswall and conventional longwall systems. This approach was decided on after a great deal of analysis and discussion of alternative methods. Several other approaches were investigated and attempted, but none proved to be more useful than the FMA production model. This model is easily understood in terms of underground mine operation and permits the input of empirical data. In addition, critical parameters can be varied readily. All of these factors were necessary to this study. The model describes a full-face cutting system.

The overall model takes the form shown in Equation (1):

Production Model

$$P_s = A_c \frac{V_s}{2 [(FL - SL) + (ST) V_s]} (SH) (WS) (F) (d) \quad (2) \quad (1)$$

where:

- P_s = Production per shift (tons)
- A_c = Available cutting time per shift (min.) = Total available shift time
— All production down time
- V_s = Shearing speed (feet/min.)
- FL = Face length (feet)
- SL = Length of sump face (feet)
- ST = Sumping time (minutes)
- SH = Seam height (feet)
- WS = Web size (feet)
- d = Density of coal (tons/cu. ft.)

The sumping time (ST) for Klosswall and for longwall is described by Equations (2) and (3), respectively.

$$ST_k = \frac{6 + 4 (SL) (SH) (WS) (d)}{C_c} + \frac{SL}{30} + TD \quad (2)$$

$$ST_L = \frac{(SH) (WS) (d)}{C_c} 2 (SL) + 50 + TD \quad (3)$$

where:

- ST_k = Sumping time for Klosswall (minutes)
- ST_L = Sumping time for longwall (minutes)
- C_c = Conveyor capacity (tons/minute)
- TD = Delay time during sumping operation

The delay times due to the sumping operation for the conventional longwall has been estimated by KETRON from empirical data. The value used is 7 minutes. The corresponding delay time for Klosswall has been estimated as 13 minutes.

The shearing speed (V_s) in feet per minute is calculated by equation (4).

$$V_s = \frac{C_c V_c}{(SH) (WS) (V_c) (d) + C_c} \quad (4)$$

where:

$$V_c = \text{Conveyor speed (feet/min.)}$$

Tons per year is then calculated from the following:

$$P_y = P_s S_n (220 - 30 M_y) (0.65)$$

where:

$$P_y = \text{tons per year}$$

$$P_s = \text{tons per shift calculated from equation (1)}$$

$$S_n = \text{number of shifts per day}$$

$$220 = \text{number of working shifts per year}$$

$$30 = \text{number of shifts estimated to be required to move longwall equipment to a new panel}$$

$$M_y = \text{number of moves per year. This term is calculated from an internal algorithm which used the seam height of face length of the current scenario and a fixed panel length of 3,024 feet. This panel length was selected as being representative of a typical longwall section.}$$

$$0.65 = \text{accounts for a reject factor of 35\%}$$

2.2.1.2 Continuous Mining Model

In performing the analysis of continuous mining systems, KETRON has estimated the return on investment (ROI) for various levels of ROM production per shift. This was done because of the amount of uncertainty in any correlation of production per shift to seam height. The analysis presented in Section 4 shows that ROI for continuous mining systems is

extremely sensitive to production per shift. The use of a generalized relationship between production and seam height would undoubtedly introduce unacceptable errors in the predicted relationship between seam height and ROI.

However, KETRON has developed an approximate regression equation to correlate ROM production per shift to average seam heights where such production levels are being achieved. Table D-I of Appendix D provides the data for the equation. The regression is assumed to be linear and the best equation for the line is determined to be:

$$P_{ms} = \text{ROM Production/Miner/Shift} = 94 (H) - 248$$

where:

$$H = \text{Seam height (feet).}$$

For each level of production per shift, the corresponding production per year is calculated from:

$$P_y = 220 \times (P_{ms}) \times 0.65 \times S_n$$

where:

$$P_y = \text{Production of clean coal per year (tons)}$$

$$220 = \text{Number of working days per year}$$

$$0.65 = \text{Accounts for reject factor of 25\%}$$

$$S_n = \text{Number of shifts per day}$$

2.2.2 Coal Price Model

Current FOB mine prices, in dollars per ton, were collected using coal industry periodicals.¹ The prices utilized were "bid" prices for "term" contracts. The average FOB mine price of twelve (12) states including: Pennsylvania, West Virginia, Virginia, Kentucky, Tennessee, Illinois, Indiana, Kansas, Alabama, Missouri, Iowa and parts of Oklahoma were averaged. The current (September 1978) value for this average is \$20.45 per ton; this value was rounded to \$20.00.¹

¹ This data is presented in Table D-II of Appendix D.

Two techniques were used to estimate the manner in which this price will vary into the future: (1) the past history of coal prices from 1940 to date were studied and the trend extrapolated into the future, and (2) commodity (coal) analysts were consulted. Both investigations resulted in the same conclusion, namely, the price of coal will escalate at the same rate as inflation. This trend in the past can be dramatically seen in Figure 1 which illustrates a deflated average value of prices for Bituminous Coal and Lignite FOB mine. The figure shows that, in constant dollars, the price of coal did not change significantly from 1940 through 1973, after which the oil embargo effects became a major factor.

FIGURE 1

Deflated Average Value, FOB Mine,
Bituminous Coal and Lignite (1967 Dollars per Ton)

SOURCE: EPRI EA4-97, pg. 2-2

It is reasonable from this analysis to assume that over the next ten (10) years, the FOB mine price of coal will excalate at the inflation rate.

The inflation rate, as measured by the Implicit Price Deflator for the Gross National Product has been rising since 1972 at a rate of 7.6%, compounded yearly. The deflator stood at 144.23 at the end of 1977 with 1972 = 100.¹ The compound rate is then:

$$\left(\frac{144.23}{100} \right)^{\frac{1}{5}} - 1 = 0.076 \text{ (7.6\%)}$$

¹

Source: Survey of Current Business, Monthly Issue.

KETRON estimates that coal prices, FOB mine, will escalate at the inflation rate through 1988.

2.2.3 Estimation of Labor Rates

Rates for UMW labor grades were estimated through 1988. Since the overall analysis is sensitive to labor rates, a realistic estimate of labor rates was needed. The following approach was used:

- (1) Determine the historical rate of wage increases in the bituminous mining industry.
- (2) Correlate this rate to a pertinent external economic indicator to verify its reasonableness in terms of current overall economic conditions.
- (3) If the rate proves reasonable, postulate a realistic labor rate scenario which will result in similar future wage changes.

Bureau of Labor Statistics data was utilized in determining the historic rate of wage increases. This data is presented in Table I, which shows the average hourly earnings for the coal industry from 1965 to 1976. The compounded rate of increase over this period is given by:

$$\left(\frac{7.91}{3.49} \right)^{\frac{1}{11}} - 1 = 0.077 \text{ (7.7\%)}$$

In order to determine if this rate of yearly increase is reasonable in light of current economic conditions, the rate was compared to the external economic indicator. The indicator selected was the Implicit Price Deflator for the Gross National Product. This indicator is normally used to express the inflation rate.

With 1972 = 100, the deflator stood at 144.23 at the end of 1977,¹ which reflects a compounded rate of inflation of 7.6% over the period. This rate corresponds closely with the wage increase rate and provides evidence that it can be sustained into the near to mid-term future.

¹ Source: Survey of Current Business.

TABLE I
Average Hourly Earnings in the Bituminous Coal Industry

Year	Average Hourly Earnings (\$)	GNP Index 1965 = 100
1965	3.49	100.0
1966	3.66	104.9
1967	3.75	107.4
1968	3.86	110.6
1969	4.24	121.9
1970	4.58	131.2
1971	4.86	139.3
1972	5.35	153.3
1973	5.75	164.8
1974	6.25	179.1
1975	7.23	207.2
1976	7.91	226.6

SOURCE: U. S. Department of Labor, Bureau of Labor Statistics, Employment and Earnings, Various Years

It was now necessary to postulate a realistic scenario for future wage increases which would result in an "over-the-period" compounded yearly increase of approximately 7.5%. To do this, the wage provisions of the current (March 1978) and the immediately previous UMWA contract were studied. This data is presented in Table II which shows the labor rate by grade, and the corresponding yearly increases.

The yearly increases are approximately 4%, with the higher increases in the most recent contract. The increase between the contract intervals averages about 26%.

TABLE II

UMWA Wage Contracts 1975-1980

	1975	1976		1977		1978		1979		1980	
UMWA Labor Grade	Daily Wage(\$)	% Increase	Daily Wage(\$)	% Increase	Daily Wage(\$)	% Increase	Daily Wage(\$)	% Increase	Daily Wage(\$)	% Increase	Daily Wage(\$)
5	55.00	4.0	57.20	3.0	58.92	24.4	73.32	4.4	76.52	4.2	79.72
4	51.98	4.0	54.06	3.0	55.68	25.9	70.08	4.6	73.28	4.4	76.48
3	49.23	4.0	51.20	3.0	52.74	27.3	67.14	4.8	70.34	4.5	73.54
2	47.58	4.0	49.48	3.0	50.96	28.3	65.36	4.9	68.56	4.7	71.76
1	47.03	4.1	48.98	2.9	50.38	28.6	64.78	4.9	67.98	4.7	71.18

Based on this information, several possible scenarios were hypothesized. It is not expected that the recent 26% increase will be repeated. Intracontract increases in the range of 4% to 5%, however, are felt to be reasonable. The scenario which best fits these conditions is found to be:

- o Assume intracontract increases of 4.5% per year
- o Assume a new contract each three years
- o Assume a 15% increase between contracts.

This scenario results in an equivalent compounded yearly increase of 7.5% which is well in keeping with past wage experience, as well as the inflation rate.

All UMWA employee wages were escalated using this model. These wages were determined as follows:

- o The current labor cost of operating crews was determined from Table II, using the 1978 wage schedule
- o The current labor cost of UMWA support personnel was similarly determined and an allocated portion of this was added to the cost of the operating crews
- o This total cost was escalated using the model developed above.

The number and type of each labor category included is described in Section 3.3 (Operating Personnel) of this report. Allocation of hourly support personnel costs was done on the basis of a ten section mine,¹ i.e., one-tenth of the total cost of hourly support personnel was added to direct labor costs.

The cost assigned to the mining section for salaried personnel was determined by allocating one-tenth of their total salary expense. The number and type of salaried personnel -- along with their estimated yearly wages is also presented in Section 3.3. This salary expense was then escalated at a rate of 7.5% per year throughout the study period.

Additionally, the labor cost, as determined above, is multiplied by a factor of 1.4 to account for costs of social security, unemployment taxes, etc.

¹ See Section 3.4 for a discussion of the overall mine scenario.

2.2.4 Equipment Maintenance Expense Model

The following schedule for equipment expenses has been incorporated into the economic model:

- (1) Rebuild shearers every two years at one-half the original equipment cost, compounded at 6.5% to the applicable year. The rebuild is assumed to occur on January 1st of the applicable year, and is expensed. As an example, the cost of rebuilding a shearer January 1st of the 5th year, which originally cost \$500,000 would be:

$$(1/2) (\$500,000) (1.065)^4 = \$321,617$$

- (2) Yearly expenses per shearer are \$12,000.
- (3) Replace the face conveyor every two years, i.e., expense the book value on December 31st of year 2 and purchase new face conveyor on January of year 3. This cycle is repeated for the life of the equipment. The equipment has been depreciated by the sum-of-the-years digits, remaining life plan -- with an estimated life of ten (10) years.
- (4) Yearly expenses per face conveyor are \$30,000 for repairs plus \$60,000 for chains.
- (5) Yearly expenses for the shields are 6% of their original cost.
- (6) Yearly expenses for all other equipment is 6% of original cost.
- (7) Rebuild continuous miners every three years at two-thirds of the original cost, compounded at 6.5% to the applicable year. The rebuild is assumed to occur on January 1st of the applicable year, and is expensed.
- (8) Yearly expenses for continuous miners is 40% of their original cost.

- (9) Rebuild shuttle cars every three years at 60% of the original cost, compounded at 6.5% to the applicable year. The rebuild is assumed to occur on January 1st of the applicable year and is expensed.
- (10) Yearly expenses for a shuttle car are: \$3,000 for cables, \$24,000 for repairs, and \$12,000 for expendable supplies.
- (11) Rebuild the roof bolter every four years at 60% of the original cost, compounded at 6.5% to the applicable year. The rebuild is assumed to occur on January 1st of the applicable year and is expensed.
- (12) Yearly expenses for the roof bolter are 15% of the original cost.

Recurring repair costs were escalated at a rate of 6.5% per year.

2.2.5 Operating Supplies Expense Model

The cost of operating supplies are calculated on a per ton basis as shown in Table III.

TABLE III
Operating Supply Expense

Supply Item	Continuous Mining (dollars/ROM ton)	Longwall Mining (dollars/ROM ton)
Rock Dust	.08	.01
Line Brattice Cloth	.04	
Posts with Caps & Wedges	.33	.33
Roof Drill Bits	.02	
Roof Bolts	.18	
Ventilation	.27	.27
Power	.32	.06
Water	.01	.01
Miner/Shearer Bits	.16	.02
Allocated Supplies	.02	.02
Miscellaneous	.10	.10
TOTAL	1.53	.82

Operating supply expenses are escalated at 6.5% per year.

2.2.6 Coal Charges Model

The coal charges included in this model are:

<u>Charge</u>	<u>Amount</u>
Reclamation (Federal statute)	\$0.15 per ton (underground)
Health and Welfare	\$1.385 per ton
Black Lung	\$0.50 per ton (underground)
Royalties	5% of sales

2.2.7 Interest Expense Model

A yearly interest expense has been included, since a conservative company will maintain some level of debt to support its operations. This level of debt is estimated for year one to be 25% of the funds required for capital equipment. This debt level is then held constant over the life of the operation. An interest rate of ten percent (10%) is assumed.

2.2.8 Depreciation Model

For the depreciation model, all capitalized equipment costs are depreciated according to the sum-of-the-years-digits, remaining life plan. An additional first-year depreciation of 20% is also taken. An equipment life of ten (10) years, with no salvage value is assumed.

Under this plan, a different fraction is applied each year to the current book value of the asset to calculate the depreciation. The book value of the asset is the original equipment cost less the depreciation to date.

The denominator of the fraction changes each year to a number equal to the sum of the digits representing the estimated remaining years of useful life of the asset. The numerator of the fraction changes each year to the number of estimated years of useful life remaining at the beginning of the year for which the computation is made.

As an example, for equipment with an estimated useful life of five (5) years, the denominator for the first year depreciation is:

$$5 + 4 + 3 + 2 + 1 = 15$$

and the numerator is 5, resulting in a fraction of 5/15.

For the second year, the denominator is:

$$4 + 3 + 2 + 1 = 10$$

and the numerator is 4, resulting in a fraction of 4/10. As permitted under current law, an additional first-year depreciation of 20% of the equipment cost is deducted. A sample depreciation schedule is provided in Figure 2 with the following parameters as input:

Equipment Cost	--	\$45,000
Estimated Useful Life	--	3 years
Salvage Value	--	0

1st Year Depreciation

<u>20% Add'l 1st Year Depreciation</u>	<u>Book Value</u>	<u>x Fraction</u>	<u>= Depre- ciation</u>	<u>Total 1st Year Depreciation</u>
\$45000x.2	\$45000-\$9000			
= \$9000	= \$36000	x 3/6	= \$18000	\$9000+\$1800
				= \$27000

2nd Year Depreciation

<u>Book Value</u>	<u>x</u>	<u>Fraction</u>	<u>=</u>	<u>Total 2nd Year Depreciation</u>	<u>Depreciation To Date</u>
\$45000-\$27000					
= \$18000	x	2/3	=	\$12000	\$27000+\$12000
					= \$39000

3rd Year Depreciation

<u>Book Value</u>	<u>x</u>	<u>Fraction</u>	<u>=</u>	<u>Total 3rd Year Depreciation</u>	<u>Depreciation To Date</u>
\$45000-\$39000					
= \$6000	x	1/1	=	\$6000	\$39000+\$6000
					= \$45000

FIGURE 2
Sample Depreciation Schedule

2.2.9 Depletion Allowance Model

The depletion allowance is calculated according to the Percentage Depletion technique. In this technique, a percentage of the gross revenue minus royalty charges is taken as an operating expense. For coal mining operations, the percentage allowed is 10%.

Current income tax laws, however, limit the amount of this deduction to 50% of the taxable income, computed without the deduction for depletion. This check is made by the model to assure the proper depletion allowance is taken under all scenarios.

2.2.10 Mine Development Cost Model

The following elements of mine development were incorporated into the model:

<u>Element</u>	<u>Cost</u>
<u>Buildings</u>	\$ 3M
warehouse	
offices	
bath house	
<u>Preparation Plant</u>	14M
700 ton per hour capacity,	(\$20K per ton-hour)
no thermal dryer, 35% reject	
80% availability	
<u>Facilities</u>	3M
storage	
disposal	
refuse	
<u>Silos</u>	3M
<u>Site Preparation</u>	1M
clear land	
access roads	
settlement ponds	
<u>Water Supply</u>	1M
preparation plant	
fire protection	
<u>Other Mining Equipment</u>	7M
rail	
portal buses	
locomotives	
pumps	
supply cars	
compressors	
<u>Exploration Expense and Environmental Study</u>	1M
(Eastern Mine)	
<u>Mine Entry Development</u>	7M
shaft or slope	
<u>Out-by Haulage Equipment</u>	3M
Total for Allocation	\$43M

In order to allocate this mine development cost to a mining section, a mine life of twenty (20) years is assumed resulting in a straight line depreciation expense of \$2.15 M per year. This cost has been charged to each operating section on a dollar per ton basis.

2.2.11 Federal Income Tax

For this study, Federal income tax was taken as 46% of taxable income where taxable income is gross revenues minus total costs minus any tax-loss carryforward from previous years. Tax-loss carryforwards occur when gross revenues minus total costs results in a negative number.

2.2.12 Net Income

Net income is calculated as operating income minus Federal income tax.

2.2.13 Investment Tax Credit (I.T.C.)

An investment tax credit is taken for each year a capital investment is made. The credit taken is 10% of the capital expenditure.

2.2.14 Cash Flow

The cash flow is calculated as:

$$\text{Net Income} + \text{Total Depreciation} + \text{Depletion} - \text{Capital Funds expended that year}$$

where total depreciation is depreciation on the equipment plus allocated depreciation.

The depreciation and depletion costs are added to net income because they are not cash expenditures.

3.0 OPERATING SCENARIOS

3.1 Mine Scenarios

Mine scenarios have been selected on the basis: (1) that they meet the requirements of the Statement of Work, (2) that they are sufficient to complete the economic analysis, and (3) that they are representative of realistic mining conditions. The following ranges satisfy these conditions:

- o face lengths of 300 to 1,000 feet
- o seam heights of 6 to 12 feet for the longwall systems
- o production rates ranging from 125 to 600 ROM tons per shift for the continuous mining systems
- o the likely effects of short-mid and long-term economic changes
- o additionally, face lengths ranging from 100 to 300 feet were studied in sufficient detail to complete the economic analysis.

It was determined from discussion with Foster-Miller Associates that, at least as currently conceived, the Klosswall system is not feasible for use in seams lower than six feet. Because this is primarily a comparative study, no longwall systems were studied below this seam height. However, the continuous mining systems, due to their great economic sensitivity to seam height, were studied to production levels thought to be representative for four feet high sections.

Within the ranges discussed above, the specific scenarios shown in Table IV were selected for detailed economic analysis. As an example, for longwall systems, the 375 foot face was considered for both a 7.5 foot and a 10.75 foot seam height. Within any one scenario, the effect of two equipment performance specifications were also studied. These specifications were total system capacity (in tons per unit time) and actual cutting time. These are discussed, in detail, in Section 3.2.

The additional face lengths were studied because the existence of optimal face lengths below 300 feet was indicated. Not all combinations of mine scenarios were permitted for this additional study; however, a sufficient number were studied to permit an understanding of the phenomenon. The scenarios permitted are discussed in Section 4.3.2.

TABLE IV
Specific Mine Scenarios Studied

Variable	Longwall Systems (feet)	Continuous Systems
Seam Heights	7.5, 10.75	NOT APPLICABLE
Face Lengths	100, ¹ 525, 200, ¹ 625, 300, ¹ 875, 375, 1000 ¹	NOT APPLICABLE
Shifts ²	1, 2, 3	1, 2, 3

3.2 Equipment Performance Specifications

In addition to the mining scenarios, the effects of various equipment performance specifications were studied. For ease of analysis, the performance specifications were configured to form the following equipment systems:

- o Normal Longwall
- o High Capacity Longwall
- o Low-Reliability Klosswall
- o High-Reliability Klosswall

¹ These face lengths were studied in sufficient detail to complete the economic analysis.

² The three shift scenarios were simulated by exercising the model for 2.5 production shifts. This was done to account for various non-productive tasks that are expected to be performed during the production shifts in the absence of a maintenance shift.

These equipment system configurations are defined in Table V. The Kloswall system is always hypothesized to have a capacity of 20 tons per minute (1,200 tons per hour), while the longwall has a normal system capacity of 12.5 tons per minute (750 tons per hour) and a high capacity of 16.7 tons per minute (1,000 tons per hour)¹ or 20.0 tons per minute, depending on the seam height.

TABLE V
Equipment System Definition

System	Scenario Name	Seam Height	Performance Specifications	
			System Capacity (Tons/Min)	Cutting Time (Min/Shift)
LONGWALL	Normal Longwall	7.5	12.5	148.5
		10.75	12.5	148.5
	High Capacity Longwall	7.5	16.7	148.5
		10.75	20.0	148.5
KLOSWALL	High Reliability Kloswall	7.5 and 10.75	20.0	162.2
	Low Reliability Kloswall	7.5 and 10.75	20.0	148.5

¹ The maximum shearer speed necessary to reach a capacity of 16.7 tons per minute in the various low seam scenarios is 22 feet per minute.

The high reliability (Hi-Rel) Kloswall system is hypothesized as achieving a cutting time per shift of 162.2¹ minutes. The low reliability (Lo-Rel) Kloswall system achieves a cutting time per shift of 148.5¹ minutes.

The subsequent analysis is done by comparing the operational and financial effects of logical combinations of the above defined mining systems.

Three (3) factors which were not varied are:

- o sumping length
- o density of coal
- o conveyor velocity

The conveyor velocity was not varied since equipment manufacturers and the mine operators stated that conveyor system typically run at 220 FPM. This includes the high capacity conveyor. Density of coal was derived by averaging the densities of coal as referenced in various mining engineering publications. A value of .042 tons/ft.³ was used. From KETRON's empirical data, the length of the sumping face was found to be typically 60 feet. Since this was approximately the same length assumed for the Kloswall system, the sumping length was held constant at 60 feet. Sensitivity analysis showed that a 10% change in sumping length resulted in a 3% change in tons per shift.

3.3 Capital Equipment Costs

Capital equipment costs for the longwall and continuous mining system elements are best estimates of typical costs being experienced today. They were arrived at through discussion with equipment manufacturers, consultations with coal industry personnel and internal (KETRON) engineering discussion. Because of assurances of data confidentiality which KETRON gave to equipment manufacturers, this report does not contain specific manufacturers' data on recommended equipment configurations by model number and cost. However, the final equipment cost estimates used by KETRON are presented in Tables D-III, IV, and V of Appendix D. A list of equipment manufacturers and coal operators contacted for this data is presented in Appendix E.

¹ Cutting times used in this study are the same times used in the Foster-Miller Kloswall study. These times were, in turn, taken from a recent Availability and Delay analysis prepared for the U.S. Bureau of Mines by the Jet Propulsion Laboratory of the California Institute of Technology.

Estimated capital equipment costs for the Kloswall equipment were updated by Foster-Miller Associates for this study. This data is also presented in Table D-IV of Appendix D.

3.4 Allocated Labor and Mine Development Expenses

For allocation of certain expenses, a hypothesis of an overall mine scenario was necessary. The scenario used is a ten section mine, with 9 continuous mining sections and one longwall (either conventional longwall or Kloswall) section. The total mine produces 1.2 million tons of clean coal per year. The mine works 220 days per year and has an average reject percentage of 35%. A mine life of 20 years is assumed.

The expense for allocated labor, both hourly and salaried is assigned on the basis of one-tenth of the total to each operating section. This is based on the assumption that each section benefits equally from their work. The personnel assigned to these categories are identified in Section 3.5.

The overall burden for mine development expenses, identified in Section 2.2.10 are allocated on a dollar per ton basis -- on the assumption that the tonnage a section produces determines the level to which they utilize these support facilities, i.e., out-by haulage, preparation plant, etc. The cost per ton has been determined as follows:

Total Cost for Allocation -- \$43 M

Mine Life -- 20 years

Burden per Year for Allocation = $\frac{\$43 \text{ M}}{20 \text{ years}}$ = \$2.15 M

Total Mine Production per Year -- 1.2 M tons

Burden per Ton = $\frac{\$2.15 \text{ M}}{1.2 \text{ M tons}}$ = \$1.79

3.5 Operating Personnel

The type and number of operating personnel assumed for the study are given below:

LONGWALL SECTION -- DIRECT LABOR

<u>Occupation</u>	<u>Number Required/ Section</u>
Shearer Operator	2
Chock Setter	4
Headgate Man	1
Utility Man	2
Mechanic	1

CONTINUOUS SECTION -- DIRECT LABOR

<u>Occupation</u>	<u>Number Required/ Section</u>
Continuous Miner Operator	1
Machine Operator Helper	1
Shuttle Car Operator	2
Roof Bolter	2
Roof Bolter Helper	2
Utility Man	2
Mechanic	1

HOURLY ALLOCATED LABOR

<u>Occupation</u>	<u>Number Required/ Section</u>
Supply Motorman	2
Trackman	4
Mason	1
Pumper	1
Utility Man	1
Roving Mechanic	1
Fire Boss	1

ALLOCATED SALARIED PERSONNEL

	<u>Number Required</u>	<u>Total Estimated Salary Expense Per Year</u>
Superintendent	1	
General Mine Foreman	1	
Asst. Mine Foreman	3	
Section Foreman	12	
Maintenance Foreman	1	
General Shop Foreman	1	
Mine Maintenance Foreman	3	
Chief Mine Engineer	1	
Draftsman	1	
Survey Crew	3	
Safety Director	1	
Safety Inspector	3	
Dust Sampler	3	
Time Keeper/Bookkeeper	1	
Purchasing Supervisor	1	
Warehouse Man	4	
		<hr/> \$940,800

4.0 DATA ANALYSIS

4.1 Output Format

As discussed in Section 2.1, the basic technique to be used for the analysis is Rate of Return on Investment (ROI). The model output format is designed to facilitate this type of analysis; a sample format is shown by Exhibit 1. It displays, for each year of equipment life, all revenues and expenses which are estimated to occur. The techniques used to estimate these revenues and expenses are discussed in Section 2. Specific parameters which may require additional explanation are discussed below:

- o Gross Revenues are calculated as tons per year multiplied by price per ton
- o Total Costs are calculated as the sum of all Direct Operating Costs plus Allocated Depreciation
- o Operating Income is Gross Revenue minus Total Costs
- o Federal Taxes are calculated at a rate of 46% of total taxable income. Total taxable income is determined within MCAM as Operating Income minus tax-loss carryforwards. When a tax-loss carryforward occurs, it is explicitly outputted as such. Any applicable Investment Tax Credit is taken when warranted.
- o Net Income is after-tax income, i.e., Gross Revenues minus Direct Operating Costs, Allocated Depreciation and Federal Income taxes net of Investment Tax Credit.
- o Cash Flow is Net Income plus all non-cash "expenses" i.e., Net Income plus Depreciation and Depletion.
- o Cost per Ton is Total Costs divided by Tons per Year. Note that this figure includes the non-cash expenses of total Depreciation and Depletion and does not include Federal taxes.
- o Return on Investment is calculated as described in Section 2.1.1 by utilizing the predicted yearly cash flows.

ANNUAL COST ANALYSIS (IN THOUSANDS) - KLOS WALL SYSTEM (2.0 SHIFTS PER DAY)
FACE LENGTH = 525. FT SEAM HEIGHT = 7.5 FT

	YEAR 0	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	YEAR 10
TONS PER YEAR		491	491	456	491	491	456	491	491	456	491
PRICE (PER TON)*		20.00	21.50	23.11	24.85	26.71	28.71	30.87	33.18	35.67	38.34
GROSS REVENUES		9830	10567	10529	12212	13128	13080	15171	16308	16249	18846
CAPITAL FUNDS											
FACE CONVEYOR	1139			1292		1466		1662		1885	
SHEARER	1247										
SHIELD SUPPORTS	2988										
OTHER EQUIPMENT	500										
TOTAL	5774										
DIRECT OPER COST											
LABOR (PROD)		736	776	818	917	967	1020	1144	1207	1273	1428
HOURLY		472	493	516	593	620	647	745	778	813	935
SALARIED		263	282	303	325	348	373	400	429	459	492
SUPPLIES		619	660	651	748	797	786	904	962	950	1092
MAINTENANCE		305	922	1053	1045	1195	1186	1355	1345	1537	1525
CHARGES		1492	1529	1453	1611	1657	1581	1759	1816	1739	1943
INTEREST		144	144	144	144	144	144	144	144	144	144
DEPRECIATION		1995	756	986	641	911	529	844	420	786	314
DEPLETION		934	1004	1000	1160	1247	1243	1441	1549	1544	1790
ALLOCATED DEPREC		880	880	815	880	880	815	800	880	815	880
TOTAL COSTS		7104	6669	6922	7147	7798	7305	8471	8323	8788	9116
OPERATING INCOME		2726	3898	3607	5065	5330	5775	6699	7986	7460	9731
TAXES (FEDERAL)		1254	1793	1659	2330	2452	2656	3082	3673	3432	4476
I.T.C.		577	0	129	0	147	0	166	0	189	0
NET INCOME		2049	2105	2077	2735	3025	3118	3784	4312	4217	5255
DEPLETION		934	1004	1000	1160	1247	1243	1441	1549	1544	1790
TOTAL DEPRECIATION		2874	1636	1801	1521	1791	1344	1724	1300	1602	1194
CASH FLOW	-5774	5857	4744	3586	5416	4597	5705	5286	7161	5477	8239
COST PER TON*		14.45	13.57	15.19	14.54	15.86	16.04	17.24	16.93	19.29	18.55
RETURN ON INVEST		0.900									

* COSTS ARE IN WHOLE DOLLARS

EXHIBIT 1

MCAM Output Format

TONS/SHIFT =	1198.78
PANELS/YEAR =	1.37
SHEARER SPEED (FT/MIN) =	12.01
CONVEYOR CAPACITY (TONS/MIN) =	20.00
CONVEYOR SPEED (FT/MIN) =	220.00
SUMPING TIME (MIN) =	33.90
CUTTING TIME (MIN) =	162.00

Other information is outputted on each page in order to provide a complete description of the scenario being studied. This additional information is:

- o system (Kloswall, longwall, continuous)
- o number of shifts per day
- o seam height
- o face length
- o conveyor capacity (representing the total system capacity)
- o conveyor speed
- o cutting time

The following variables are calculated:

- o tons per shift
- o shearer speed
- o sumping time per cycle

All output reports, with detailed data for analysis, are provided in Volume II of this study.

4.2 Production Models

The models used for estimating production per shift are described in Section 2.2.1. The specific consequences of using each of these models, i.e., longwall and continuous miner, will now be discussed and should be clearly understood by the user of this report. Assumptions implicit in each of the models have major impacts on the study results.

4.2.1 Longwall Production Systems Model

The longwall/Kloswall system production equation used in this study assumes that the system will always operate so as to load the conveyor to capacity. This means that, regardless of its potential shearing ability, the shearer will never cut more or less than enough to fully load the conveyor. Thus, the conveyor capacity serves in the model as the variable through which the average system capacity (in tons per minute of operating time) can be inputted. It must be clear to the reader, that the shearer speed in this model is a function of the system/conveyor capacity and can be used to assess the feasibility of the inputted capacity.

4.2.2 Continuous Mining Systems

The continuous mining system's economics are analyzed as a function of ROM production per shift. The regression equation described in Section 2.2.1.2 was developed to provide the reader with a means of correlating various production levels with seam height. However, because of the limited amount of data, this regression equation should be considered to describe only an approximate relationship.

4.3 Analysis of Longwall Systems

All analyses of the longwall systems have been done in the framework of the operating scenarios described in Section 3. Within each mine scenario, the analysis is performed for each of the equipment systems defined in Section 3.2., i.e.:

- o normal longwall system
- o high capacity longwall system
- o Hi-Rel Kloswall system
- o Lo-Rel Kloswall system

Regardless of the general scenario studied, all Rates of Return on Investment are quite good. Typically, for 2 shift operation, the analysis predicts a Return on Investment ranging from 40% to 105%.

4.3.1 Comparative Analysis of Longwall Systems

Using the scenarios described in Section 3, a detailed analysis comparing a conventional longwall system to a Kloswall system was performed. The complete data base for this analysis is provided in Appendix B. Appendix C contains a scenario-by-scenario analyses of this data base. A summary of the results and a discussion are provided in the following paragraphs.

4.3.1.1 Summary of Results

In the 7.5 foot seam height, the Kloswall system compares as follows to the longwall system:

- o the Kloswall system always results in a higher production rate -- this advantage ranges from 4% to 56%

- o the costs of the two systems are comparable in this seam height
- o the Kloswall system always results in a higher Return on Investment -- this advantage ranges from 1.5% to 27.8%.

In the 10.75 foot seam height, the Kloswall system has the following comparisons to the conventional longwall system:

- o the Kloswall system does not always produce a higher rate -- the high capacity longwall system will generally produce more coal per shift. Under these conditions, production per shift ranges from a 58% advantage for the Kloswall system to a 10% advantage for the longwall system. The circumstances under which the two systems are compatible occur when high capacity longwall systems are compared to the Kloswall systems.
- o the costs of the two systems are comparable in this seam height
- o the Return on Investment is not always higher for the Kloswall system -- in the scenario where a high capacity longwall system is compared to the low-reliability Kloswall system, the longwall system has a 7.7% advantage in the 375 foot face and essentially the same ROI in the 525 foot and 675 foot face. It has a 2.0% disadvantage in the 875 foot face. In all other scenarios, the Kloswall possesses an advantage ranging from 0.9% to 29.5%.

4.3.1.2 Discussion

The analysis indicates that the Kloswall system is expected to outperform the normal longwall system in all scenarios in the lower seam height. The crucial factor leading to this result is the deeper web at which the Kloswall shearer cuts. The deep web allows the shearer to match the capacity of the current top-capacity conveyors at a relatively low shearer haulage speed. The maximum attainable shearer speed for current normal longwall shearers limits the shearer capacity in this seam height to well below the capacity of the top-capacity conveyors.

This disadvantage for the normal longwall systems disappears in the higher seam. In this seam height, a state-of-the-art longwall system can match the performance of a Kloswall system. Only if the Kloswall system is indeed more reliable than the normal longwall system will it out-perform the state-of-the-art longwall in the high seam scenario.

It is interesting to note that, in the high seam height, neither the longwall nor the Kloswall shearer has to cut at the maximum haulage speed to load the conveyor to capacity. The longwall shearer reaches a capacity of 1,200 tons per hour at a haulage speed of 16.4 feet per minute, while the Kloswall shearer reaches this capacity at 8.52 feet per minute.

4.3.2 Sensitivity to Initial Investment

The sensitivity of ROI to initial equipment costs for the Kloswall system was investigated. Because the costs for the Kloswall shearer and shields are currently engineering estimates, we wished to investigate the correlation between initial investment and ROI. For this, we selected the following scenarios:

Face Length	525 feet
Seam Height	7.5 feet and 10.75 feet
Cutting Time	162.2 minutes
Shifts/Day	2

The costs of the Kloswall shearer and shields were increased, simultaneously, by 10%, 20%, 40%, 60%, and 100%. The effect on ROI for each escalation was determined from MCAM. This data is presented in Tables VI and VII and graphically displayed in Figure 3. The data allows comparison of various levels of initial Kloswall cost with the estimated ROI for conventional longwall systems under the same scenario. This comparison shows the following:

- o When compared to normal longwall systems, the Kloswall initial equipment cost could be increased approximately 50 to 60 percent and still result in ROI's comparable to conventional longwall systems.
- o When compared to high capacity longwall systems, the Kloswall initial equipment costs could be increased by approximately 25 percent and still result in an ROI comparable to a conventional longwall system in a 7.5 foot seam. In a 10.75 foot seam, Kloswall initial equipment cost could be increased by approximately 10 percent and still result in an ROI comparable to a conventional longwall in this seam height.

TABLE VI

ROI as a Function of Kloswall Shearer and Shield Cost,
 With Comparison to Conventional Longwall Systems
 525 Foot Face Length, 7.5 Foot Seam Height, 2 Shift Operation

Total Kloswall Equipment Cost (K dollars)	Change In Kloswall Initial Cost for Shearer and Shields (Percent)	Return On Investment (Percent)		
		Hi-Rel Kloswall	Normal Longwall	Hi-Capacity Longwall
5398	Base	93.0	71.4	80.3
5774	+10	90.0		
6150	+20	84.8		
6902	+40	76.1		
7653	+60	69.0		
9157	+100	57.6		

TABLE VII

ROI as a Function of Kloswall Shearer and Shield Cost,
 With Comparison to Conventional Longwall Systems
 525 Foot Face Length, 10.75 Foot Seam Height, 2 Shift Operation

Total Kloswall Equipment Cost (K dollars)	Change In Kloswall Initial Cost for Shearer and Shields (Percent)	Return On Investment (Percent)		
		Hi-Rel Kloswall	Normal Longwall	Hi-Capacity Longwall
6168	Base	93.0	64.9	87.6
6620	+10	87.0		
7072	+20	81.8		
7978	+40	73.1		
8884	+60	66.1		
10695	+100	54.6

FIGURE 3

Sensitivity of ROI to Kloswall Equipment Cost Estimates and Relationship to Current Longwall Systems

Overall, this analysis indicates that fairly large errors in the cost estimates for Kloswall equipment could be tolerated, particularly for low seam application, and still have the Kloswall system maintain its advantage over conventional longwall. This tolerance to error decreases in higher seams and when compared to high capacity longwall systems.

4.3.3 Optimal Face Length Analysis

One of the results of this study is the assessment of optimal face lengths for longwall mining. Given that the production model used does accurately describe the production to be expected from a longwall system, then there will be a face length beyond which additional investment in capital equipment will not provide sufficient production to offset its initial cost. Typical curves for production per shift and for equipment costs as a function of face length are shown in Figures 4 and 5. The existence of an optimum face length is indicated by the asymptotical nature of the production function and the linear nature of the capital cost function.

FIGURE 4: Form of Production per Shift as a Function of Face Length

FIGURE 5: Form of Equipment Costs as a Function of Face Length

To fully explore this phenomenon, it was necessary to exercise MCAM for face lengths from 100 feet to 1,000 feet. For this analysis, eight scenarios were studied, each for 2 shift per day operation. The eight scenarios are defined in Table VIII.

TABLE VIII
Scenarios Studied for Analysis of
Optimal Face Length

Equipment System	Seam Height
Normal Longwall	7.5 foot seam
High Capacity Longwall	7.5 foot seam
Normal Longwall	10.75 foot seam
High Capacity Longwall	10.75 foot seam
Low Reliability Klosswall	7.5 foot seam
High Reliability Klosswall	7.5 foot seam
Low Reliability Klosswall	10.75 foot seam
High Reliability Klosswall	10.75 foot seam

These scenarios provided sufficient information to understand the optimal face length phenomenon.

A summary of the data obtained for this analysis is presented in Table IX which presents a ranking of scenarios by maximum Return on Investment and displays the economically optimal face length. However, remember that the panel length is fixed at 3,024 feet for the study. This factor and others should be variable for a generalized analysis. Detailed data for each face length and scenario together with graphs of each scenario are presented in Appendix A.

TABLE IX
Scenario Ranking by Return on Investment (ROI)
(2 Shift Per Day Operation)
(Panel Length of 3,024 Feet)

Rank	Scenario	Approximate Maximum ROI (%)	Optimum Face Length (Feet)
1	High Capacity Longwall; 10.75 foot seam	105	200 - 375
2	High Reliability Klosswall; 10.75 foot seam	100	300 - 400
3	High Reliability Klosswall; 7.5 foot seam	100	300 - 500
4	High Capacity Longwall; 7.5 foot seam	94	200 - 400
5	Low Reliability Klosswall; 10.75 foot seam	93	200 - 500
6	Low Reliability Klosswall; 7.5 foot seam	91	300 - 500
7	Normal Longwall; 7.5 foot seam	81	200 - 400
8	Normal Longwall; 10.75 foot seam	79	200

The following analysis can be made from the following data:

- o In Longwall systems, the ROI begins to decrease at approximately a 400 ft. face length, and the investor is indifferent between a range of face lengths from 200 to 400 ft. The maximum ROI ranges from approximately 80% to 105% depending on the seam height, with the high capacity systems showing the highest rate of return in each seam height.

- o In Kloswall systems, the ROI begins to decrease at approximately a 500 ft. face length; however, it does not reach the peak area until approximately 300 ft. Between face lengths ranging from 300 to 500 ft., the investor is again indifferent to the face length. The maximum ROI ranges from approximately 90% to 100% with the High Reliability system providing the highest rate of return in each seam height.

4.4 Analysis of Continuous Mining Systems

The analysis of continuous mining systems has been done in terms of production per shift. The production rates studied are related approximately to seam heights through the regression equation described in Section 2.

4.4.1 Sensitivity to Production per Shift

For purposes of this analysis, it is convenient to study ROI with respect to production per shift.

Table X provides a summary of the data used for analysis. The data is plotted in Figure 6. For this analysis, equipment cost was held constant at \$650K and 2 shift per day operation is assumed. From Figure 6, we can see that ROI is highly dependent on production per shift. The data plots into a nearly linear line, the slope of which is 46% ROI/100 ROM Tons of Production, i.e., for each additional 100 ROM tons per shift, the ROI increases by 46%. Figure 6 also depicts the point of production beyond which a negative ROI will be experienced. This is at approximately 220 ROM tons per shift; which corresponds to about 27 shuttle cars (@ 8 tons) per shift.

TABLE X
ROI As A Function of Production Per Shift -- 2 Shift Operation

ROM Tons/Shift	ROI
128	< 0
222	≈ 0
315	56.7
411	102.8
600	186.0

FIGURE 6

Return on Investment on Continuous Mining System
As a Function of ROM Tons Per Shift

4.4.2 Comparison to Longwall Systems

The analysis shows that continuous mining systems have the potential for significantly greater rates of return on investment than longwall systems. Data to support this is summarized in Table XI (also included in Appendix B) and on the detailed outputs in Volume II. As discussed in Section 4.4.1, this potential is largely a function of production per shift.

Table XI compares the ROI predicted for the high reliability Klosswall system and the high capacity conventional longwall system to the continuous mining system. The data is representative of 2 shift operation.

TABLE XI

Comparison of Longwall and Continuous Mining Systems,
Various Face Lengths and Production Rates,
2 Shift Operation

Face Length	ROI(%), Kloswall System ¹		ROI(%), Longwall System ²		ROI(%), Continuous Mining System				
	7.5 foot seam	10.75 foot seam	7.5 foot seam	10.75 foot seam	ROM Tons per Shift				
					128	222	315	411	600
375	100.3	100.2	89.7	99.3	<0	=0	56.7	102.8	186.0
525	96.0	93.0	80.3	87.6					
675	88.6	86.7	70.1	78.8					
875	79.1	76.5	61.6	67.6					

¹ High Reliability System, Ref. Tables B-I and B-V.

² High Capacity System, Ref. Tables B-II and B-VI.

4.5 Effects of Number of Shifts per Day

Data concerning the effect of the number of shifts per day on ROI are presented in Tablex B-IX through B-XIII in Appendix B and in the detailed outputs of Volume II. One, two and two and a half shift operation was studied.

As expected, the ROI generally increases for an increase in the number of shifts per day. For longwall systems, changing from one to two shift operation typically produces a 45% increase in ROI; changing from two to three operations, typically increases ROI by 15%.

For the continuous mining system, the change from one to two shift operation results in increases ranging from 56% at a production rate of 315 ROM tons/shift to 98% at a 600 ROM tons/shift production rate. For a change from two to three shifts at production rates below approximately 375 ROM tons/shift, actually results in a lower ROI which says that there is not sufficient additional coal mined to offset the added operating and support costs. For production rates of approximately 375 ROM tons/shift and higher, the extra shift does increase ROI though not nearly as much as the change from one to two shifts.

5.0 CONCLUSIONS

The first conclusion to come from this study is that deep web (Kloswall) mining systems find their greatest advantage in mid-seam heights. A 7.5 foot seam was investigated for this study. Here, cutting a deeper web permits loading a high capacity face conveyor while maintaining reasonable shearer speeds. Conventional longwall systems would require shearer speeds beyond the current state-of-the-art to load the same face conveyors in these seam heights.

Current state-of-the-art face conveyors can carry 1,200 tons per hour and the state-of-the-art shearer speed for conventional longwall systems is 25 feet per minute. This upper limit on shearer speed limits the maximum production for conventional longwall systems in the 7.5 foot seam to approximately 1,000 tons per hour. Because more coal is taken per linear foot by the deep web (Kloswall) system, it is able to load the 1,200 ton per hour face conveyor in this seam height while maintaining a relatively low shearer speed of 12 feet per minute. It is not currently known what the upper limit on the Kloswall shearer speed will be. However, the Foster-Miller Kloswall report derives a shearer speed of 13.4 feet per minute, i.e., above the maximum rate assumed by this study.

In higher seam heights, state-of-the-art longwall systems could be equipped with 1,200 ton per hour face conveyors and load then to capacity without exceeding 25 foot per minute shearer speeds. When the Kloswall system is compared to such state-of-the-art longwall systems in the 10.75 foot seam height, quite comparable economic results are projected. Only if the Kloswall system can work with greater reliability (as measured by actual cutting time), can it provide an economic advantage.

Also of interest in this seam height is the fact that calculated shearer speeds are relatively low. The shearer speed for the longwall was calculated to be only 16.4 feet per minute and for the Kloswall system it is only 8.5 feet per minute. This indicates that even greater system capacity is possible in such seam heights.

A second major conclusion is that Continuous mining systems possess a greater potential for profitability than either of the longwall systems studied. This potential is highly sensitive to production rate, however, and can be a two-edged sword. The study shows that if the production rate falls below 220 ROM tons per shift, a negative ROI will occur. Each additional 100 ROM tons per shift above this point, however, is projected to result in an increase in ROI of 46%. This result implies that efforts designed to improve the availability of continuous mining systems are well worth their cost. Such efforts would include improvements in maintenance procedures and in operator training.

The third major conclusion is that economically optimum longwall mining scenarios can be ascertained by using discounted cash flow techniques. The study was expanded to apply this concept to discovering the economically optimal face length, given the fixed conditions of the study such as panel length and sumping length. There is no reason, however, that additional work with this technique would not provide a method for varying any set of parameters and determining an economically optimal mine layout.

The study has found then, that the deep web (Kloswall) longwall mining system will possess an economic advantage over conventional longwall systems under conditions where its improved system capacity can be utilized or where it does indeed exhibit a higher reliability. These conditions cannot always be assumed to be satisfied, however, and each case should be studied, using a discounted cash flow technique, on its own merits. The Kloswall system will tend toward its greatest advantage in mid-seam heights, i.e., approximately 7.5 feet.

Further, the profitability of continuous mining systems, given sufficient production rates, appear worthy of careful consideration.

APPENDIX A

SUMMARY DATA FOR OPTIMAL FACE LENGTH ANALYSIS, LONGWALL SYSTEMS

TABLE A-I
LONGWALL SYSTEM DATA

Shifts per Day	2		2		2		2	
Seam Height (Feet)	7.5		7.5		10.75		10.75	
Cutting Time (Minutes)	148.5		148.5		148.5		148.5	
Conveyor Capacity (Tons/Min)	12.5		16.7		12.5		20.0	
Nomenclature	Normal		Hi-Capacity		Normal		Hi-Capacity	
Face Length (Feet)	ROI (%)	P _S (Tons)	ROI (%)	P _S (Tons)	ROI (%)	P _S (Tons)	ROI (%)	P _S (Tons)
100	60.5	372	73.1	445	64.6	417	88.2	572
200	81.4	560	94.3	683	79.1	612	106.4	867
300	81.2	672	93.1	832	76.3	725	104.4	1046
375	78.1	731	89.7	911	74.0	782	99.3	1141
525	71.4	812	80.3	1022	64.9	861	87.6	1273
675	61.9	868	70.1	1096	55.9	912	78.8	1359
875	52.9	914	61.6	1164	47.0	957	67.6	1438
1000	47.9	936	55.7	1195	42.2	977	61.9	1474

ROI: Return on Investment

P_S: Production per Shift

TABLE A-II
KLOSWALL SYSTEM DATA

Shifts per Day	2		2		2		2	
Seam Height (Feet)	7.5		7.5		10.75		10.75	
Cutting Time (Minutes)	148.5		162.2		148.5		162.2	
Conveyor Capacity (Tons/Min)	20.0		20.0		20.0		20.0	
Nomenclature	Lo-Reliability		Hi-Reliability		Lo-Reliability		Hi-Reliability	
Face Length (Feet)	ROI (%)	P _S (Tons)	ROI (%)	P _S (Tons)	ROI (%)	P _S (Tons)	ROI (%)	P _S (Tons)
100	54.5	408	61.9	446	64.6	466	69.9	509
200	84.8	667	90.4	729	88.3	745	95.7	813
300	91.5	846	100.0	924	93.1	930	101.7	1016
375	91.2	948	100.3	1035	91.6	1033	100.2	1129
525	87.7	1099	96.0	1200	87.5	1183	93.0	1292
675	80.6	1205	88.6	1317	78.8	1287	86.7	1406
875	73.9	1307	79.1	1427	69.6	1384	76.5	1511
1000	68.8	1355	76.0	1480	64.7	1429	71.1	1561

ROI: Return on Investment

P_S: Production per Shift

FIGURE A-1: NORMAL LONGWALL, 7.5 FOOT SEAM

FIGURE A-2: HIGH CAPACITY LONGWALL, 7.5 FOOT SEAM

FIGURE A-3: NORMAL LONGWALL, 10.75 FOOT SEAM

FIGURE A-4: HIGH CAPACITY LONGWALL, 10.75 FOOT SEAM

FIGURE A-5: LOW RELIABILITY KLOSSWALL, 7.5 FOOT SEAM

FIGURE A-6: HIGH RELIABILITY KLOSSWALL, 7.5 FOOT SEAM

FIGURE A-7: LOW RELIABILITY KLOSSWALL, 10.75 FOOT SEAM

FIGURE A-8: HIGH RELIABILITY KLOSSWALL, 10.75 FOOT SEAM

APPENDIX B

COMPARATIVE SUMMARY DATA TABLES

SHIFTS PER DAY 2

SEAM HEIGHT 7.5 (FT)

CONVEYOR CAPACITY, KLOSWALL 20.0 (TONS/MIN)

CUTTING TIME, KLOSWALL 162.2 (MIN)

CONVEYOR CAPACITY, LONGWALL 12.5 (TONS/MIN)

CUTTING TIME, LONGWALL 148.5 (MIN)

Face Length (feet)	KLOSWALL SYSTEM				LONGWALL SYSTEM			
	Tons Per Shift	Initial Investment (K Dollars)	Return on Investment (%)	Average Cost/Ton (Dollars)	Tons Per Shift	Initial Investment (K Dollars)	Return on Investment (%)	Average Cost/Ton (Dollars)
375	1,035	4,323	100.3	16.19	731	3,953	78.1	17.54
525	1,200	5,398	96.0	15.95	812	5,054	71.4	17.60
675	1,317	6,474	88.6	16.22	866	6,155	61.9	18.28
875	1,427	7,908	79.1	16.51	914	7,623	52.9	18.82

TABLE B-1: NORMAL LONGWALL; HI-REL KLOSWALL

SHIFTS PER DAY 2

SEAM HEIGHT 7.5 (FT)

CONVEYOR CAPACITY, KLOSWALL 20.0 (TONS/MIN)

CUTTING TIME, KLOSWALL 162.2 (MIN)

CONVEYOR CAPACITY, LONGWALL 16.7 (TONS/MIN)

CUTTING TIME, LONGWALL 148.5 (MIN)

Face Length (feet)	KLOSWALL SYSTEM				LONGWALL SYSTEM			
	Tons Per Shift	Initial Investment (K Dollars)	Return on Investment (%)	Average Cost/Ton (Dollars)	Tons Per Shift	Initial Investment (K Dollars)	Return on Investment (%)	Average Cost/Ton (Dollars)
375	1,035	4,323	100.3	16.19	911	4,264	89.7	16.73
525	1,200	5,398	96.0	15.95	1,022	5,489	80.3	16.78
675	1,317	6,474	88.6	16.22	1,096	6,715	70.1	17.41
875	1,427	7,908	79.1	16.51	1,164	8,349	61.6	17.97

TABLE B-II: HIGH CAPACITY LONGWALL; HI-REL KLOSWALL

SHIFTS PER DAY 2

SEAM HEIGHT 7.5 (FT)

CONVEYOR CAPACITY, KLOSWALL 20.0 (TONS/MIN)

CUTTING TIME, KLOSWALL 148.5 (MIN)

CONVEYOR CAPACITY, LONGWALL 12.5 (TONS/MIN)

CUTTING TIME, LONGWALL 148.5 (MIN)

Face Length (feet)	KLOSWALL SYSTEM				LONGWALL SYSTEM			
	Tons Per Shift	Initial Investment (K Dollars)	Return on Investment (%)	Average Cost/Ton (Dollars)	Tons Per Shift	Initial Investment (K Dollars)	Return on Investment (%)	Average Cost/Ton (Dollars)
375	948	4,323	91.2	16.73	731	3,953	78.1	17.54
525	1,099	5,398	87.7	16.47	812	5,054	71.4	17.60
675	1,205	6,474	80.6	16.77	866	6,155	61.9	18.28
875	1,307	7,908	73.9	17.10	914	7,623	52.9	18.82

TABLE B-III: NORMAL LONGWALL; LO-REL KLOSWALL

SHIFTS PER DAY 2

SEAM HEIGHT 7.5 (FT)

CONVEYOR CAPACITY, KLOSWALL 20.0 (TONS/MIN)

CUTTING TIME, KLOSWALL 148.5 (MIN)

CONVEYOR CAPACITY, LONGWALL 16.7 (TONS/MIN)

CUTTING TIME, LONGWALL 148.5 (MIN)

Face Length (feet)	KLOSWALL SYSTEM				LONGWALL SYSTEM			
	Tons Per Shift	Initial Investment (K Dollars)	Return on Investment (%)	Average Cost/Ton (Dollars)	Tons Per Shift	Initial Investment (K Dollars)	Return on Investment (%)	Average Cost/Ton (Dollars)
375	948	4,323	91.2	16.73	911	4,264	89.7	16.73
525	1,099	5,398	87.7	16.47	1,022	5,489	80.3	16.78
675	1,205	6,474	80.6	16.77	1,096	6,715	70.1	17.41
875	1,307	7,908	73.9	17.10	1,164	8,349	61.6	17.97

TABLE B-IV: HIGH CAPACITY LONGWALL; LO-REL KLOSWALL

SHIFTS PER DAY 2

SEAM HEIGHT 10.75 (FT)

CONVEYOR CAPACITY, KLOSWALL 20.0 (TONS/MIN)

CUTTING TIME, KLOSWALL 162.2 (MIN)

CONVEYOR CAPACITY, LONGWALL 12.5 (TONS/MIN)

CUTTING TIME, LONGWALL 148.5 (MIN)

Face Length (feet)	KLOSWALL SYSTEM				LONGWALL SYSTEM			
	Tons Per Shift	Initial Investment (K Dollars)	Return on Investment (%)	Average Cost/Ton (Dollars)	Tons Per Shift	Initial Investment (K Dollars)	Return on Investment (%)	Average Cost/Ton (Dollars)
375	1,129	4,905	100.2	14.11	782	4,715	74.0	17.52
525	1,292	6,168	93.0	15.70	861	6,041	64.9	17.74
675	1,406	7,431	86.7	16.08	912	7,367	55.9	18.41
875	1,511	9,115	76.5	16.42	957	9,135	47.0	19.09

TABLE B-V: NORMAL LONGWALL; HI-REL KLOSWALL

SHIFTS PER DAY 2

SEAM HEIGHT 10.75 (FT)

CONVEYOR CAPACITY, KLOSWALL 20.0 (TONS/MIN)

CUTTING TIME, KLOSWALL 162.2 (MIN)

CONVEYOR CAPACITY, LONGWALL 20.0 (TONS/MIN)

CUTTING TIME, LONGWALL 148.5 (MIN)

Face Length (feet)	KLOSWALL SYSTEM				LONGWALL SYSTEM			
	Tons Per Shift	Initial Investment (K Dollars)	Return on Investment (%)	Average Cost/Ton (Dollars)	Tons Per Shift	Initial Investment (K Dollars)	Return on Investment (%)	Average Cost/Ton (Dollars)
375	1,129	4,905	100.2	14.11	1,141	5,026	99.3	15.62
525	1,292	6,168	93.0	15.70	1,273	6,477	87.6	15.79
675	1,406	7,431	86.7	16.08	1,359	7,927	78.8	16.31
875	1,511	9,115	76.5	16.42	1,438	9,861	67.6	16.91

TABLE VI: HIGH CAPACITY LONGWALL; HI-REL KLOSWALL

SHIFTS PER DAY 2

SEAM HEIGHT 10.75 (FT)

CONVEYOR CAPACITY, KLOSWALL 20.0 (TONS/MIN)

CUTTING TIME, KLOSWALL 148.5 (MIN)

CONVEYOR CAPACITY, LONGWALL 12.5 (TONS/MIN)

CUTTING TIME, LONGWALL 148.5 (MIN)

Face Length (feet)	KLOSWALL SYSTEM				LONGWALL SYSTEM			
	Tons Per Shift	Initial Investment (K Dollars)	Return on Investment (%)	Average Cost/Ton (Dollars)	Tons Per Shift	Initial Investment (K Dollars)	Return on Investment (%)	Average Cost/Ton (Dollars)
375	1,033	4,905	91.6	16.30	782	4,715	74.0	17.52
525	1,183	6,168	87.5	16.22	861	6,041	64.9	17.74
675	1,287	7,431	78.8	16.64	912	7,367	55.9	18.41
875	1,384	9,115	69.6	16.99	957	9,135	47.0	19.09

TABLE B-VII; NORMAL LONGWALL; LO-REL KLOSWALL

SHIFTS PER DAY 2

SEAM HEIGHT 10.75 (FT)

CONVEYOR CAPACITY, KLOSWALL 20.0 (TONS/MIN)

CUTTING TIME, KLOSWALL 148.0 (MIN)

CONVEYOR CAPACITY, LONGWALL 20.0 (TONS/MIN)

CUTTING TIME, LONGWALL 148.0 (MIN)

Face Length (feet)	KLOSWALL SYSTEM				LONGWALL SYSTEM			
	Tons Per Shift	Initial Investment (K Dollars)	Return on Investment (%)	Average Cost/Ton (Dollars)	Tons Per Shift	Initial Investment (K Dollars)	Return on Investment (%)	Average Cost/Ton (Dollars)
375	1,033	4,905	91.6	16.30	1,141	5,026	99.3	15.62
525	1,183	6,168	87.5	16.22	1,273	6,477	87.6	15.79
675	1,287	7,431	78.8	16.64	1,359	7,927	78.8	16.31
875	1,384	9,115	69.6	16.99	1,438	9,861	67.6	16.91

TABLE B-VIII: HIGH CAPACITY LONGWALL; LO-REL KLOSWALL

FACE LENGTH 675 (FEET)

SEAM HEIGHT 7.5 (FEET)

CONVEYOR CAPACITY, KLOSWALL 20.0 (TONS/MIN)

CUTTING TIME, KLOSWALL 162.2 (MIN)

CONVEYOR CAPACITY, LONGWALL 12.5 (TONS/MIN)

CUTTING TIME, LONGWALL 148.5 (MIN)

Number Of Shifts Per Day	HI-REL KLOSWALL SYSTEM		NORMAL LONGWALL SYSTEM	
	Return On Investment (%)	Average Cost/Ton (Dollars)	Return On Investment (%)	Average Cost/Ton (Dollars)
1	40.1	20.59	23.2	23.45
2	88.6	16.22	61.9	18.28
2.5	109.5	15.73	74.8	17.75

TABLE B-IX: EFFECT OF NUMBER OF SHIFTS PER DAY;
NORMAL LONGWALL, HI-REL KLOSWALL

FACE LENGTH 675 (FEET)

SEAM HEIGHT 7.5 (FEET)

CONVEYOR CAPACITY, KLOSWALL 20.0 (TONS/MIN)

CUTTING TIME, KLOSWALL 148.5 (MIN)

CONVEYOR CAPACITY, LONGWALL 16.7 (TONS/MIN)

CUTTING TIME, LONGWALL 148.5 (MIN)

Number Of Shifts Per Day	LO-REL KLOSWALL SYSTEM		HIGH CAPACITY LONGWALL SYSTEM	
	Return On Investment (%)	Average Cost/Ton (Dollars)	Return On Investment (%)	Average Cost/Ton (Dollars)
1	34.5	21.54	27.4	22.45
2	80.6	16.77	70.1	17.41
2.5	99.6	16.25	87.2	16.80

TABLE B-X: EFFECT OF NUMBER OF SHIFTS PER DAY;
HIGH CAPACITY LONGWALL; LO-REL KLOSWALL

FACE LENGTH 675 (FEET)

SEAM HEIGHT 10.75 (FEET)

CONVEYOR CAPACITY, KLOSWALL 20.0 (TONS/MIN)

CUTTING TIME, KLOSWALL 162.2 (MIN)

CONVEYOR CAPACITY, LONGWALL 12.5 (TONS/MIN)

CUTTING TIME, LONGWALL 148.5 (MIN)

Number Of Shifts Per Day	HI-REL KLOSWALL SYSTEM		NORMAL LONGWALL SYSTEM	
	Return On Investment (%)	Average Cost/Ton (Dollars)	Return On Investment (%)	Average Cost/Ton (Dollars)
1	38.9	20.51	20.4	23.79
2	86.7	16.08	55.9	18.41
2.5	104.5	15.54	69.3	17.82

TABLE B-XI: EFFECT OF NUMBER OF SHIFTS PER DAY;
NORMAL LONGWALL, HI-REL KLOSWALL

FACE LENGTH 675 (FEET)

SEAM HEIGHT 10.75 (FEET)

CONVEYOR CAPACITY, KLOSWALL 20.0 (TONS/MIN)

CUTTING TIME, KLOSWALL 148.5 (MIN)

CONVEYOR CAPACITY, LONGWALL 20.0 (TONS/MIN)

CUTTING TIME, LONGWALL 148.5 (MIN)

Number Of Shifts Per Day	LO-REL KLOSWALL SYSTEM		HIGH CAPACITY LONGWALL SYSTEM	
	Return On Investment (%)	Average Cost/Ton (Dollars)	Return On Investment (%)	Average Cost/Ton (Dollars)
1	33.5	21.43	34.3	20.91
2	78.8	16.64	78.3	16.31
2.5	95.1	16.04	95.2	15.75

TABLE B-XII: EFFECT OF NUMBER OF SHIFTS PER DAY;
HIGH CAPACITY LONGWALL, LO-REL KLOSWALL

Number of Shifts Per Day	CONTINUOUS MINING SYSTEMS									
	128 ROM Tons/Shift		222 ROM Tons/Shift		315 ROM Tons/Shift		411 ROM Tons/Shift		600 ROM Tons/Shift	
	Return on Investment (%)	Average Cost/Ton (Dollars)	Return on Investment (%)	Average Cost/Ton (Dollars)	Return on Investment (%)	Average Cost/Ton (Dollars)	Return on Investment (%)	Average Cost/Ton (Dollars)	Return on Investment (%)	Average Cost/Ton (Dollars)
1	<0	NA	<0	39.50	0.3	30.67	35.2	27.39	88.3	22.79
2	<0	NA	≈ 0	32.34	56.7	26.83	102.8	24.06	186.0	20.16
2.5	<0	NA	<0	34.27	51.1	27.64	112.0	24.96	217.0	20.84

TABLE B-XIII: EFFECTS OF NUMBER OF SHIFTS PER DAY
FOR CONTINUOUS MINING SYSTEMS

APPENDIX C

COMPARATIVE SUMMARIES

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SPECIFIC COMPARATIVE ANALYSIS
7.5 FOOT SEAM HEIGHTS, 2 SHIFT OPERATION

Normal Longwall; Hi-Rel Kloswall (Ref: Table B-1)

- o Production per shift is always higher for the Kloswall system.
The difference ranges from 41.5% in the 375 foot face to 56.1% in the 975 foot face.
- o The initial investment for the Kloswall system is higher than, but comparable to, the investment for the longwall system.
This ranges from 3.7% in the 875 foot face to 9.3% in the 375 foot face.
- o Return on Investment is always higher for the Kloswall system.
This improvement remains in a narrow range from 22.2% in the 375 foot face to 26.2% in the 675 foot face.

High Capacity Longwall; Hi-Rel Kloswall (Ref: Table B-2)

- o Production per shift is always higher for the Kloswall system.
The difference ranges from 13.6% in the 375 foot face to 22.6% in the 875 foot face.
- o The initial investments for the two systems are comparable.
The difference ranges from 1% higher for the Kloswall in the 375 foot face to 5.6% less for the Kloswall in the 875 foot face.
- o Return on Investment is always higher for the Kloswall system.
This improvement ranges from 10.6% in the 375 foot face to 17.5% in the 675 foot face.

Normal Longwall; Lo-Rel Kloswall (Ref: Table B-3)

- o Production per shift is always higher for the Kloswall system.
The difference ranges from 29.7% in the 375 foot face to 43.0% in the 875 foot face.
- o The initial investment for the Kloswall system ranges from 3.7% higher in the 875 foot face to 9.3% higher in the 375 foot face.
- o Return on Investment is always higher for the Kloswall system.
This improvement ranges from 13.1% in the 375 foot face to 21.0% in the 875 foot face.

High Capacity Longwall; Lo-Rel Kloswall (Ref: Table B-4)

- o Production per shift is always higher for the Kloswall system.
The difference ranges from 4.1% in the 375 foot face to 12.3% in the 875 foot face.
- o The initial investments for the two systems are comparable.
The difference ranges from 1.3% more for Kloswall to 5.6% less for Kloswall.
- o Return on Investment is always higher for the Kloswall system.
This improvement ranges from 1.5% in the 375 foot face to 12.3% in the 875 foot face.

SPECIFIC COMPARATIVE ANALYSIS
10.75 FOOT SEAM HEIGHTS, 2 SHIFT OPERATION

Normal Longwall; Hi-Rel Kloswall (Ref: Table B-5)

- o Production per shift is always higher for the Kloswall system.
The difference ranges from 44.4% in the 375 foot face to 57.9% in the 875 foot face.
- o The initial investments for the two systems are quite comparable.
The difference ranges from 4.0% more for the Kloswall system in the 385 foot face to 0.2% less for this system in the 875 foot face.
- o Return on Investment is always higher for the Kloswall system.
This improvement ranges from 26.2% in the 375 foot face to 29.5% in the 875 foot face.

High Capacity Longwall; Hi-Rel Kloswall (Ref: Table B-6)

- o Production per shift is quite comparable between the two systems.
The difference varies from a 1.0% advantage for the longwall to a 5.1% advantage for Kloswall.
- o The initial investment is always higher for the longwall system.
The difference ranges from 2.5% in the 375 foot face to 8.2% in the 875 foot face.
- o Return on Investment is always higher for the Kloswall system.
This improvement ranges from 0.9% in the 375 foot face to 8.9% in the 875 foot face.

Normal Longwall; Lo-Rel Kloswall (Ref: Table B-7)

- o Production per shift is always higher for the Kloswall system.
The difference ranges from 32.1% in the 375 foot face to 44.6% in the 875 foot face.
- o The initial investment for the two systems is quite comparable.
The difference ranges from 4.0% more for the Kloswall system in the 375 foot face to 0.02% less for this system in the 875 foot face.
- o Return on Investment is always higher for the Kloswall system.
This improvement ranges from 17.6% in the 375 foot face to 22.6% in the 875 foot face.

High Capacity Longwall; Lo-Rel Kloswall (Ref: Table B-8)

- o Production per shift is always higher for the longwall system.
This longwall advantage ranges from 3.9% in the 875 foot face to 10.5% in the 375 foot face.
- o The initial investment is always slightly higher for the longwall.
This ranges from 2.5% in the 375 foot face to 8.2% in the 875 foot face.
- o Return on Investment is quite comparable between the two systems.
The difference ranges from a 7.7% advantage for the longwall in a 375 foot face to a 2.0% disadvantage in a 875 foot face.

APPENDIX D

PRODUCTION AND COST DATA

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Mine Name, Location and Seam Height	Thousands of Tons Per Year	Tons Per Day ^①	Shifts Per Day	Number of Continuous Miners Per Shift	Tons Per Shift Per Continuous Miner
Harmony Mining Co. -- PA Lo. Freeport 3'6"	150	682	2	2	170
Helvetia Coal Co. -- PA Up. Freeport 4'4"	315	1432	3	5	95
Florence No. 2 -- PA Up. Freeport 4'4"	289	1314	3	8	55
Eastern Associated -- PA Lo. Kittanning 3'6"	114	518	2	8	32
Duquesne Light Co. -- PA Sewickley 4'4"	727	3304	3	8	138
Döverspike Bros. Coal Co. -- PA Lo. Kittanning 3'6"	93	422	2	2	106
Apache Mining Co. -- KY Elkhorn 3'9"	30	136	1	1	136
Martin County Coal Corp. -- KY Coalburg 7'10"	823	3741	3	6	208
Pikeville Coal Co. -- KY Lo. Elkhorn 4'6"	590	2682	2	8	168
Peabody Coal -- IL No. 6 9'4"	2807	12759	2	8	797
Sahara Coal Co. -- IL No. 5 5'6"	501	2277	3	2	380

① 220 days per year

TABLE D-I: Production per Shift for Continuous Mining Systems;
Source: Keystone Manual 1978 Edition

Producing Districts		FOB Mines \$/ton Term	
		Ask	Bid
(1)	Central Pennsylvania	\$23.00	\$21.00
(2)	Western Pennsylvania	22.50	21.00
(3)	Northern West Virginia	23.75	23.25
(4)	Ohio	24.25	23.75
(7)	Southeastern West Virginia & parts of Virginia	24.50	21.75
(8)	Southern West Virginia eastern Kentucky northern Tennessee & parts of Virginia	25.00	22.00
(9)	Western Kentucky	23.00	20.00
(10)	Illinois	22.50	20.50
(11)	Indiana	21.50	19.25
(12)	Iowa	16.00	15.00
(13)	Alabama & southern Tennessee	24.00	22.00
(15)	Kansas, Missouri & parts of Oklahoma	17.50	16.00

TABLE D-II

Current Contract Steam Coal Prices

Source: Coal Week

Equipment		Cost
Shearer, 6' to 9' seam		\$ 700K
Shearer, 9' to 12' seam		\$ 900K
750 ton/hour face conveyor	375' face	\$ 503K
	525' face	\$ 704K
	675' face	\$ 905K
	875' face	\$1,173K
1200 ton/hour face conveyor	375' face	\$ 814K
	525' face	\$1,139K
	675' face	\$1,465K
	875' face	\$1,899K
Shields 6' - 9' seam		\$ 30.0K each
Shields 9' - 12' seam		\$ 37.5K each
Other Equipment ¹		\$ 500K

TABLE D-III
Longwall Equipment Costs

Source: Equipment Manufacturers

¹ Includes state loader, power pack, electric drive motors and power center.

Equipment	Cost
Shearer 6' - 9' seam	\$1,134K
Shearer 9' - 12' seam	\$1,247K
1200 ton/hour face conveyor 375' face	\$ 814K
525' face	\$1,139K
675' face	\$1,465K
875' face	\$1,899K
Shields 6' - 9' seam	\$ 25.0K each
Shields 9' - 12' seam	\$ 31.25K each
Other equipment ¹	\$ 500K

TABLE D-IV
Kloswall Equipment Cost

Source: Foster-Miller Associates, Updated Costs

1 Includes stage loader, power pack, electric drive motors and power center.

Equipment	Cost
Continuous Miner 3' to 6.5' seam	\$ 350K
Continuous Miner 6' to 12' seam	\$ 388K
Shuttle car	\$ 70K each
Roof Bolter	\$ 80K
Other Equipment ¹	\$ 80K

TABLE D-V
Continuous Mining Equipment Costs

Source: Equipment Manufacturers

1 Includes scoop, power center and rectifier

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APPENDIX E

FIELD TRIPS AND VISITS MADE IN
CONJUNCTION WITH KLOSWALL ECONOMIC ANALYSIS

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Equipment and Manufacturer Contacts

The following is a chronological listing of field trips and visits made in conjunction with the Kloswall program.

In each case, the date, place and names of the participants are given together with a summation of relevant discussion.

DATE: July 17, 1978

VISIT TO: National Mine Service Company, Pittsburgh, Pa.

ATTENDING: Mr. W. Von der Linden, Vice President, NMS Company
Mr. E. Schroeder, KETRON, INC.

DATE: July 19, 1978

VISIT TO: Dowty Corporation, Zelienople, Pa.

ATTENDING: Mr. H. Martin, General Manager
Mr. E. Schroeder, KETRON, INC.
Mr. C. Gabrill, KETRON, INC.

DATE: July 18, 1978

VISIT TO: Joy Manufacturing Co., Franklin, Pa.

ATTENDING: Mr. R. Breithaupt, Manager, Longwall Systems
Mr. D. Heinzer, Longwall Systems Design
Mr. E. Schroeder, KETRON, INC.
Mr. C. Gabrill, KETRON, INC.

DATE: July 27, 1978

VISIT: Carbon Fuel Co., Chesapeake, West Virginia

ATTENDING: Mr. P. Longenecker, Director, Mine Planning & Development
Mr. E. Schroeder, KETRON, INC.

DATE: July 29, 1978

VISIT TO: Dean Witter, Inc., New York, NY

ATTENDING: Mr. F. Price, First Vice President
Mr. B. Resnick, KETRON, INC.
Mr. R. Davis, KETRON, INC.

DATE: August 2, 1978
VISIT TO: Consolidation Coal Company, Washington, Pa.
ATTENDING: Mr. R. Tetrick, Longwall Coordinator, Robinson Run 95
Mr. E. Schroeder, KETRON, INC.

The following listing of manufacturers were contacted (by mail) for cost data of continuous mining systems:

- o Jeffrey Mining Machinery Division
- o Long Airdox
- o Lee Norse
- o Joy Manufacturing

APPENDIX F

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APPENDIX F

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