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METHANE DRAINAGE WITH HORIZONTAL BOREHOLES IN ADVANCE OF LONGWALL MINING

— TECHNICAL AND ECONOMIC FEASIBILITY —

FINAL REPORT

MAY 1981

Prepared for
Methane Recovery from Coalbeds Project
Morgantown Energy Technology Center
Contract No. DE-RP21-81MC16444

by

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FOREWORD

This document was prepared by TRW Energy Engineering Division for the Methane Recovery from Coalbeds Project under Department of Energy Contract DE-RP21-81MC16444. Technical direction was provided by the Morgantown Energy Technology Center with Mr. J. R. Duda as Project Manager and Dr. H. D. Shoemaker as Technical Project Officer of the subject contract effort.

This study was conducted in partial fulfillment of the contract.

METHANE DRAINAGE WITH HORIZONTAL BOREHOLES
IN ADVANCE OF LONGWALL MINING
- AN ANALYSIS -

FINAL REPORT

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Prepared for

METHANE RECOVERY FROM COALBEDS PROJECT
MORGANTOWN ENERGY TECHNOLOGY CENTER
CONTRACT NO. DE-RP21-81MC16444

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ABSTRACT

The U.S. Department of Energy (DOE) Morgantown Energy Technology Center has implemented a comprehensive program to demonstrate the technical and economic viability of coalbed methane as an energy resource. The program is directed toward solution of technical and institutional problems impeding the recovery and use of large quantities of methane contained in the nation's minable and unminable coalbeds.

Conducted in direct support of the DOE Methane Recovery from Coalbeds Project, this study analyzes the economic aspects of a horizontal borehole methane recovery system integrated as part of a longwall mine operation. It establishes relationships between methane selling price and annual mine production, methane production rate, and the methane drainage system capital investment. Results are encouraging, indicating that an annual coal production increase of approximately eight percent would offset all associated drainage costs over the range of methane production rates and capital investments considered.

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1. SUMMARY

1.1 BACKGROUND

Although government and industry projects have demonstrated the technical viability of vertical, slant, and horizontal borehole techniques for draining coalbed methane on an R&D scale, they have not been used to drain, collect, and ultimately utilize significant amounts of the 700 trillion cubic feet of methane contained in the nation's coalbeds. Lack of market demand, high investment costs, interference with coal production operations are examples of reasons given by mine operators for not installing methane drainage systems. In view of the contribution this energy source could make to the nation's energy problem, there is a clear need to better understand the economics of coalbed methane production and the interactions between methane drainage and other mine subsystems.

This study addresses the economics and interactions of a horizontal borehole drainage system integrated into a typical million plus tonnage class (MMTPY) longwall mine. Specifically, it determines and analyzes relationships between the required selling price of methane and annual mine production, methane production rate, drainage system capital investment, and mine ventilation costs.

1.2 APPROACH

Engineering data developed for the longwall mine included a mine plan, development mining and panel extraction sequences, ventilation system, equipment and labor requirements, drainage system configuration and equipment, etc., to the level of detail needed to prepare investment, operating, and maintenance costs estimates. Methane production rates of 1.0, 1.5, and 2.0 million standard cubic feet per day were selected as reasonable estimates based on historical data from previous studies. These data were used as inputs to the TRW Resource Economic Venture Analysis (REVA) discounted cash flow model to determine the required methane selling price to produce a return on investment of 20 percent at the three methane production levels. Analyses were then conducted to determine the sensitivity of required selling price to changes in annual coal production, drainage system capital investment, and ventilation system costs.

1.3 RESULTS

- <u>Required Methane Selling Price</u>

  The required selling price of methane recovered from the longwall mine, which assumes no increase in annual coal production attributable to the methane drainage system, was determined to be approximately $5.40, $3.70, and $2.80 per thousand cubic feet for methane production rates of 1.0, 1.5, and 2.0 million cubic feet per day, respectively. At these prices, revenue from methane sales offset all methane drainage system costs including a 20 percent return on investment. At the intermediate and high production rates, these selling prices are presently within the competitive price range of natural gas and will become even more so at anticipated higher levels subsequent to decontrol of natural gas.

- <u>Annual Mine Production</u>

  As illustrated in Figure 1-1, an annual coal production increase of approximately eight percent will offset the methane drainage system costs for the range of methane production rates analyzed. This result is particularly significant for several reasons. First, the modest increase in coal production is believed to be achievable using current methane drainage technology to eliminate or minimize some of the methane-caused operating delays. Second, at the increased coal production level, installation and operation of the drainage system costs the mine operator nothing even if the methane is vented to the atmosphere. Third, revenues from methane sales or on-site utilization for coal drying or power generation can be used to increase the mine profit margin or to decrease the required coal selling price at the same rate of return. Finally, methane drainage systems installed in very gassy mines offer the potential of coal production increases and methane production rates well above those analyzed during this study.

- <u>Methane Production Rate</u>

  The sensitivity of required selling price to methane production rate diminishes with increasing daily production. Assuming no increase in annual coal production, increasing the methane production rate from 1.0 to 1.5 million cubic feet per day reduces the selling price by 70 percent, and doubling the production rate reduces the price by approximately one-half.

- <u>Drainage System Cost</u>

  Methane selling price is insensitive to -5 to +10 percent change in the expected capital investment cost of the drainage system. Within reasonable limits, methane production rate and drainage system capital investment requirements should not deter implementation of systems to drain, collect, and utilize coalbed methane.

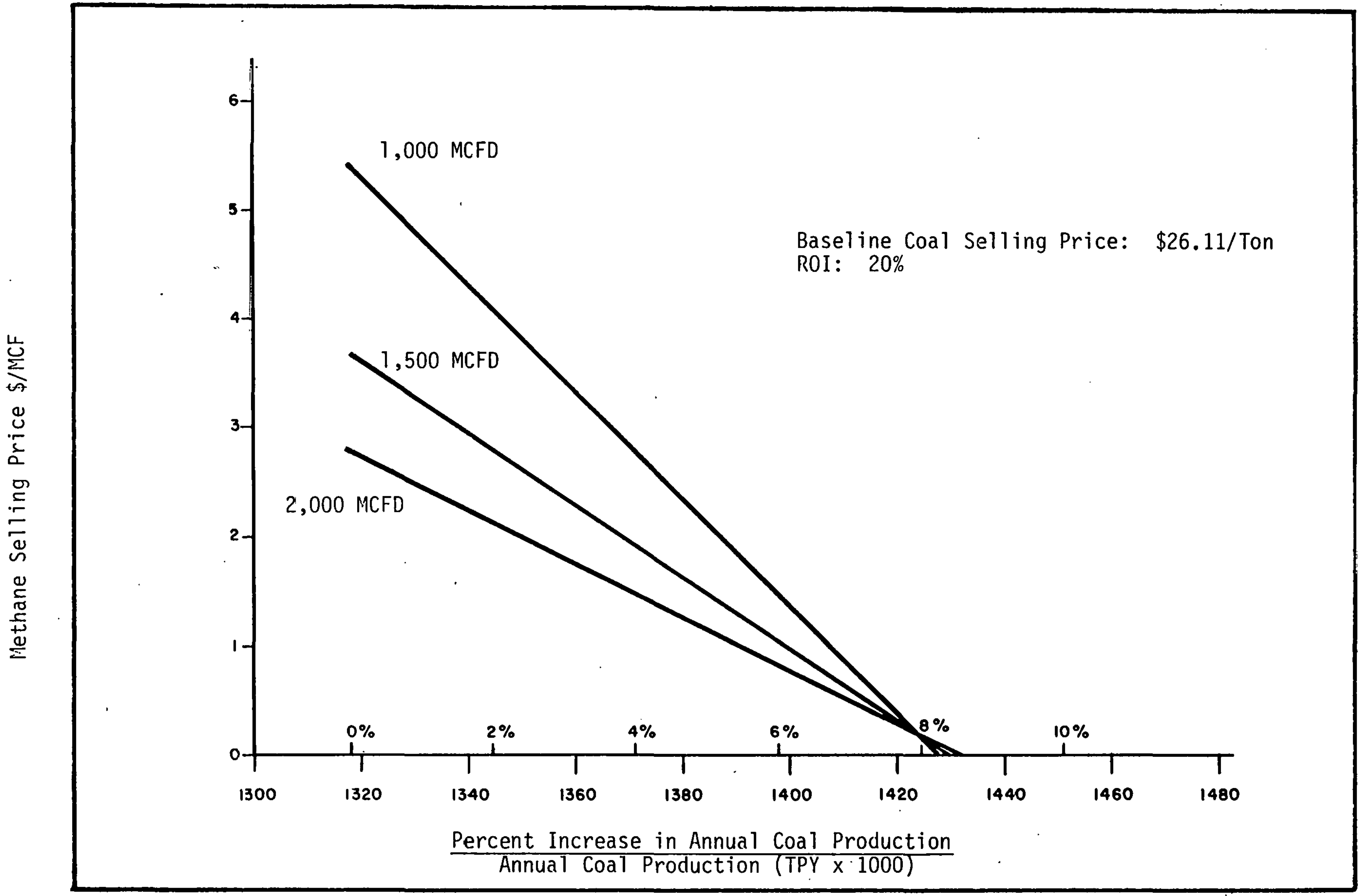

Figure 1-1. Methane Selling Price Vs. Annual Coal Production

- <u>Ventilation System Cost</u>

  Results of this study indicate that a horizontal borehole drainage system has no appreciable effect on methane selling price attributable to changes in the initial capital investment cost of a contemporary longwall mine ventilation system. It is expected, however, that better understanding of interactions between ventilation predrainage and other mining subsystems offers several cost reduction possibilities. Among these are reducing the number or diameter of ventilation shafts, smaller fans, and development of totally new mine-wide ventilation system concepts which take into account the overall decrease in methane emissions.

1.4 RECOMMENDATIONS

The above results lead to the following recommendations:

- Additional investigation is needed to better understand and quantify the interactions between methane predrainage, ventilation and other mine systems such as dust suppression, extraction and haulage. Results of such investigations would provide data needed to support development of optimized mine plans which balance technical, operational, regulatory and economic considerations related to methane predrainage.

- Technical and cost data for each methane drainage technique should be updated and validated through cooperative agreements with companies involved in production or end-utilization of methane. The data should then be analyzed using a methodology which integrates methane drainage techniques into typical longwall and room-and-pillar mining operations. The analytical results should be formatted to permit extrapolation to site-specific characteristics that differ from typical mining conditions. The end product, typically a handbook, would contain data, user guidelines, and instructions to the level of detail necessary for mine planners with limited knowledge of methane drainage to:

  - Tailor and further refine the analyses by incorporating mine-specific geotechnical parameters, operational practices, and corporate accounting considerations.
  - Rapidly conduct first-order analyses to determine the economic feasibility of implementing specific or combinations of methane drainage techniques.
  - Determine the technical and economic impacts of the drainage system on mine subsystems such as ventilation, face equipment, haulage and support operations.
  - Select the technique(s) and end uses most applicable and of greatest benefit to the mining operation.
  - Develop mine plans and operational practices which maximize resource recovery.

- Continued government support is needed to enhance the technical and economic viability of coalbed methane drainage systems for the following reasons:

  - This study reinforces results, conclusions and recommendations of other related studies regarding the potential economic benefits of coalbed methane.
  - The mining industry itself cannot, for a number of reasons, support the massive research efforts needed to develop systems for draining, collecting and utilizing coalbed methane.
  - The traditional methane removal method--dilution and venting to the atmosphere--does not, for economic and strategic reasons, serve the best interests of the mining industry or the nation.

2. INTRODUCTION

2.1 BACKGROUND

Initial methane drainage research activities conducted by government and industry concentrated on the development and demonstration of techniques directed toward improving the safety of underground mining operations. Lack of consumer demand for methane further constrained the research to methods for venting the methane safely either at the surface or into the mine ventilation system. As a result, only a minute amount of methane extracted to date has been utilized for pipeline gas, LNG production, chemical feedstock, boiler fuel, or gas turbine power generation.

The following techniques have been demonstrated on an R&D scale for draining methane from coal seams in advance of and/or concurrent with coal extraction operations:

- Horizontal boreholes from shafts
- Vertical boreholes to virgin coal seams
- Directional slant holes
- Vertical boreholes into gob
- Horizontal boreholes from underground workings.

Numerous reports and papers have documented the research activity results and the additional development efforts needed to recover and utilize the projected 700 trillion cubic feet of methane contained in the nation's remaining four trillion tons of identified and hypothetical coal reserves. Although many of those studies conclude or imply that methane drainage will permit higher productivity and lower ventilation cost, limited information is available to quantify the postulated economic benefits.

This study is intended to quantify the relationship of the following parameters to the required selling price of methane:

- Daily methane production rate
- Methane drainage system's capital investment
- Annual coal production.

2.2 STUDY OBJECTIVES

The objectives of this analysis of draining methane in advance of longwall mining are to:

- Define the equipment, manpower, and consumables requirements to drain methane safely in concurrence with longwall panel development according to current regulations and guidelines.
- Determine the relationship of methane selling price to methane production rate.
- Determine the effect of the capital cost of the methane drainage system and of annual coal production on methane selling price.

2.3 STUDY APPROACH

Realizing that many independent factors influence the economic viability of a methane drainage system, a limited parametric analysis was conducted to better understand the relationship of various factors to methane selling price. This section summarizes each of the tasks and their relationship to achieving the objectives set forth above.

A longwall mine scenario was assumed as base case. Steady-state production will be achieved with two dual drum longwall shearers with development work carried on by milling head continuous miners and dual boom roof bolters.

For the purpose of the Discounted Cash Flow (DCF) analysis, the capital and operating costs were determined. These include initial and deferred investments, manpower, consumables, power, and maintenance.

Having defined all cash flows involved in a longwall mine venture, a Discounted Cash Flow Rate-of-Return analysis was performed to compute coal selling price for the base case coal rate considered. This cost was used in the derivation of methane selling price for the subsequent tasks.

All costs associated with an underground methane drainage system, including initial and deferred investments and O&M costs, were defined so that a representative selling price could be calculated. The methane produced was assumed to be injected into an existing high pressure public utility pipeline. The price of the methane produced considered a 20 percent rate-of-return on all investment operating and maintenance costs required to produce it through to the compressor outlet.

Impact on the mine's ventilation system was determined with respect to design and cost having analyzed the performance requirements of the current federal regulations. Title 30 CFR, Part 75, Subpart D, was used as the reference for this task. No assumptions were made as to future modifications to the regulations.

Impact on methane selling price as a function of methane production rates and percent change in annual coal production were determined utilizing a series of DCF computer runs. Methane selling price versus annual coal production was plotted for three methane production rates. This was to permit the determination of methane selling price knowing the mean methane production rate from the mine and the effect of the methane drainage system on annual coal production.

This same data was also represented in a different format by plotting methane selling price against mean methane production rate for three annual coal production rates.

In both cases, annual coal production was varied because the relationship of methane drainage to delays in longwall production due to methane emissions is dependent upon factors which are very site-specific and cannot be readily determined for this hypothetical case.

Though a determined effort was made to define the costs associated with an underground methane drainage system, the degree of accuracy of the cost estimate is dependent upon potential future changes in the state-of-the-art and federal regulations. For this reason, the relationship of the methane drainage system's capital investment to methane selling price was determined by varying the system's baseline investment by -5, +5, and +10 percent. A negative value was taken to include possible cost reductions that might be realized through contractual agreements with equipment suppliers. A +10 percent change in the system's capital estimate was assumed to be a reasonable upper limit.

3. METHANE DRAINAGE SYSTEM

3.1 LONGWALL MINING SCENARIO

A one-line diagram of the longwall mine used in this analysis is shown on Figure 3-1. Assuming a rectangular mining property, panels are developed and extracted using a half-advance, half-retreat approach to distribute the overburden weight evenly over the unmined coal and to reduce initial capital investment costs for such items as track, cable, conveyor belt, and piping.

Two shafts are sunk initially to provide for access, material handling, and ventilation. Continuous miner sections develop the entry network necessary for two longwall sections and then proceed to outline follow-on panels in advance of longwall extraction operations. In the eighth and ninth years, a ventilation shaft is sunk in the center of the southern portion of the mine property and the mains are advanced south to intersect the shaft bottom. The mine plan is the mirror image of the north, and the haulage and mining equipment is retreated from the north and installed in like manner in the south.

Toward the end of the 20-year mine life, the longwall and continuous mining sections are retreated back to the shafts, and as much of the remaining barrier pillars are extracted as roof conditions permit.

Mining-related cost data was used on the following information and assumptions:

- Time and motion studies conducted by the industry for various government sponsors indicate that, in medium- to high-seam coal, longwall and continuous miner section production averages approximately 900 and 300 tons per shift, respectively. These rates were arbitrarily reduced 10 percent to better represent a mine with production delays due to excessive methane concentrations at the face.

- Assuming that 22 days are required to move longwall section equipment to a new panel, two longwall sections operating three shifts per day, 198 of the 220 scheduled working days per year, produce 2 x 3 x 198 x 810 = 962,280 tons. Using a coal density of 80 pounds per cubic foot and a seam thickness of 6 feet, the time to extract two 500-foot by 4,500-foot panels is:

$$\frac{2 \times 80 \times 6 \times 500 \times 4{,}500}{2{,}000 \times 957{,}420} = 1.13 \text{ years}$$

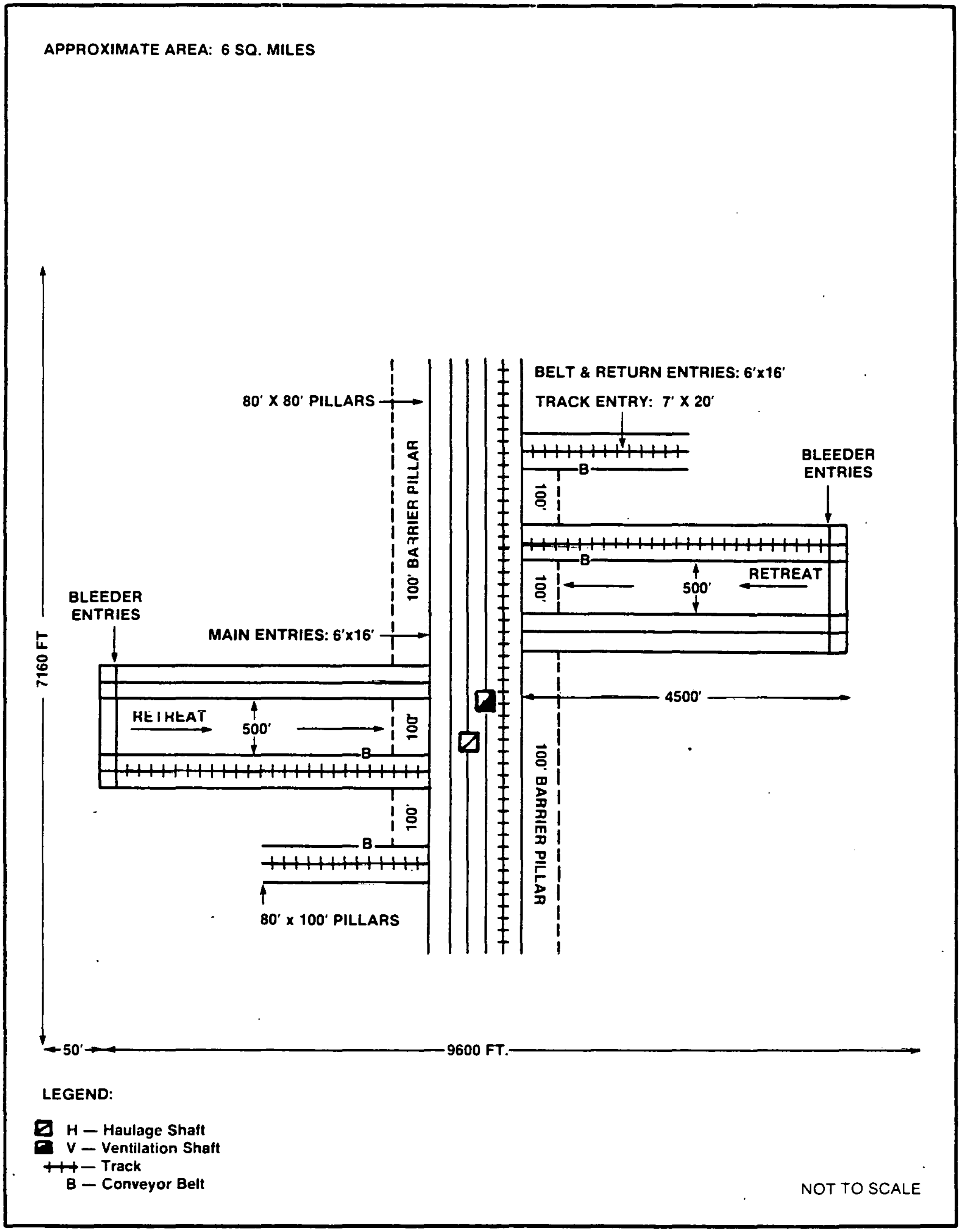

Figure 3-1. Mine Plan (Northern Half)

- As shown below, approximately 106,541 tons of coal must be extracted by continuous miner sections to outline each longwall panel.

Seam thickness:	6 ft
Panel dimensions:	500 ft by 4,500 ft
Main entries and crosscuts:	96 ft centers
Panel entries:	98 ft centers
Panel crosscuts:	116 ft centers
Coal density:	80 lbs/ft^3

Item	Height	Width	Length	No.	Volume
Main Entries	6 ft	16 ft	500 ft	6	288,000 ft^3
Main Entry Crosscuts	6 ft	16 ft	80 ft	$\left(\frac{500}{96}\right)^* \times 5$	230,400 ft^3
Panel Entries	6 ft 6 ft	16 ft 20 ft	4,500 ft 4,500 ft	2 1	864,000 ft^3 540,000 ft^3
Panel Crosscuts	6 ft	16 ft	80 ft	$\left(\frac{4,500}{116}\right)^* \times 2$	599,040 ft^3
Bleeder Entries	6 ft	16 ft	500 ft	2	96,000 ft^3
Bleeder Crosscuts	6 ft	16 ft	80 ft	$\left(\frac{500}{96}\right)^* \times 1$	46,080 ft^3
				TOTAL:	2,663,520 ft^3

*Quotient in parentheses is rounded up to the next highest integer.

$$\frac{2,663,520 \text{ ft}^3 \times 80 \text{ lbs/ft}^3}{2,000 \text{ lbs/ton}} = 106.541 \text{ tons}$$

- In accordance with standard industry practice, two continuous miner sections were provided for each of the two longwall sections. Three of the sections are active two shifts per day, 220 days per year. The spare section operates when any of the three active sections is down for maintenance or rebuild. Annual coal production from the continuous miner sections is 3 x 2 x 220 x 270 = 356,400 tons, sufficient to ensure that mine development does not constrain the more capital intensive and higher production rate longwall sections.

- In consideration of contingencies, the analysis assumed 3 rather than 356,400 ÷ 106,541 = 3.3 panels were developed and available for methane drainage each year.

- Total average annual mine production from longwall and continuous miner sections was 962,280 plus 356,400 ≈ 1.32 million tons.

3.2 GAS PRODUCTION ASSUMPTIONS

For the purpose of this analysis it was necessary to make several simplifying assumptions. It was assumed that each longwall panel would yield 80 percent of the contained methane in approximately one year. This is compatible with the time required to mine a panel, though methane production rate is recognized to be dependent upon coal geology in terms of cleat spacing and permeability. Additionally, a steady-state production rate was assumed to simplify the analysis without affecting the results adversely. The production rates used throughout the analysis are the time-weighted average of the varying production rates typically observed.

The compressor is driven by a natural gas engine which is fueled directly by the collected methane. A rule-of-thumb estimate that five percent of the methane production would be consumed by the engine was used for this analysis. The following additional assumptions were made for this analysis:

- Ten 500-foot-long horizontal boreholes will be sufficient to drain each longwall panel and adjacent barrier pillars.

- Each hole is allowed to drain at least one year.

- The collected gas is pipeline-quality with no upgrading required.

- In situ gas pressure, under unrestricted flow conditions, is approximately 25 psig.

- The methane is injected into a high pressure utility pipeline.

3.3 LEGAL CONSTRAINTS

The 1969 Federal Coal Mine Health and Safety Act and the 1977 Mine Safety and Health Act mandated that all personnel must work in a safe environment both above and below ground. An adequate ventilation system which provides the necessary amount of fresh air and dilutes and renders harmless explosive and toxic gases must be incorporated in every underground mine operation. Though the laws, in their initial form, did not specifically address underground methane pipeline systems, the intent of the law is directly applicable. The following considerations for the design and operation of a methane drainage system are readily derived from the regulations:

- Methane should readily drain with minimal head loss under its natural pressure to avoid pressure buildup within the system which may induce leakage or increase emissions through the coal itself.

- Since an underground coal mine provides a harsh environment, redundant safety features must be incorporated in the form of a bypass system and automatic shut down capability.

- Methane concentrations between five and 15 percent by volume are explosive. The system must be designed to prevent methane at or above 1.5 percent concentration during a malfunction or because of damage to the system.

- At no time should the safety of the mine personnel be compromised.

3.4 METHANE COLLECTION SYSTEM

This section describes the hardware associated with draining methane from each longwall panel for a period of at least one year prior to coal extraction. Three panels will be developed each year requiring that identical setups be installed on opposite sides of the haulage shaft once the main and development entries have been advanced far enough to allow access to the panels. As each new panel is developed, the drainage system from the previously developed panel is dismantled and transferred to the new panel. There is one main collection line for the mine connected to the surface compressor facility through a 10-inch inside diameter (I.D.) vertical borehole.

3.4.1 Drainage Hole Requirements

The longwall panels are approximately 4,500 feet long and 500 feet wide (see Figure 3-1, a one-line diagram of the mine layout). As each continuous miner sections advances the three development entries, the post-mounted hydraulically driven drill bores 500-foot-long horizontal drainage holes on 410-foot centers at a predetermined acute angle to the long axis of the entries. Each hole is then reamed to 4-7/8 inches for 20 feet and a 20-foot length of 4-inch I.D. carbon steel standpipe is cemented in the hole.

A 4-inch manual throttling ball valve is connected to the collar so that differential pressures between the holes can be counteracted by adjusting the headloss due to friction in each hole.

A 2-inch I.D. 100-psig safety shutoff valve is connected in series with a reducer at each borehole. It is automatically activated by a spring to shut off the hole in the event line pressure or borehole pressure exceeds 100 psig.

Following in series is a 2-inch I.D. three-way electro-pneumatic actuation valve. The valve is actuated by either an 0.5 Amp electrical signal from the methane detection system or by the pneumatic shutdown system.

Connected to this three-way valve is a 2-inch I.D. carbon steel pressure relief line which is connected to the three-way valves at each drainage hole and to the 10-inch vertical borehole.

Next in series is a 2-inch I.D. safety shutoff valve, automatically activated by its spring set at 30 psig. This valve will close in the event line pressure exceeds 30 psig, redirecting the methane into the pressure relief line, previously described.

At the junction of the 2-inch lateral gathering lines with the 8-inch mainline, a 3-inch manual globe valve will be connected with the appropriate reducers. Figure 3-2 is a schematic of the drainage hardware installed at each borehole.

3.4.2 Dewatering System

The methane collected will have varying amounts of entrained water and water slugs, depending upon the coal geology, and will be dewatered prior to entering the main collection line. The dewatering equipment consists of a float trap, a gas/liquid centrifugal separator, and a drip tank for water collection. Methane flow rates will be measured by a venturi flow meter in series with the lateral gathering line. A pressure differential indicator will be used to measure the pressure of methane through the line.

3.4.3 Main Collection Line

The main collection line is 8-inch I.D. polyethylene pipe chosen because of its resiliency and ease of handling. At 1,000-foot intervals, 8-inch electro-pneumatically actuated emergency shutdown valves are installed to

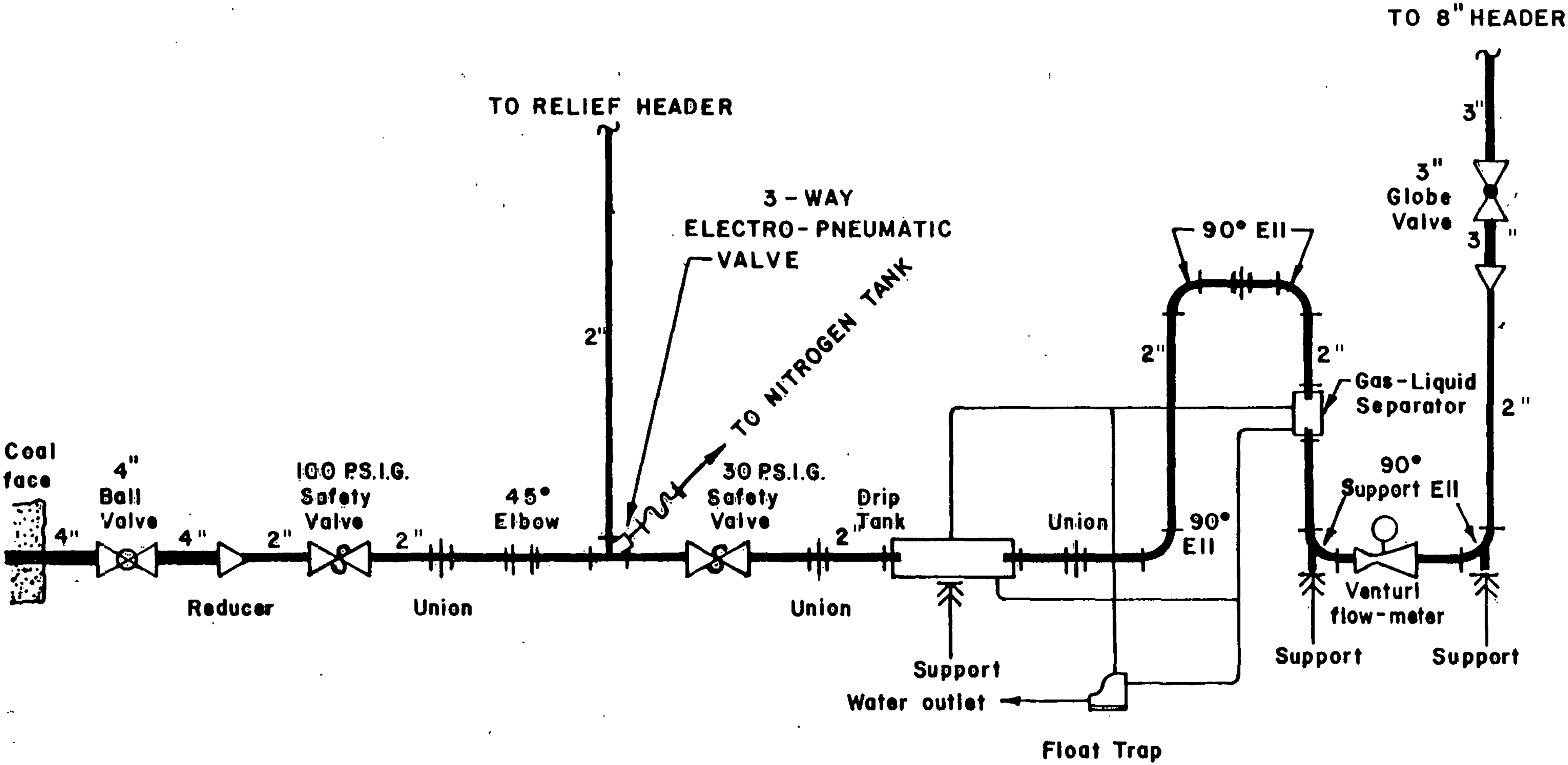

Figure 3-2. Schematic Diagram of Drainage Hole Hardware

isolate the line into segments to prevent excessive emissions of methane into the return air in the event of a break in the main collection line. The valve is closed by a 0.5 Amp electric signal from the methane detection system when methane concentration in the return air exceeds 1.5 percent by volume. Also in series with the main collection line are 8-inch safety shutoff valves automatically activated by a spring set at 25 psig. Should the line pressure exceed 25 psig, the valve will close, redirecting the methane into the pressure relief line by activating the 2-inch, 30 psig safety shutoff valves in each of the lateral gathering lines.

3.4.4 Pneumatic Safety Shutdown System

Each longwall panel drainage system will be equipped with two 300-cubic foot pressurized cylinders charged with nitrogen to 1,200 psig. A manifold will connect the two cylinders in such a way that when one tank becomes depleted, the other comes on line. A needle valve regulator will reduce the pneumatic line pressure to 30 psig. The pneumatic line is 1/2-inch I.D. polyethylene tubing which runs the entire length of the lateral gathering lines and the main collection pipeline. In the event of a roof fall on any part of the system, the tubing will break and activate the electro-pneumatic valves in the system to close.

3.4.5 Methane Detection System

The 1969 Federal Coal Mine Health and Safety Act mandates that the methane concentration in return air not exceed 1.5 percent by volume and no more than 2.0 percent when advancing into virgin areas.

It is also surmised by the intent of the law that a methane drainage system should be totally located in return air.

Methane sensors will be located at each drainage borehole and at 1,000-foot intervals along the main pipeline. Four sensors will be operated by each four-channel control station which includes a power supply, four sensor amplifiers, and strip recorders. In all, there will be fourteen such setups throughout the mine under steady-state conditions. The control stations will be hard-wire connected to each of the electro-pneumatically actuated safety shutoff valves with actuation by a 0.5 Amp signal.

3.4.6 Surface Compressor Facility

The surface compressor facility is a self-contained unit with a reciprocating two-stage compressor driven by a reciprocating natural gas engine.

Since this analysis considers three methane production rates, three separate compressors were sized to meet the flow rate requirements of 1,000, 1,500, or 2,000 SCFM. The fuel for the engine will be tapped directly from the vertical borehole and as a "rule-of-thumb", approximately five percent of the gas produced is consumed by the compressor.

4. CAPITAL, OPERATING, AND MAINTENANCE COSTS

The total capital requirement to bring the base case mine into full production and replace or rebuild equipment was based on results of an equipment productivity analysis, the mine plan developed, and cost data provided by equipment manufacturers. Initial, deferred, and working capital requirements are included in this section.

Also included is a detailed discussion of the operating and maintenance (O&M) costs associated with both the production of coal and methane from the mine.

Finally, this information provided the necessary data to conduct a DCF analysis to determine methane selling price for the various parametric combinations considered. This allowed comparison among the hypothetical cases to determine the relationships of methane production rate and capital investment to methane selling price.

4.1 INITIAL CAPITAL COSTS

The initial capital cost of developing each mine is represented by the sum of the direct and indirect costs associated with completing the fixed facilities and installing all equipment. The direct investments all fall into one of the following five categories:

a. Face equipment
b. Safety equipment
c. Other underground equipment
d. Surface facilities and equipment
e. Methane drainage equipment (hypothetical cases)

Each of these categories of direct investment is discussed below and included with each is a discussion of the effects a methane drainage system would have, if any, on the costs of each category.

The indirect cost associated with mine development is taken as two percent of the sum of the direct costs. Table 4-4 includes this cost for both the base and the methane drainage cases.

4.1.1 Face Equipment

The face equipment quantities and investments, shown on Table 4-1, are for both the base and methane drainage cases.

Table 4-1. Face and Safety Equipment, Initial Capital Investment Requirements
(1980 $ in Thousands)

Life Yrs	Item	Unit Cost	Base Case No. Req'd	Base Case Total Cost
Longwall Face Equipment				
10	Dual Drum Shearer	1,700	2	3,400
	Shield Supports	30	220	6,600
	Flight Conveyor	450	2	900
	Stageloader	120	2	240
	Belt Tailpiece	70	2	140
	Crusher	120	2	240
	Hydraulic Power Pack	120	2	240
	Electric Motors	70	Lot (2)	140
	Power Center, Switch Gear, Lighting	280	Lot (2)	560
10	Single Props	0.6	200	120
Total Longwall Face Equipment				12,580
Continuous Mining Face Equipment				
10	Continuous Miner	430	4	1,720
	Twin Boom Roof Bolter	125	4	500
	Shuttle Car	104	8	832
	Feeder Breaker	59	4	236
	Trickle Rock Duster	5	4	20
	Section Power Center	22	4	88
	Section Cable & Coupler (Sets)	30	4	120
	Auxiliary Fan	10	4	40
10	Sectionalizing Switch House	20	4	80
Total Continuous Mining Face Equipment				3,636

-- continued --

Table 4-1. Face and Safety Equipment, Initial Capital Investment Requirements
(1980 $ in Thousands)
(Continued)

Life Yrs	Item	Unit Cost	Base Case No. Req'd	Base Case Total Cost
	Safety Equipment			
5	Conveyor Motor Fire Protection	1	4	4
	Conveyor Belt Detection System	0.28/1000 ft	13,000 ft	3.6
	Auto Controls & Alarms	-	-	119
	Breathing Apparatus	1.35	5	6.8
	Self Rescuer	0.11	235	25.9
	Stretcher Set	0.30	5	1.5
	Safety Lamps	0.08	60	4.8
	Methanometer	0.65	35	22.8
	Fire Chemical Car	6.7	5	33.5
	Dust Sampler	0.68	15	10.2
5	Lamps & Batteries	0.05	285	14.3
	Total - Base Case			246.4

Compressor Station Safety Equipment for the Methane Drainage Cases

Life Yrs	Item	Unit Cost	No. Req'd	Total Cost
5	Process Gas Analyzer	4	1	4
	6 In. Auto. Shutoff Valve	3.8	1	3.8
5	Mobile Gas Analyzer	1.0	2	2
	Additional Investment			9.8

Two longwall sections and four continuous mining sections are purchased. Three continuous mining sections work six machine shifts per day to develop main, longwall panel, and bleeder entries. The normally idle fourth section is used for development work when any of the other three sections are out of service for repair and maintenance.

4.1.2 Safety Equipment Inventory and Cost

Table 4-1 shows the investment required for procurement of safety equipment for the base case. Included is the safety equipment associated with the surface compressor facilities for all the methane drainage cases. The total amount of safety equipment required to be purchased for the latter cases is much more significant than $9,800, but because the safety equipment is incorporated inseparably into the drainage system, the remaining costs were included in the following category.

4.1.3 Other Underground Equipment

Table 4-2 is subdivided into two categories: the first includes all the other underground equipment associated with the base case; the second includes all the additional underground equipment needed for the methane drainage cases. The amount of equipment from both groups is enough to bring the mine up to full coal and methane production, the latter being concurrently drained from two longwall panels.

4.1.4 Surface Facilities and Equipment Costs

The investment estimate for the surface facilities and equipment is detailed in Table 4-3 and is common to all cases. The additional costs for the surface compressor facility vary due to the three methane production rates considered, which are 1.0, 1.5, and 2.0 million standard cubic feet per day. For each methane production rate, only the compressor cost associated with that production rate should be considered.

4.1.5 Initial Capital Investment Summary

Table 4-4 summarizes the initial capital investment required for the base and methane drainage cases, including all indirect costs. The compressor facilities cost is considered separately in the DCF analysis because it varies with methane production.

Table 4-2. Other Underground Equipment, Initial Capital Investment Requirements (1980 $ in Thousands)

Life Yrs	Item	Unit Cost	Base Case No. Req'd	Base Case Total Cost
10	Triple Duty Rock Duster	37	3	111
	Mantrip Jeep	30	5	150
	Mechanic Jeep	24	5	120
	Personnel Jeep	24	3	72
	Supply Locomotive	81	2	162
	Supply Car	8	6	48
	48" Conveyor System (ft)	22.6/1000 ft	3,000 ft	67.8
	36" Conveyor System (ft)	16.0/1000 ft	10,000 ft	160
	Main Belt Power Center	19	2	38
	Panel Belt Power Center	19	2	38
	Main Belt Starter	6	2	12
	Panel Belt Starter	6	2	12
	High Voltage Cable (ft)	16.0/1000 ft	20,000 ft	320
	Couplers	1	19	19
	Transformer/Rectifier-Track	22	7	154
	Trolley & Feeder Wire (ft)	4.0/1000 ft	13,000 ft	52
	Track (60 lb)	16.9/1000 ft	13,000 ft	219.7
	Drainage & Fresh Water Lines (ft)	6.3/1000 ft	20,000 ft	126
	Pumps (Drainage)	-	-	26.9
	Telephone System	-	-	16
	48" Belt Take-Up	7.9	2	15.8
	36" Belt Take-Up	7.9	2	15.8
	Primary Switch House	20	1	20
	150 Hp Conveyor Head Drive	34	6	204
10	Conveyor Tail Units	4	4	16
	Total - Base Case			2,196

Table 4-2. Other Underground Equipment, Initial Capital Investment Requirements
(1980 $ in Thousands)
(Continued)

Additional Investment for the Methane Drainage Cases

Life Yrs	Item	Unit Cost	Base Case No. Req'd	Base Case Total Cost
10	Post Mounted Horizontal Drill & Hydraulic Power Pack	25	3	75
	USBM Designed Stuffing Box	0.75	3	2.25
	Mainline 8-5/8 In. O.D. Polyethylene Pipe	7.62/1000 ft	22,500 ft	171.45
	Lateral Gathering 2-3/8 In. O.D. Carbon Steel Pipe	1.22/1000 ft	450 ft	0.55
	Pressure Relief Line 2-3/8 In. O.D. Carbon Steel Pipe	1.22/1000 ft	22,500 ft	27.45
	4 In. Carbon Steel Borehole Casing	3.56/1000 ft	600 ft	2.14
	10-7/8 In. O.D. Vertical Borehole Casing	20.56/1000 ft	1,200 ft	24.67
	Contractor Drilling of 10-7/8 In. Borehole Incl. 25 Ft. of Standpipe	30/1000 ft	1,200 ft	36.0
	Multichannel Underground Methane Detection System			
	4 Sensors & Power Supply	0.75	14 (set)	10.5
	Sensor Amplifier	0.45	54	24.3
	Control Station	2.8	14	39.2
	Strip Recorder	0.325	54	17.55
10	Standby Power Supply	0.86	3	2.58

Table 4-2. Other Underground Equipment, Initial Capital Investment Requirements
(1980 $ in Thousands)
(Continued)

Additional Investment for the Methane Drainage Cases (Continued)

Life Yrs	Item	Unit Cost	Base Case No. Req'd	Base Case Total Cost
10	Water Separation Equipment Incl.:			
	Float Trap Gas/Liquid Separator Drip Tank	0.31	30	9.3
	Emergency Shutdown System (Electro-Pneumatic Actuation)			
	2 In. Valves (Electro-Pneumatic)	0.225	30	6.75
	8 In. Valves (Electro-Pneumatic)	1.72	23	39.56
	Nitrogen Tank Manifold	0.25	6	1.5
	2 In. 30 psi Relief Valve	0.225	30	6.75
	1/2 In. I.D. Polyethylene Black Tubing	0.019/100 ft Coil	22,500 ft	4.28
	Safety Shutdown Devices			
	3 In. Globe Valve	0.340	30	10.2
	2 In. 100 psi Safety Valve	0.130	30	3.9
↓	8 In. 25 psi Security Shutoff Valve	2.25	9	20.25
10	4 In. Ball Valve	0.461	30	13.83

Table 4-2. Other Underground Equipment, Initial Capital Investment Requirements
(1980 $ in Thousands)
(Continued)

Additional Investment for the Methane Drainage Cases (Continued)

Life Yrs	Item	Unit Cost	Base Case No. Req'd	Base Case Total Cost
10	Gas Metering			
↓	Venturi Flow Meter	0.075	30	2.25
↓	Pressure Differential Indicator	0.525	30	15.75
10	Surface Orifice Meter	2.2	1	2.2
	TOTAL			570.16
	Contingency @ 3 Percent			17.1
	Additional Investment - Methane Drainage Cases			587.26

Table 4-3. Surface Facilities and Equipment, Initial Capital Investment Requirement (1980 $ in Thousands)

Life Yrs	Item	Base Case No. Req'd	Base Case Total Cost
	Surface Facilities & Equipment		
10	Front-End Loader	1	108
10	Fork Lift	1	43
10	Bulldozer	1	170
5	Utility Truck	1	11
5	Pickup Truck	1	8
20	Site Preparation	-	41
20	Ventilation Fan	1	141
10	Bulk Rock Dust Facility	-	26
20	Substation & Distribution	1	92
20	Bathhouse Office Lamphouse	1	393
20	Shop & Warehouse	1	269
10	Powder & Cap House	1	9
10	Oil Storage	1	30
10	Water Storage	1	30
10	Supply Yard	1	30
10	Mine Drainage Treatment Plant	1	65
20	Exploration	-	183
20	Landscaping	-	17
20	Roads & Parking Lot	-	92
20	Shafts & Hoists (Initial)	2/1	7,533
20	Loading Facilities & Silo.	1	2,960
	Total		12,251

Additional Initial Investment for the Surface Facilities

10	Compressor Station for the 1,000 MSCFD Case	1	125
10	Compressor Station for the 1,500 MSCFD Case	1	185
10	Compressor Station for the 2,000 MSCFD Case	1	245

Table 4-4. Initial Capital Investment Summary for Base Case and Methane Drainage Cases (1980 $ in Thousands)

Category	Base Case	Methane Drainage Cases
Face Equipment	16,216	16,216
Safety Equipment	246.4	256.2
Other Undergrounc Equipment	2,196	2,196
Underground Methane Drainage Equipment	-	587.3
Surface Facilities and Equipment	12,251	12,251
Surface Methane Compressor Station	-	(considered separately)
Total Direct Cost	30,909.4	31,506.5
Field Indirect Costs @ 2%	618.2	630.1
	31,527.6	32,136.6
Engineering @ 2%	630.6	642.7
	32,158.2	32,779.3
Overhead and Administration @ 5%	1,607.9	1,639.0
	33,766.1	34,418.3
Other @ 2%	675.3	688.4
	34,441.4	35,106.7
Contingency @ 15%	5,166.2	5,266.0
TOTAL COST TO COMPLETION	39,607.6	40,372.7

4.2 DEFERRED CAPITAL INVESTMENTS

In addition to the initial investment made during the period of the mine's development, further investment in capital equipment is needed at discrete intervals during mine life.

In this analysis, all deferred investments fall into one of two general categories. The first of these encompasses capital requirements needed to extend various mining systems as the underground workings advance. Investments in this category, such as rail, conveyor, piping, cable, methane drainage equipment, etc., are shown in Table 4-5. For the mine, with the exception of the ventilation system, these systems are extended to their final size in the second year of operation. An additional ventilation shaft is sunk in years 8 and 9.

The second category of deferred investments covers those required to finance replacement of mining equipment at the end of useful life. Tables 4-1, 4-2, and 4-3 show replacement lives assumed for each item of equipment.

4.2.1 Mine Life Investment Summary

Table 4-6 summarizes the initial and deferred investments for the three development years and 22 production years of the base case mine, excluding investments associated with the methane drainage cases.

4.3 OPERATING AND MAINTENANCE COSTS

The following information and tables are based on the 1978 Wage Agreement, discussions with mine operators and industry vendors, and calculations made to determine all other O&M costs.

Any mine operator will confirm the fact that slight changes in operating and maintenance (O&M) costs can "make or break" a mine operation. The importance of O&M costs, therefore, necessitated detailed investigations of manpower, power, and equipment rebuild cost elements for the base and methane drainage cases.

4.3.1 Manpower Requirements

The quantity and annual cost of manpower for the mine are shown on Table 4-7 and were derived from conditions of the National Bituminous Coal

Table 4-5. Deferred Investment (1980 $ in Thousands)

Item	Base Case Year 2	Year 8	Year 9
Conveyor Belt and Equipment	167	-	-
High Voltage Cable	136	-	-
Trolley and Feeder Wire	34	-	-
Couplers	9	-	-
Waterlines	54	-	-
Track	144	-	-
Ventilation Shaft	-	1615	1615
TOTAL	544	1615	1615

Additional Deferred Investment for the Methane Drainage Cases

Item	Year 2	Year 8	Year 9
Polyethylene Pipe	97.2	-	-
Relief Line	15.6		-
Methane Detection System	16.1	-	-
Valves	47.7	-	-
Polyethylene Tubing	2.4	-	-
Vertical Borehole	-	-	40.5
Additional Deferred Investment	179.0	-	40.5

Table 4-6. Base Case Mine Investment Summary
(1980 $ in Thousands)

Initial Investment: $39,607.6

Deferred Investment Summary (1980 $ in Thousands)

Category	Life (Years)	Initial Investment ($)	No. of Times Replaced	Deferred Investment ($)
Longwall Face Equipment	10	12,580.0	1	12,580.0
Continuous Mining Equipment	10	3,636.0	1	3,636.0
Safety Equipment	5	246.4	3	739.2
Other Underground Equipment	10	2,196.0	1	2,196.0
Surface Facilities	10	552.0	1	511.0
Surface Facilities	5	19.0	3	57.0
Year 2	-	-	-	544.0
Year 8	-	-	-	1,615.0
Year 9	-	-	-	1,615.0
Total Deferred Investment				$23,493.2

Total Investment: $63,100.8

Table 4-7. Manning Requirements and Associated Annual Costs

Personnel	Base Wage Rate Per Day ($)	Base Case	
		No. Req'd Per Day	Cost Per Year ($)
Face Workers - Labor			
Shearer Operators	80.32	12	212,045
Shield Operators	74.14	18	293,594
Head Gate Cornerman	77.08	6	101,746
Tail Gate Cornerman	77.08	6	101,746
Mechanic	80.32	6	106,022
Utility Men	74.14	12	195,730
Subtotal		60	1,010,883
Continuous Miner Operator	80.32	6	106,022
Continuous Miner Helper	80.32	6	106,022
Roof Bolter Operator	80.32	12	212,044
Roof Bolter Helper	80.32	6	106,022
Shuttle Car Operator	74.14	12	195,730
Bratticeman	71.78	6	94,750
Utility Man	74.14	6	97,865
Mechanic	80.32	6	106,022
Subtotal		60	1,024,477
Other Underground Labor			
Crib Man	71.78	12	189,499
Beltman	71.78	12	189,499
Trackman	71.78	12	189,499
Wireman	71.78	12	189,499
Mason (Precision)	71.78	10	157,916
Pumper	71.78	3	47,375
General Inside Labor	71.78	10	157,916
Roving Mechanic	80.32	3	53,011
Fire Boss	80.32	3	53,011
Subtotal		77	1,227,225
Outside Labor			
Hoistman	70.70	3	46,662
Lampman	70.70	3	46,662
Front-End Loader Operator	70.70	3	46,662
Shop Mechanic	72.47	6	95,660
Unit Train Car Loader Oper.	70.70	3	46,662
Beltman	70.70	3	46,662
Surface Utility Man	68.07	3	44,926
Labor - Unskilled	68.07	3	44,926
Subtotal		27	418,822
TOTAL LABOR		224	3,681,407
Allowance @ 10% for absenteeism, shift differential, weekend maintenance, etc.			368,141
TOTAL			4,049,548

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Table 4-7. Manning Requirements and Associated Annual Costs (Continued)

Additional Manning Requirements for the Methane Drainage Cases

Personnel	Wage Rate Per Day ($)	Base Case	
Underground Labor		No. Req'd Per Day	Cost Per Year ($)
Driller	74.14	3	48,932
General Repairman & Welder	77.08	3	50,873
Total		6	99,805
Allowance @ 10%, same as above			9,981
Additional Annual Costs			109,786

Wage Agreement of 1978. As required by this agreement, a $0.60 per hour cost of living increase has been added to each hourly employee's 1980 wages.

Other than the total number of face workers, the manpower complement is not directly related to annual coal production. This is especially evident in the "outside labor" and the "salaried personnel" categories. Manpower requirements for the surface facilities and management are dictated by specific functions and are not directly related to mine output.

An additional driller and general repairman are required each shift for the methane drainage cases and their job will be drilling, equipment installation, and maintenance. Table 4 8 includes all the supervisory personnel required at the mine site. The cost of this category of manpower is determined on a salaried basis and is not directly related to coal production.

4.3.2 Operating Supplies and Replacement Parts Costs

Operating supplies include those consumables directly related to coal and methane production. Table 4-9 lists the major supplies that are consumed on an annual basis.

Roof support comprises roof bolts with accompanying hardware and secondary roof support in the form of posts, timbers, and crib blocking.

Brattice cloth and material used to construct stoppings, overcasts, undercasts, regulators, and doors are covered by ventilation ducting.

The consumables' cost for the methane drainage equipment was calculated as two percent of the mine's other operating supplies cost. This is reasonable because the methane drainage system will require more roof support in the vicinity of the drainage hole manifolds, additional ventilation costs in the form of brattice cloth and stoppings, and additional costs for drill steels, bits, and hydraulic oil for the horizontal drill.

Also included in Table 4-9 are annual replacement parts costs, which vary proportionately with output. These parts must be purchased each year to keep the respective equipment functioning. The replacement parts' cost for the two horizontal drills was considered to be minor enough to be included in the five-percent miscellaneous costs incorporated into the calculations. The workload of these drills is rather small with each drilling 5,000 feet of hole per year.

Table 4-8. Salaried Personnel and Associated Annual Costs (1980 $)

Personnel	Annual Salary	Base and Methane Drainage Cases	
		Quantity	Annual Cost ($)
Salaried Personnel			
Superintendent	43,000	1	43,000
General Mine Foreman	29,000	1	29,000
Assistant Mine Foreman	27,300	3	81,900
Longwall Coordinator	27,300	1	27,300
Maintenance Superintendent	29,200	1	29,200
General Shop Foreman	22,100	1	22,100
Mine Maintenance Foreman	21,800	3	65,400
Chief Mine Engineer	32,800	1	32,800
Draftsman	13,300	1	13,300
Survey Crew	14,400	2	28,800
Safety Director	28,900	1	28,900
Safety Inspector	21,300	3	63,900
Dust and Noise Technician	17,600	3	52,800
Office Manager	23,000	1	23,000
Timekeeper/Bookkeeper	16,100	1	16,100
Purchasing Supervisor	23,000	1	23,000
Warehouseman	14,400	3	43,200
Section Foreman (+ Longwall)	23,900	12	286,800
Total Annual Cost of Salaried Personnel		38	910,500

Table 4-9. Annual Operating Supplies and Replacement Parts Costs (1980 $)

Base Case	Base Case Annual Cost	Base Case Cost/Ton
Operating Supplies		
Pick and Bit Costs	$ 619,780	$0.47
Emulsion, Hydraulic and Lubricating Oils	$ 290,110	$0.22
Drill Steels	$ 26,370	$0.02
Roof Support	$1,054,940	$0.80
Rock Dust	$ 184,620	$0.14
Ventilation Ducting/Brattice Cloth Stoppings	$ 382,420	$0.29
Miscellaneous @ 10% of above	$ 255,820	$0.19
Subtotal	$2,814,060	$2.13
Replacement Parts		
Shearer Face Conveyor & Stage Loader Roof Supports	$ 672,530	$0.51
Continuous Miners	$ 263,740	$0.20
Roof Bolters	$ 26,370	$0.02
Shuttle Cars	$ 65,930	$0.05
Track/Belt/Feeders	$ 382,420	$0.29
Supply Cars and Motors	$ 39,560	$0.03
Power Distribution Equipment	$ 184,620	$0.14
Cables and Trolley Wire	$ 184,620	$0.14
Portal Buses and Jeeps	$ 92,310	$0.07
Pumps and Piping	$ 39,560	$0.03
Surface Parts and Supplies	$ 382,420	$0.29
Miscellaneous @ 10% of above	$ 233,410	$0.18
Subtotal	$2,567,490	$1.95
TOTAL	$5,381,550	$4.08

Additional Operating Supplies for the Methane Drainage Cases

Drainage Hole Grouting Roof Support Horizontal Drill Steels and Bits Pipe Hangers, Gaskets, Fittings Nitrogen Tank Leasing Etc.		
Taken as 2 Percent of the Above Operating Supplies Cost	$ 56,280	$0.04

4.3.3 Annual Power Costs

Power costs for the base and methane drainage cases are shown in Table 4-10, based on a bulk purchase price to the mine of 30 mills/KWh. Daily kilowatt-hour demand for each item of equipment is calculated by estimating an equivalent number of hours that each item will operate at rated motor horsepower. This figure is then multiplied by the typical nameplate rating in kilowatts.

The adverse power factor which exists in various degrees when any three-phase AC electrical equipment is used has been accounted for in the 30 mills/KWh. This approach was used since power costs are site-specific and a contract with the neighboring power company would have to be negotiated to better estimate this operating cost.

Power consumption obviously will increase with increased coal production, and this additional cost has been accounted for by multiplying the total annual output by the power cost per ton for each coal production rate considered.

4.3.4 Equipment Rebuild Costs

Substantial overhaul of mining equipment is an ongoing process at large mine sites. Often this is done in well-equipped machine shops located directly in the mine workings.

The depreciation schedule of a piece of equipment does not necessarily correspond to its operative life. In the interest of conservation, each piece of equipment is to be rebuilt at specific time intervals within its economic life, based on the type of job a particular machine must perform.

The longwall shearers and continuous miners are exposed to the most rigorous conditions within a mine, as is indicated in the frequency and cost of their maintenance. Longwall shearer costs were estimated by the manufacturer, based upon tonnage produced. For the purposes of the cash flow analysis and knowing the annual coal production of both mines, these costs in terms of tons were translated to annual outlays. Certain equipment on the longwall face, such as the roof supports, required less frequent maintenance than other equipment. This is the reason for the fluctuating annual costs, coupled with the less frequent maintenance costs of other underground equipment.

Table 4-10. Annual Power Costs

Load on System During 195 Productive Days	Hp Per Unit	KW Per Unit	Base Case		
			No. of Units	Hrs/Day of Full Load	KW Hrs/Day
Dual Drum Shearer	300	223.7	2	10	4,474
Flight Conveyor	500	372.8	2	10	7,456
Stage Loader	150	111.9	2	10	2,238
Impact Crusher	100	74.6	2	10	1,492
Emulsion Pumps	200	149.1	2	10	2,982
Total KWH/Working Day					18,642
Total Consumption for 195 Working Days					3,635,190
220 Productive Days					
Continuous Miner	500	372.8	3	4	4,474
Twin Boom Roof Bolter	80	59.6	3	6	1,073
Shuttle Car	120	89.5	6	6	3,222
Feeder Breaker	80	59.6	3	6	1,073
Triple Duty Rock Duster	50	37.3	3	4	448
Auxiliary Fan	25	18.6	3	12	670
Mantrip Jeep	10	7.5	5	2	75
Mechanic Jeep	10	7.5	5	7	263
Personnel Jeep	10	7.5	3	7	158
Supply Motor	60	44.7	2	12	1,073
48" Conveyor	150	111.9	4	10	4,476
36" Conveyor	150	111.9	2	10	2,238
Ventilation Fans	525	391.4	*	24	9,393.6
Hoist	1100	820.3	1	15	12,305
Pumps, etc.	-	-	400 Hp Total	10	2,982
Workshops, Lighting, etc.	-	-	100 Hp Total	24	1,789
Outside Electrical Equip.	-	-	100 Hp Total	12	895
Total KWH/Working Day					46,607.6
Total Consumption for 220 Working Days					10,253,672
TOTAL ANNUAL CONSUMPTION					13,888,862

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Table 4-10. Annual Power Costs (Continued)

Load on System During 145 Non-Productive Days	Hp Per Unit	KW Per Unit	Base Case		
			No. of Units	Hrs/Day of Full Load	KW Hrs/Day
Hoists				2	1,641
Ventilation Fans*				24	9,393.6
Mine Pumps & Misc.				24	7,158
Lighting & Misc.					
Surface Equipment				12	895
Total					19,087.6
Consumption for the 145 Non-Productive Days					2,767.702
Total Annual Consumption					16,656,564
Annual Cost at 30 Mills/KWHr					$499,697

Additional Power Costs for the Methane Drainage Cases

Horizontal Hole Drill	30	22.4	3	2	134.4
220 Days Consumption					29,570
Additional Annual Cost at 30 Mills/KWHr					$887

*Power consumption by the ventilation fans is averaged over the mine life. One fan operates for the first 10 years, then two fans operate at separate shafts for the remaining 10 years of the mine life.

Additional rebuild costs are incurred for the horizontal drill and the surface compressor facility in the applicable cases. These deferred costs are given in Table 4-11.

4.3.5 Total Annual Mine Operating Costs

Table 4-12 summarizes all the annual operating costs for the base case mine. These costs include union welfare and health benefits, abandoned mine reclamation fund, and royalty. These costs are described in more detail in Section 5.4.2 on page 5-6.

Table 4-11. Additional Operating and Maintenance Costs - Equipment Rebuild Costs (1980 $ in Thousands)

YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Base Case																				
Shearer	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140
Face Conveyor and Stage Loader	210	530	210	530	210	530	210	530	210	210	530	210	530	210	530	210	530	210	530	210
Roof Supports	-	600	-	600	-	600	-	600	-	-	-	600	-	600	-	600	-	600	-	600
Continuous Miners	-	-	323	-	-	323	-	-	-	-	-	-	323	-	-	323	-	-	-	-
Twin Boom Bolters	-	-	-	-	165	-	-	-	-	-	-	-	-	-	165	-	-	-	-	-
Shuttle Cars	-	-	-	-	323	-	-	-	-	-	-	-	-	-	323	-	-	-	-	-
TOTAL	350	1270	673	1270	838	1593	350	1270	350	350	670	950	993	950	1158	1273	670	950	670	950

Additional Operating and Maintenance Costs for the Methane Drainage Cases

YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Horizontal Drill	-	-	-	-	15	-	-	-	-	-	-	-	-	-	15	-	-	-	-	-
Compressor Station	-	-	-	-	53	-	-	-	-	-	-	-	-	-	53	-	-	-	-	-
ADDITIONAL COSTS					68										68					

Table 4-12. Total Annual Mine Operating Costs
(1980 $ in thousands)

Direct Labor	$ 4,960.0
Power Supplies	$ 500.2
Operating Supplies & Replacement Parts	$ 5,381.6
Payroll Overhead	$ 1,984.0
Union Welfare	$ 2,109.7
Union Health Benefits	$ 336.0
Black Lung Benefit Tax	$ 652.1
Abandoned Mine Reclamation Fund	$ 195.6
Royalty	$ 1,956.2
Indirect Cost	$ 1,533.0
Fixed Cost (taxes and insurance)	$ 1,188.2
TOTAL PER YEAR	$19,608.4

Annual Cost Per Ton: $\frac{\$19,608,400}{1,318,680 \text{ tons/yr}} = \$14.87/\text{ton}$

5. ECONOMIC ANALYSIS

5.1 GENERAL

This economic evaluation of methane drainage systems was performed by utilizing the TRW REVA (Resource Economic Venture Analysis) program. The main feature of this evaluation is the use of DCF analysis to calculate a product selling price required to meet a specified return on investment under a realistic venture setting. The sections below discuss the assumptions that were made and the computational procedure.

5.2 ASSUMPTIONS

5.2.1 Overall Financial Setting

It was assumed that the mine is a stand-alone venture. While a particular mine may be only a part of a parent company's total operation, that mine is normally evaluated as a single entity. As such, neither tax credits (if they are assumed in the analysis) nor operating losses (if they occur) are passed through the accounts of the parent company for use in reducing tax liabilities of the overall operation. Instead, such tax credits and operating losses are absorbed by the mining venture. This is accomplished by accumulating and carrying forward such accounts to the point in time where they can be applied against positive tax liabilities of the venture.

As a stand-alone venture, it also was assumed that capital investments come from 100-percent equity funding.

Both assumptions of a stand-alone venture and equity financing are standard conditions employed in economic analyses of mining operations.

5.2.2 Economic Parameters

After-tax rate-of-return on investment (ROI)	20 percent
Financing method	100 percent equity
Mine productive life	22 years
Project start date	1980
Royalty	$1.50/ton
Federal income tax rate	48 percent

Depletion allowance	10 percent (see Section 5.2.5)
Investment tax credit rate	(Discussed below)
Severance tax	0
Depreciation method	Straight line or sum-of-years digits (see Section 5.2.4)
Inflation rates	
Capital	0
Operating cost	0
Selling price	0

Additional assumptions regarding annual cost items such as Black Lung Benefits Tax, Abandoned Mine Reclamation Fund, union health benefits, etc., are discussed in Section 5.3.3.

The rates used for investment tax credit are those prescribed by the Federal Tax Code. The applicable rate depends on both equipment type and the expected useful life of that item. In general, buildings, roads, offices, landscaping, and other capital expenditures not directly related to production do not qualify for investment tax credit. Of the qualifying equipment, the rate is determined by useful life. In the present analysis, equipment that will last for 10 years or more is subject to a 10-percent investment tax credit rate, while equipment with a life of five years is subject to two-thirds of this rate, or 6.67 percent.

5.2.3 Inflation Factors

Though inflation in both operating costs and income is a reality in today's economic environment, it was not considered in this analysis for a number of reasons. The behavior of the inflation rate is unpredictable from industry to industry. In the REVA model, only the first year of the endeavor is used for comparison. All future cash flows are considered real dollars prior to discounting them by the desired rate of return. Should the inflation rates of supplies, labor, and investment be relatively the same, the effect of inflation for analysis purposes washes out.

5.2.4 Depreciation Methods

For this study, both straight line and accelerated (sum-of-years digits) depreciation were employed, depending on the type of investment. This is in accordance with current tax law governing treatment of depreciable assets. Only production equipment (face, safety, underground, and surface) were depreciated by the accelerated technique. For all other investments, including site preparation, buildings, surface facilities, field indirect costs, engineering, etc., straight line depreciation was applied.

5.2.5 Depletion Allowance

Percentage depletion (as applied to coal mining) is calculated at 10 percent of gross income (revenues minus royalties) up to a limit of 50 percent of taxable income for that year (taxable income is figured without regard to tax credits or tax loss carryovers). Further details of this procedure are given in Section 5.4.5.1.

5.3 MINE PLANT DEVELOPMENT SCHEDULE

Table 5-1A is the schedule of the initial investment for the three development years and the corresponding O&M costs and coal production.

Table 5-1B is the schedule of the initial investment for the methane drainage cases. The development phase of the mine is extended an additional year to allow for longwall panel drainage prior to extraction. Full mine production is also delayed one year to achieve a steady-state situation of panel drainage and extraction.

5.4 REVA APPROACH

5.4.1 Investment, Depreciation, and Tax Credits

The values of initial investments by category are provided to the model. These are allocated by year per the construction schedule given in Tables 5-1A and 5-1B. Data are in 1980 dollars.

Depreciation of initial capital is calculated by depreciation type and useful life. Depreciation for each investment category is calculated separately and then summed to obtain the total depreciation for that year. Salvage value was disregarded, as only salvage values greater than 10 percent of the initial cost need be included in depreciation calculations (per Federal Tax Code).

Investment tax credits are calculated by category from the investment amount, the tax credit rate, and the investment schedule. These credits are

Table 5-1A. Initial Investment Schedule, Operating Costs and Tonnage Produced During Development - Base Case

Item	Development Phase			Production Phase
	Year -3	Year -2	Year -1	Year +1
Site Preparation	100%	-	-	-
Surface Facilities & Equipment	50%	50%	-	-
Shafts	50%	50%	-	-
Face Equipment	-	34%	66%	-
Other Underground Equipment	-	49%	49%	2%
Field Indirect, Engineering, Overhead & Administration, Misc. Construction Costs	12%	40%	40%	8%
Contingency	-	30%	50%	20%
Operating & Maintenance Costs (percentage of full production)	-	35%	60%	100%
Annual Tonnage (percentage of full production)	-	22%	56%	100%

Table 5-1B. Initial Investment Schedule, Operating Costs and Tonnage Produced During Development - Methane Drainage Cases

Item	Development Phase				Production Phase
	Year -4	Year -3	Year -2	Year -1	Year +1
Site Preparation	100%	-	-	-	-
Surface Facilities & Equipment	50%	50%	-	-	-
Shafts	50%	50%	-	-	-
Face Equipment	-	15%	30%	55%	-
Other Underground Equipment	-	49%	49%	2%	-
Field Indirect, Engineering, Overhead, & Administration, Misc. Construction Costs	12%	40%	40%	8%	-
Contingency	-	-	30%	50%	20%
Operating & Maintenance Costs (as a percentage of full production)	-	35%	40%	60%	100%
Annual Tonnage (as a percentage of full production)	-	22%	27%	56%	100%
Methane Production (as a percentage of full production)	-	-	50%	100%	100%

assumed to be available at the time when the investments are made (i.e., progress payments). However, in the case of a stand-alone venture, such credits must be accrued until years in which there are sufficient tax liabilities against which the credits can be applied.

5.4.1.1 Deferred Investments

From useful life, the model will automatically make an investment payment to replace equipment in the appropriate year. Depreciation of deferred investments is calculated and added to the yearly depreciation established for initial investments. Investment tax credits are calculated in a similar manner and are available at the time the investments are made, provided that sufficient offsetting tax liabilities exist.

5.4.2 Annual Operating and Maintenance Costs

The elements constituting total annual operating and maintenance costs are given in Table 5-2, along with their method of calculation. Some items (direct labor, pick and bit cost, and health benefits) are calculated directly in dollars per year. Other cost elements, such as general supplies, replacement parts, and power are calculated from a per-ton basis from the appropriate annual production. A discussion of the different elements follows.

- Direct labor (annual): the makeup of labor costs as given in Tables 4-7 and 4-8.
- Power cost per ton: basis given in Table 4-10.
- General operating supplies per ton: includes lubricating and hydraulic oils, drill steel, roof supports, rock dust, and ventilation ducting. These are listed in Table 4-9.
- Replacement parts: includes components and spare parts for mine machines, roof bolters, shuttle cars, track, feeders, locomotives, power equipment, cable and trolley wire, portable buses and jeeps, pumps, piping, and surface equipment. These are listed in Table 4-9.
- Payroll overhead: taken as 40 percent of direct labor.
- Union welfare: costs associated with union benefit and pension plans are computed in accordance with the 1978 UMW agreement. Contributions are based on manhours worked and tonnage, as follows.

Table 5-2. Annual Cost Basis

Item	Method of Calculation
Direct Labor	Annual Amount ($/year)
Power	$/ton x TPY*
Operating Supplies	
General	$/ton x TPY
Replacement Parts	$/ton x TPY
Bit & Pick Cost	Annual Amount ($/year)
Total	(Sum of above elements)
Payroll Overhead	40% of Direct Labor
Union Welfare	Annual Amount + $1.385/ton x TPY
Union Health Benefits	Annual Amount
Union Health Benefits	Annual Amount
Black Lung Benefits Tax	$.50/ton x TPY
Abandoned Mine Reclamation Tax	$.15/ton x TPY
Royalties	$1.50/ton x TPY
Indirect Costs	15% of (Direct Labor + Operating Supplies)
Fixed Costs (taxes and insurance)	3% of Initial Investment

*TPY = Tons Per Year

Payment	Per Manhour	Per Ton
1950 Pension Fund	0	.95
1974 Pension Trust	.75	.085
1950 Benefit Trust	0	.35
1975 Benefit Trust	.02	0
Total	$0.77/manhour	$1.385/ton

The number of manhours worked per year is based on eight hours per day, 220 days per year, or 1,760 hours per year for each man. Table 4-7 gives the number of underground, hourly personnel for each mining scenario. This factor plus the annual tonnage is used to determine the total annual contribution to these funds.

- Union health benefits: estimated at an average cost of $1,500 per year for each hourly employee. This is considered an average cost of carrying private health insurance on a group policy for mines in the eastern and mid western regions of the United States.

- Black Lung Benefits Tax, Abandoned Mine Reclamation Fund, and royalties: all these costs are based on annual production.

- Indirect costs: taken as 15 percent of the sum of direct labor and operating supplies.

- Fixed costs to cover property taxes and insurance on the equipment, taken as three percent of the initial investment (in 1980 dollars).

All of the above costs are estimated for 1980. Additional costs to rebuild the mining equipment are added to annual costs in the appropriate years. These are given in Table 4-10.

5.4.3 Working Capital

Working capital is needed to fund operating expenses during development and to meet obligations incurred in advance of revenue payments for an appropriate period. Elements which comprise working capital include cash on hand to cover current expenses, accounts receivable, payroll, inventory, and tax escrow. While these funds are tied up in the operation of a project, for cash flow purposes they are an investment. Working capital, however, is non-depreciable and is recovered in full at the end of the project life. The basis for estimating working capital for this study is given in Table 5-3.

Table 5-3. Working Capital Basis

Element	Amount
Direct Labor	3 months or 1/4 of annual direct labor
Operating Supplies	3 months or 1/4 of annual operating supplies
Payroll Overhead	3 months or 1/4 of annual overhead costs
Indirect Cost	4 months or 1/3 of annual indirect costs
Fixed Cost (tax escrow)	0.5 percent of initial capital (1980 dollars)
Spare Parts & Misc.	3/17 of the total of the above elements

Since working capital funds are tied up during the mine life, the schedule of working capital reserves (both initial and yearly additions) must be included when calculating the present investment values.

5.4.4 Revenues

Calculation of the required revenues (and ultimately a selling price) is an iterative process in which an initial estimate of the selling price is made, revenue-streams generated, depletion allowances and taxes calculated, a net cash flow stream and its present value formulated, comparison with the present value of investments made, and a new cost determined. The process is repeated until a selling price is found such that the present value of the net cash flow is equal to the present value of investments when the specified return on investment is used as the discount factor.

5.4.5 Taxes

To calculate taxes on a yearly basis, the following quantities must be known: revenues, operating costs, depreciation, depletion allowance, tax credits, and tax loss carryovers. At this point in the analysis, the first three items are known. It remains to calculate depletion allowance and tax credits.

5.4.5.1 Depletion

Depletion is always calculated on a project basis without regard for tax credits or tax loss carryovers. There are two methods for calculating this allowance: cost depletion or percentage depletion. Because of uncertainties in evaluating the property basis for cost depletion, only percentage depletion was considered in this study.

Percentage depletion is taken as 10 percent of revenues minus royalties, up to a maximum of 50 percent of taxable income. For this purpose, taxable income is defined as revenues minus operating costs minus depreciation. No tax credits or tax loss carryovers are applied in this calculation.

The first step in determining depletion is to calculate the percentage of revenue less royalty and compare this value to the 50-percent limitation on taxable income. The smaller of these two values is selected as the allowance under percentage depletion.

5.4.5.2 Federal Taxes

Federal taxes (without regard for tax credits and carryovers) are taken as the federal tax rate (48 percent) times taxable income (now defined as revenues less operating costs less depreciation less depletion). Should the federal tax liability in any year be less than zero (indicating an operating loss), the actual tax paid is zero, and the tax loss for that year can be carried forward (up to five years) to reduce tax liabilities in future years. Investment tax credits can also be carried forward (up to seven years).

5.4.6 Net Cash Flow and Present Values

Net cash flow is defined as the after-tax income from the operation, and represents revenues minus operating costs minus taxes. This is calculated for each year of the project (C_i). The objective of the analysis is to seek a selling price such that the present value of the net cash flow is equal to the present value of the investments:

$$\sum_{i=1}^{N} \frac{C_i}{(1+r)^i} = \sum_{i=1}^{N} \frac{I_i}{(1+r)^i}$$

where r is the return on investment, I_i the investment in year "i", and N the project life. The procedures are repeated for different production costs until one is found that satisfies the present value conditions given above.

Rather than setting a price for the methane produced, it was determined. The base case coal selling price was found using the previously described procedure. Then for each combination of methane production and annual coal production, an overall coal selling price is derived, including the income necessary to meet the rate of return on the methane drainage program investment. This coal cost is compared to the baseline case with the corresponding mine production but without the methane drainage program investment. The difference in annual cost divided by the annual methane produced yields the after-tax methane selling price for the desired rate of return.

6. RESULTS

6.1 GENERAL

For the base case longwall mine without methane drainage, the discounted cash flow analysis established a base coal selling price of $26.11 per ton. This base case mine required a total investment of $63.1 million and an annual cost of $22.5 million. The mining venture required $34.4 million in annual revenue to recover investment, annual cost, taxes, and earn a 20 percent return on investment.

When methane drainage is included in the mining system, there are two products: coal and methane. The required revenue (which is now higher than the base case due to increased investment and operating expenses) can be allocated between the two products. There are several ways in which to allocate the revenue: the coal price can be held constant while the methane price is varied to cover the remaining revenue, or the methane price can be fixed, letting the coal price fluctuate. In this study, it was decided to hold the coal selling price constant at $26.11 per ton, the value obtained from the base case mine with no methane drainage. Thus, the additional revenue required for the methane drainage cases must be derived from the sale of methane.

6.2 METHANE SELLING PRICE VS. ANNUAL COAL PRODUCTION

The three methane production rates of 1.0, 1.5, and 2.0 million cubic feet per day were plotted against percent change in annual coal production to determine the relationship to methane selling price. This is shown in Figure 6-1. Figure 6-1 indicates that for the three methane production rates, zero methane selling price (breakeven) occurs at an increase in annual coal production of approximately eight percent. At this point, the methane drainage program pays for the additional investment, manpower, and O&M costs incurred in the installation and operation of the system. The increase in coal production required to cover the cost of the methane drainage system is a modest 67 tons per longwall shift, well within the capabilities of the longwall. Should productivity increase beyond this point, the coal selling price would decrease. The mining company could then decide to lower the market price of the coal or retain a larger rate of return on investment at the same market price.

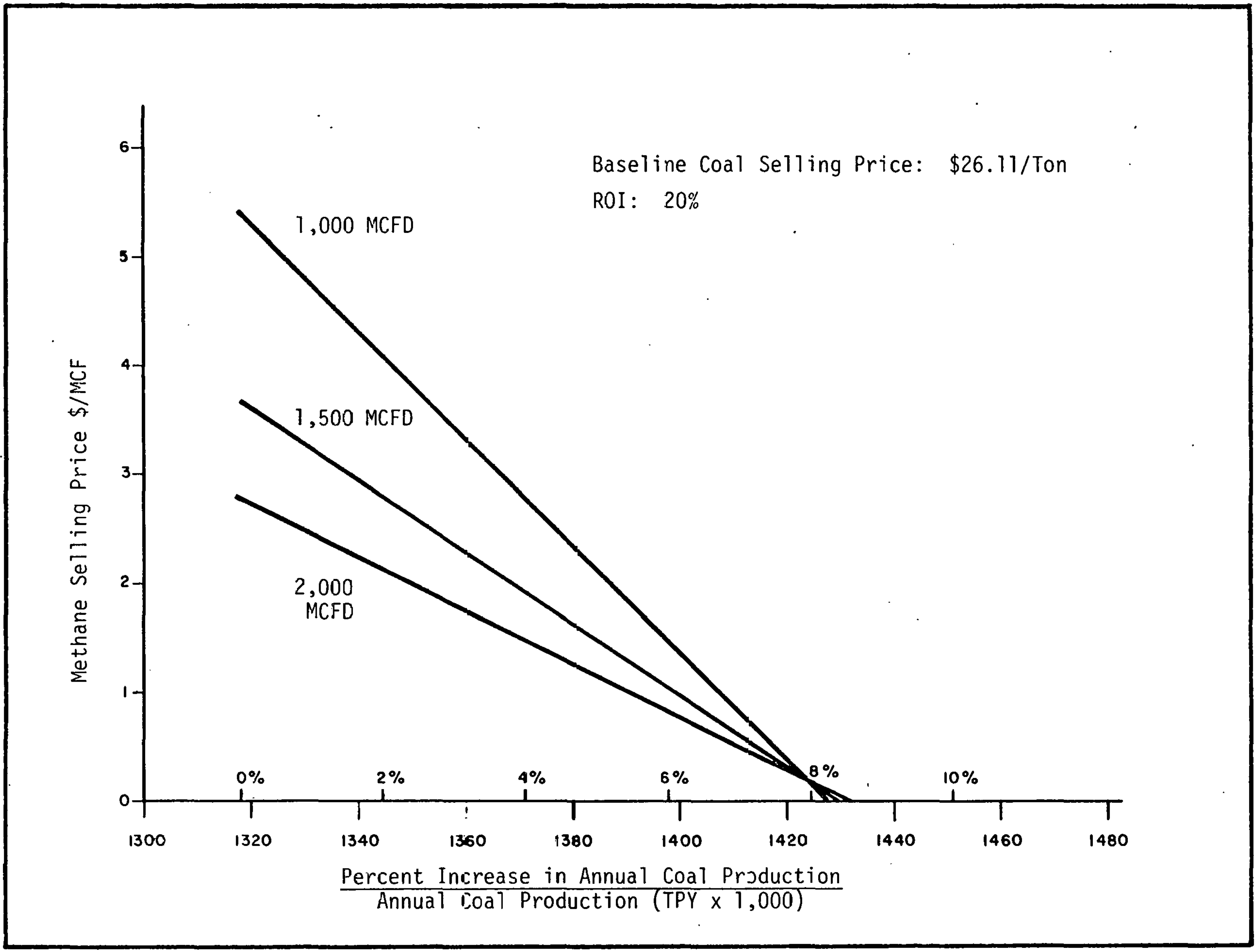

Figure 6-1. Methane Selling Price Vs. Annual Coal Production

6.3 METHANE SELLING PRICE VS. METHANE PRODUCTION RATE

The relationship between methane selling price and methane production rate is shown in Figure 6-2. At the base coal production, the methane price falls from $5.40 to $2.80 as the production level increases from 1.0 to 2.0 million cubic feet per day. There is an approximate reciprocal relationship between price and production rate, with price being most sensitive to production at the lower production rate. As daily methane production increases 50 percent (1.0 to 1.5 MMCF), the selling price decreases 33 percent (from $5.40 to $3.60 per MCF), but when methane production increases by another 50 percent (1.5 to 2.0 MMCF), methane selling price decreases by an additional $0.80 per MCF, or about 15 percent.

Also shown in Figure 6-2 are the methane price and production relationships at different coal production levels. As coal production increases, methane price becomes less sensitive to methane production. This is due to the fact that with increased coal sales, less revenue is required from the sale of methane.

6.4 METHANE SELLING PRICE VS. CAPITAL INVESTMENT FOR DRAINAGE

Three daily methane production rates of 1.0, 1.5, and 2.0 MMCFD were plotted against percent change in the capital investment for drainage. This is shown in Figure 6-3. Methane selling price was found to be essentially insensitive to capital investment of the methane drainage system over the range of -5 to +10 percent of the baseline investment. Methane selling price, however, is sensitive to daily methane production, but diminishes with increasing production. This insensitivity to changes in capital investment for methane drainage equipment is due to the fact that this investment represents only 2.7 percent of the total mine investments.

6.5 IMPACT OF METHANE DRAINAGE ON THE VENTILATION SYSTEM

Because the methane is drained in concurrence with main entry and panel development, the underground personnel are still exposed to the same methane emission rates in these entries as they would with no panel drainage. The ventilation system, therefore, must perform the same function of maintaining methane concentration in the intake air of less than 1.0 percent by volume and 1.5 percent by volume in the return air. In addition, the ventilation system must be designed to prevent exceeding these concentrations in the

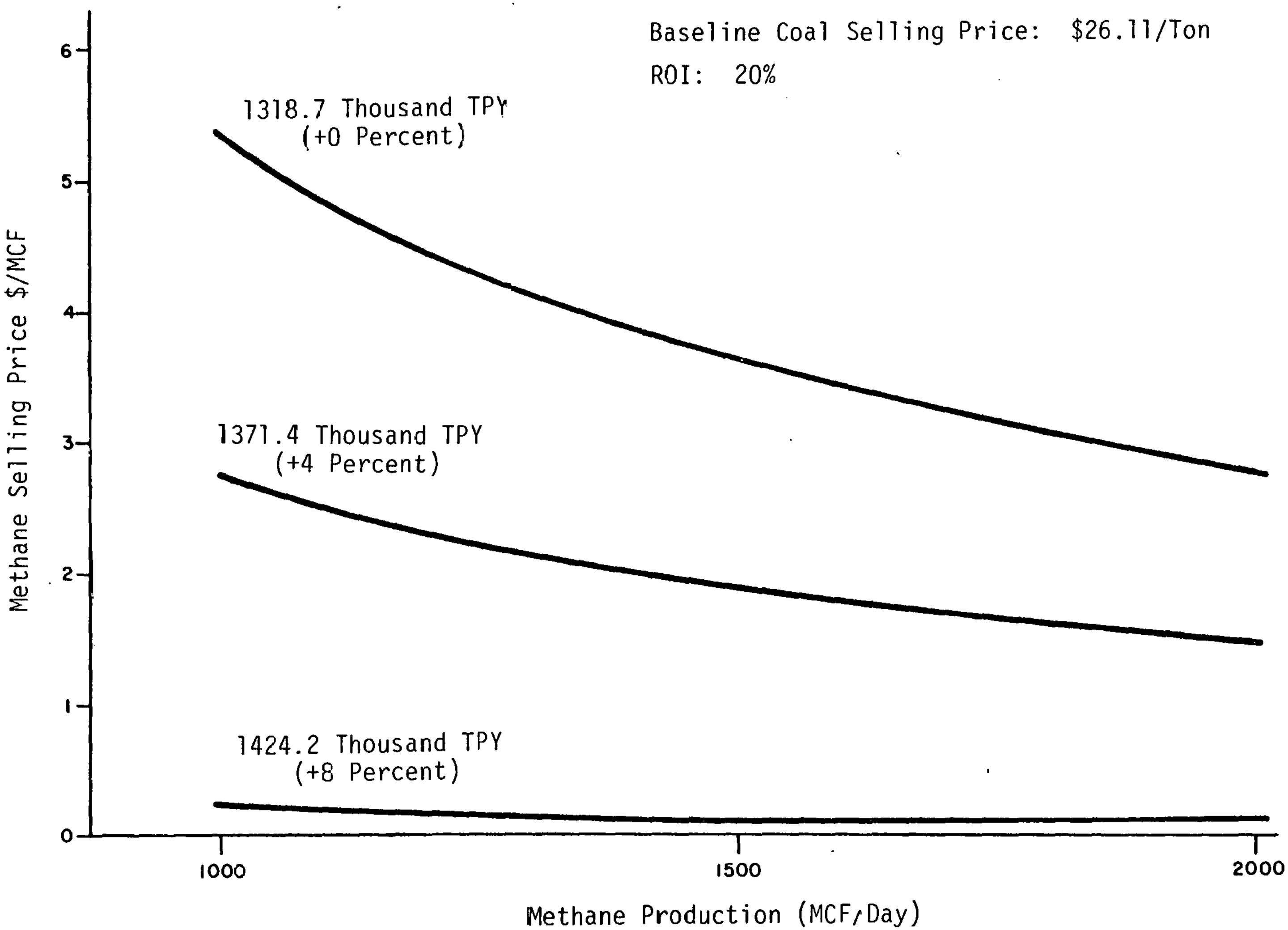

Figure 6-2. Methane Selling Price Vs. Methane Production Rates

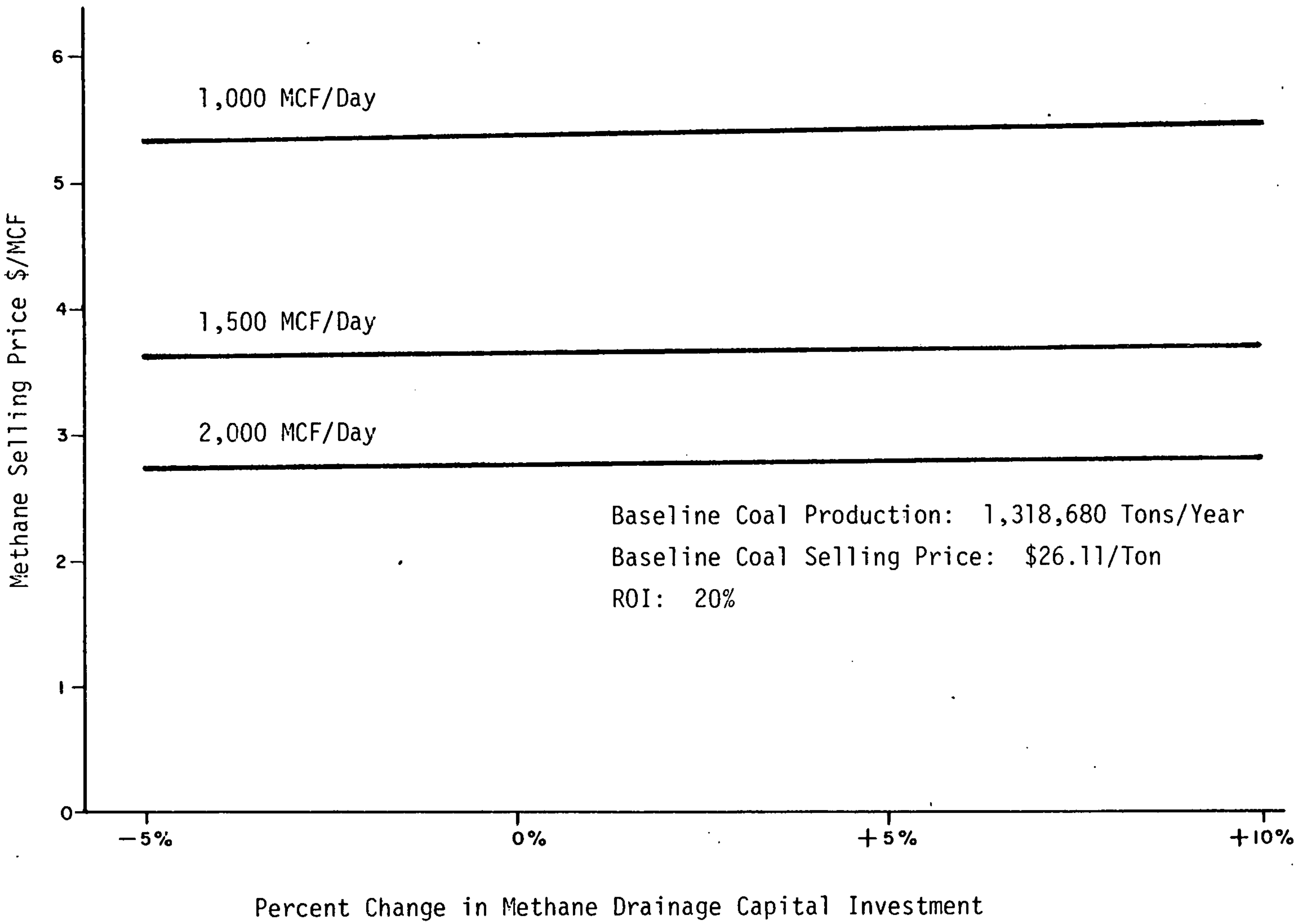

Figure 6-3. Methane Selling Price Vs. Methane Drainage System's Capital Investment

event of a break in the drainage line which transmits large quantities of methane. This could very well mandate an overdesigned return airway system with increased flow rates to adequately dilute and render harmless an emission of highly concentrated methane. For example, a break in the eight-inch mainline would release approximately 700 cubic feet of methane for the security valve spacing of 1,000 feet. The quantity of air necessary to dilute this to the legal maximum of 1.5 volume percent is:

$$\frac{700}{0.015} - 700 = 45,967 \cong 46,000 \text{ CFM}$$

This would require the air velocity to be about 500 FPM which could cause rock dust agitation, increased headloss due to friction and greater leakages through stoppings. An additional entry might be necessary to reduce the air velocity for the required quantity of air.

It should be noted also that these calculations assume steady-state flow rates, which is really never the case.

It is therefore possible that ventilation costs could be greater because of the increased numbers of stoppings and overcasts needed to isolate return entries, the increased number of return entries to reduce velocity for the required volume of air and possibly a larger fan and/or shaft to accommodate greater flow rates.

6.6 RATE OF RETURN SENSITIVITY

An assumed rate of return on investment (ROI) of 20 percent was used throughout this analysis to establish a coal selling price, determine required methane selling prices, and calculate the coal production increase needed to offset drainage system costs. Recognizing that the desired or required rate of return varies from company to company, a discounted cash flow analysis was made at a lower value, 15 percent, to illustrate the sensitivity of costs and required coal production increase as a function of rate of return.

As shown in the following table, a five percent change in the assumed rate of return reduces significantly both the required methane selling price and coal production increase.

Table 6-1. ROI Sensitivity Results

	Rate of Return		% Decrease
	20%	15%	
Coal selling price per ton	$26.11	$24.22	7
Methane selling price per MCF			
@ 1,000 MCF/day	$ 5.40	$ 3.80	30
@ 1,500 MCF/day	$ 3.70	$ 2.50	32
@ 2,000 MCF/day	$ 2.80	$ 1.90	32
Coal production increase required to offset drainage system costs	8%	6%	25

7. RECOMMENDATIONS

The analysis results lead to the following recommendations:

- Additional investigation is needed to better understand and quantify the interactions between methane predrainage, ventilation and other mine systems such as dust suppression, extraction and haulage. Results of such investigations would provide data needed to support development of optimized mine plans which balance technical, operational, regulatory, and economic considerations related to methane predrainage.

- Technical and cost data for each methane drainage technique should be updated and validated through cooperative agreements with companies involved in production or end-utilization of methane. The data should then be analyzed using a methodology which integrates methane drainage techniques into typical longwall and room-and-pillar mining operations. The analytical results should be formatted to permit extrapolation to site-specific characteristics that differ from typical mining conditions. The end product, typically a handbook, would contain data, user guidelines, and instructions to the level of detail necessary for mine planners with limited knowledge of methane drainage to:

  - Tailor and further refine the analyses by incorporating mine-specific geotechnical parameters, operational practices, and corporate accounting considerations.
  - Rapidly conduct first-order analyses to determine the economic feasibility of implementing specific or combinations of methane drainage techniques.
  - Determine the technical and economic impacts of the drainage system on mine subsystems such as ventilation, face equipment, haulage, and support operations.
  - Select the technique(s) and end uses most applicable and of greatest benefit to the mining operation.
  - Develop mine plans and operational practices which maximize resource recovery.

- Continued government support is needed to enhance the technical and economic viability of coalbed methane drainage systems for the following reasons:

  - This study reinforces results, conclusions, and recommendations of other related studies regarding the potential economic benefits of coalbed methane.
  - The mining industry itself cannot, for a number of reasons, support the massive research efforts needed to develop systems for draining, collecting, and utilizing coalbed methane.

- The traditional methane removal method--dilution and venting to the atmosphere--does not, for economic and strategic reasons, serve the best interests of the mining industry or the nation.

8. REFERENCES

1. Cervik, J., 1979, Experience with methane control from horizontal boreholes: paper presented at the Second International Mine Ventilation Congress, Reno, NV.

2. Energy Applications, Inc., 1976, Design and recommended specifications for a safe methane gas piping system: Bureau of Mines Open File Report 109-76.

3. Federal Coal Mine Health and Safety Act of 1969, Code 7 Federal Regulations, Title 30.

4. Gabello, D. P., Felts, L. L., and Hayoz, F. P., 1980, Economic analysis of advanced technology bits and picks for a longwall mining system.

5. Irani, M. C., Kapsch, F. F., Jeran, P. W., and Pepperney, S. J., A fail-safe control system for a mine methane pipeline: Bureau of Mines Report of Investigations 8424.

6. Mine Safety and Health Administration, 1978, Piping methane in underground coal mines: Information Report 1094.

7. Occidental Research Corp., 1980, Methane drainage in advance of mining phase II design and verification milestone report: for TRW Energy Systems Group.

8. Schonfeldt, H. A. von, Pothini, B. R., and Aul, G. N., 1980, Advance methane control and its impact on gas emissions in the Pocahontas #3 coal seam: paper presented at the 1980 SPE/DOE Symposium on Unconventional Gas Recovery, Pittsburgh, PA.