CHAPTER VIII. OVERALL PLANT OPTIMIZATION

Introduction

In this chapter, the information developed in the previous chapters on subsystem optimizations of each of the phases; coal preparation and pretreatment, gasification, shift conversion, gas purification, and methanation are to be integrated to arrive at an overall plant optimization for the production of pipeline gas. Various alternate pipeline gas production processes selected will be examined, so that comparison can be made to determine the economic potential of each alternate.

In estimating the gas prices, based on the O.C.R. accounting procedures, from the cost of production of the gas by the various alternates, the fixed investment for the optimal design of each phase must be first computed. Information needed in the computer calculation of gas prices is described later. The effects of changes in the key parameters affecting the price of gas are described. The steps involved in various alternates having a technical uncertainty which may critically affect the success or failure of the selected alternate are identified.

1. Description of Gas Manufacturing Processes

Before the price of pipeline gas can be calculated, the alternate gasification processes must be clearly defined. In the study of thermodynamics and kinetics of gasifier performance, five major gasification schemes were formulated in Section 3.3 of Chapter IV. Studies made in that chapter were mainly concerned with the determination of operating conditions and the process design of gasification schemes. In this section, we discuss the interrelation of various phases which must be individually arranged to construct an integrated pipeline gas manufacturing plant. Essentials of the five alternate processes formulated are as follows:

1.1 Alternate I

The flow sheet of this alternate is shown in Figure VIII-1. The partially cleaned coal received from the mine is sent to a coal preparation plant for grinding and screening. A portion of this crudely prepared coal is transferred to the coal storage field, and the remainder is pulverized to proper sizes. After the pulverized coal has been dried in a dryer, it is fed to a pretreater. The coal is made nonagglomerating by reacting with steam and a small amount of oxygen in the pretreater. The pretreated coal is introduced to a train of gasifiers through either lock hoppers or piston feeders.

In the gasifier, coal is fluidized and gasified by steam and oxygen. It is also possible to operate the gasifier under a slag condition at a higher temperature. Gas coming out of the gasifier contains mainly CO and H_2. The effluent gas, after passing through a waste heat recovery system, is introduced to a shift converter. The gas mixture is catalytically shifted to a desired hydrogen to carbon monoxide ratio. After the temperature of the shifted gas is lowered in a product cooling system, it is introduced to the gas purification unit where CO_2, H_2S, C_6H_6, and other impurities are removed from the gas stream. Prior to entering the methanator, the purified gas is mixed with a portion of the hot product gas from the methanator. The CO in the mixed gas is catalytically reacted with hydrogen in the methanator. When the gas mixture in the methanator reaches a maximum allowable temperature

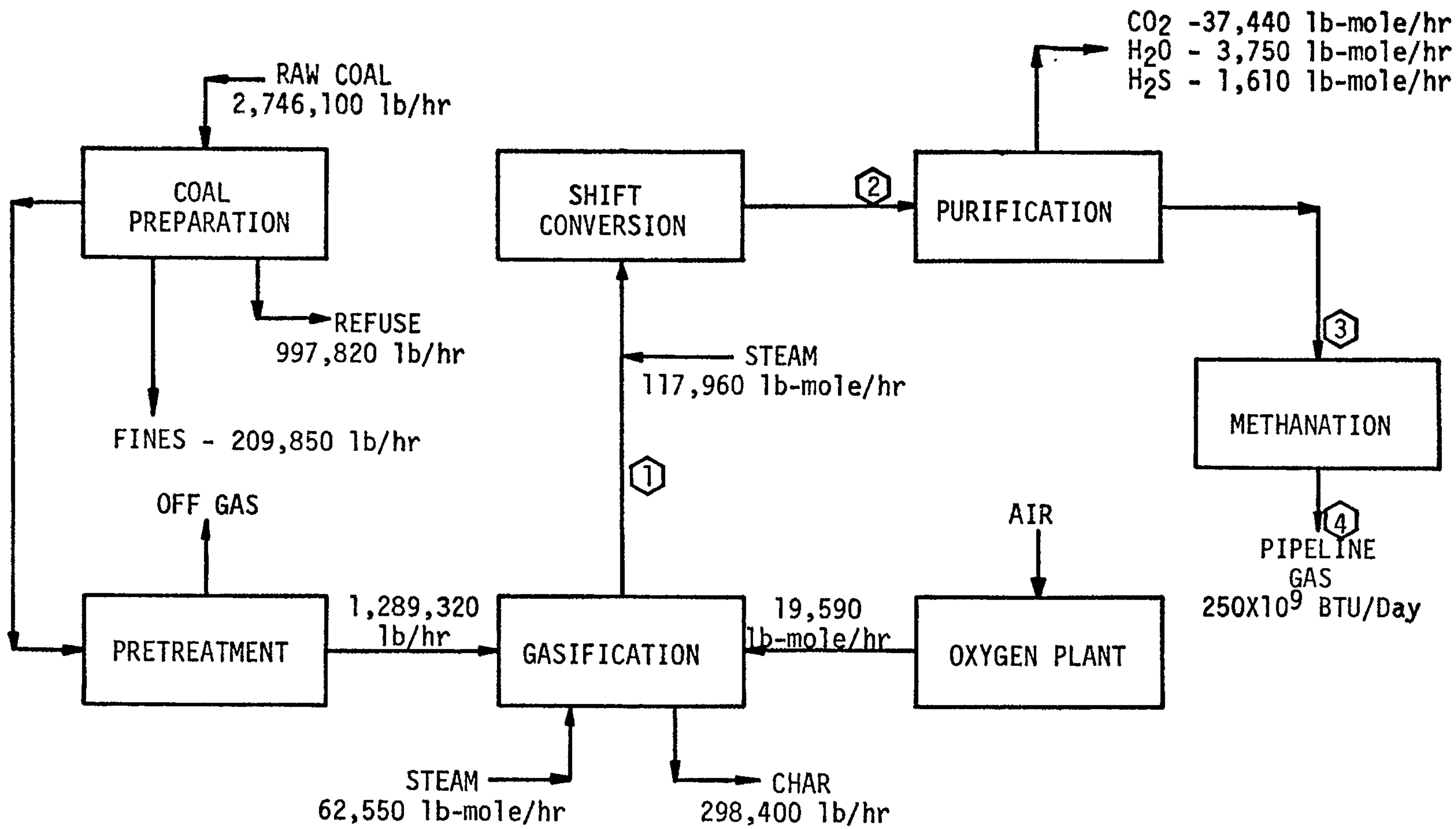

Figure VIII-1 Coal Gasification Process -- Alternate I it is quenched with the cold feed gas. The procedure is repeated until the desired conversion is reached. The effluent gas from the methanator is passed through another waste heat recovery system where the excess water vapor is condensed before the gas enters the pipeline.

1.2 Alternate II

Depending on the type of gasifier selected, this alternate process can be divided into three processes.

i. Alternate II-1

Stage I is a slag bed and Stage II is a fluidized bed. The schematic flow diagram of this alternate is shown in Figure VIII-2. The coal preparation and pretreatment section are the same as Alternate I. In the gasification phase, two reactors, Stage I and Stage II, are connected in series. The pretreated coal enters the gasification phase at the top of Stage II, where it is fluidized and reacted with the hot gas from Stage I. The partially reacted coal flows into Stage I through a standpipe. Stage I is a slag bed where the char from Stage II reacts nearly completely with oxygen and steam. The ash is discharged from Stage I in the form of molten slag. The effluent gas of Stage I enters the bottom of Stage II. The product gas from Stage II goes into a shift conversion unit. The gas, thereafter, follows the same route as described in Alternate I.

ii. Alternate II-2

Both Stage I and Stage II are fluidized beds. A schematic flow diagram of this alternate is shown in Figure VIII-3. In this process, Stage II of the gasifier is the same as the one described in Alternate II-1. The only difference between the two processes is that

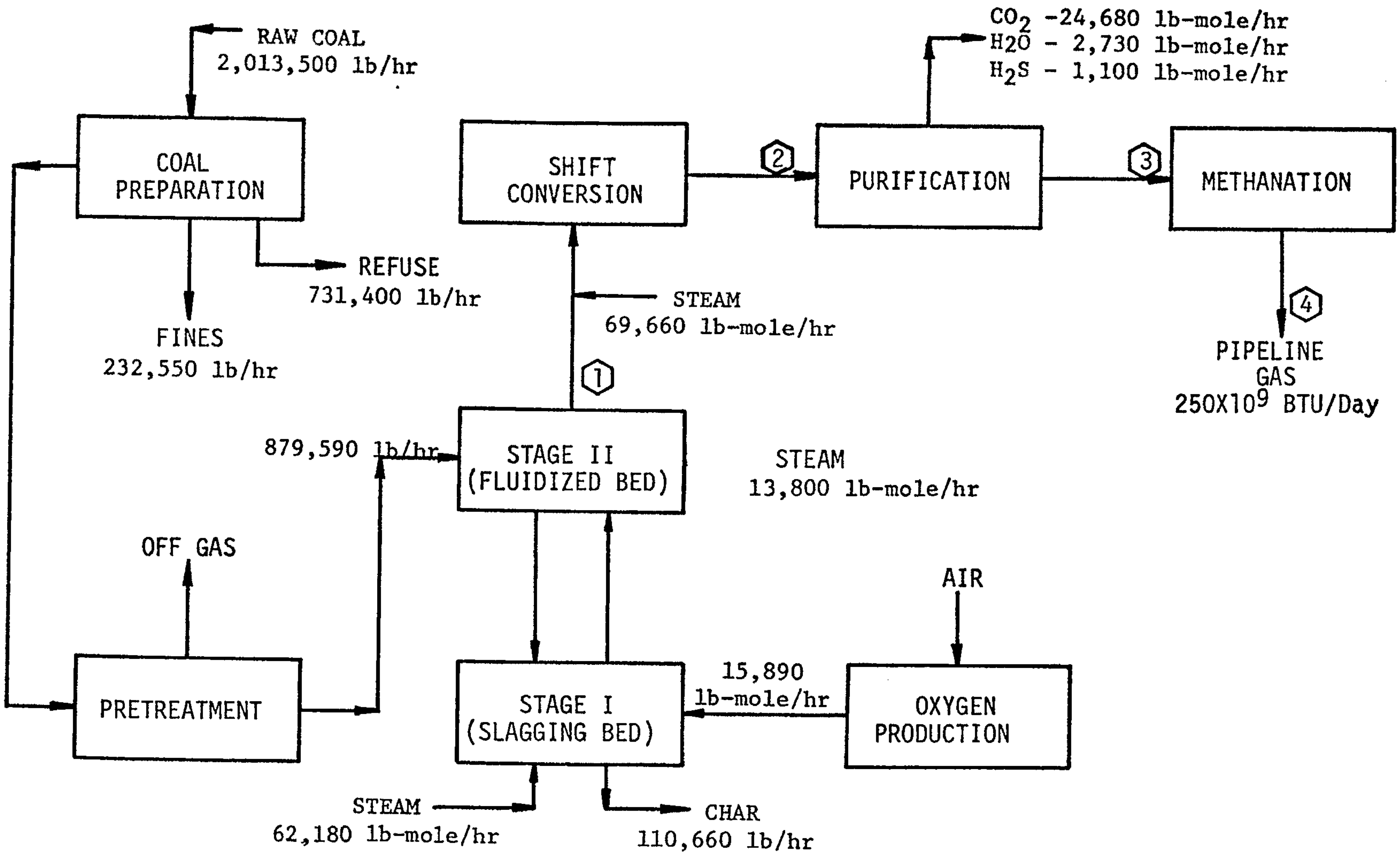

Figure VIII-2 Coal Gasification Process -- Alternate II-1

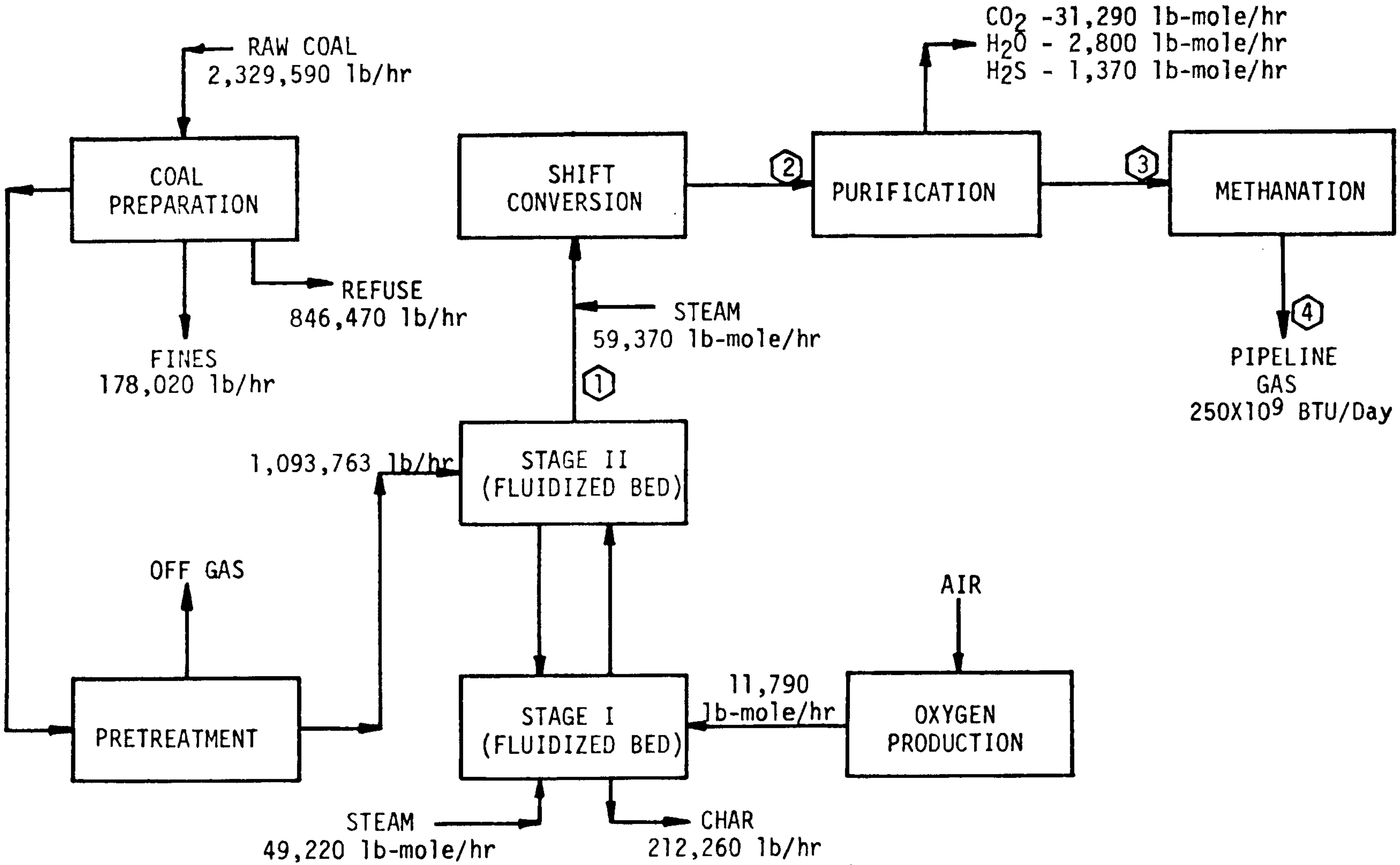

Figure VIII-3 Coal Gasification Process -- Alternate II-2

Stage I of this alternate is a fluidized bed. Since Stage I is a fluidized bed, the bed temperature is lower than that of the slag bed. From the shift conversion to the end of the process, the gas passes through the same steps as described in Alternate I.

iii. Alternate II-3

Stage I is a slag bed and Stage II is an entrained bed. A schematic flow diagram of this alternate is shown in Figure VIII-4. In this process, untreated coal may be fed directly. The pulverized coal, through a feeding system, either by piston feeders or lock hoppers, is introduced into the bottom part of Stage II of the gasifier. The coal particles react with the gaseous medium while they are entrained through Stage II. The solid particles are separated from the gas stream by a cyclone separator. The partially reacted char, collected in the cyclone, is then introduced to Stage I where it reacts with oxygen and steam. The solid free gas from Stage II follows the same steps as the gas coming out of the gasifier in Alternate I for the production of pipeline gas.

1.3 Alternate III

A schematic flow diagram is shown in Figure VIII-5. Coal from the mine is prepared and pulverized. The coal is then pretreated by steam and oxygen in the pretreatment section before it can be gasified. Pretreated coal is fed to a train of fluidized bed hydrogasifiers, where the pretreated coal is brought into contact with a gas mixture rich in hydrogen. The partially reacted char is transferred into a train of gasifiers. Char particles are fluidized and reacted with steam and oxygen in the gasifiers. The effluent gas from the gasifiers is completely shifted, purified, and is then returned to the hydrogasifiers. The gas

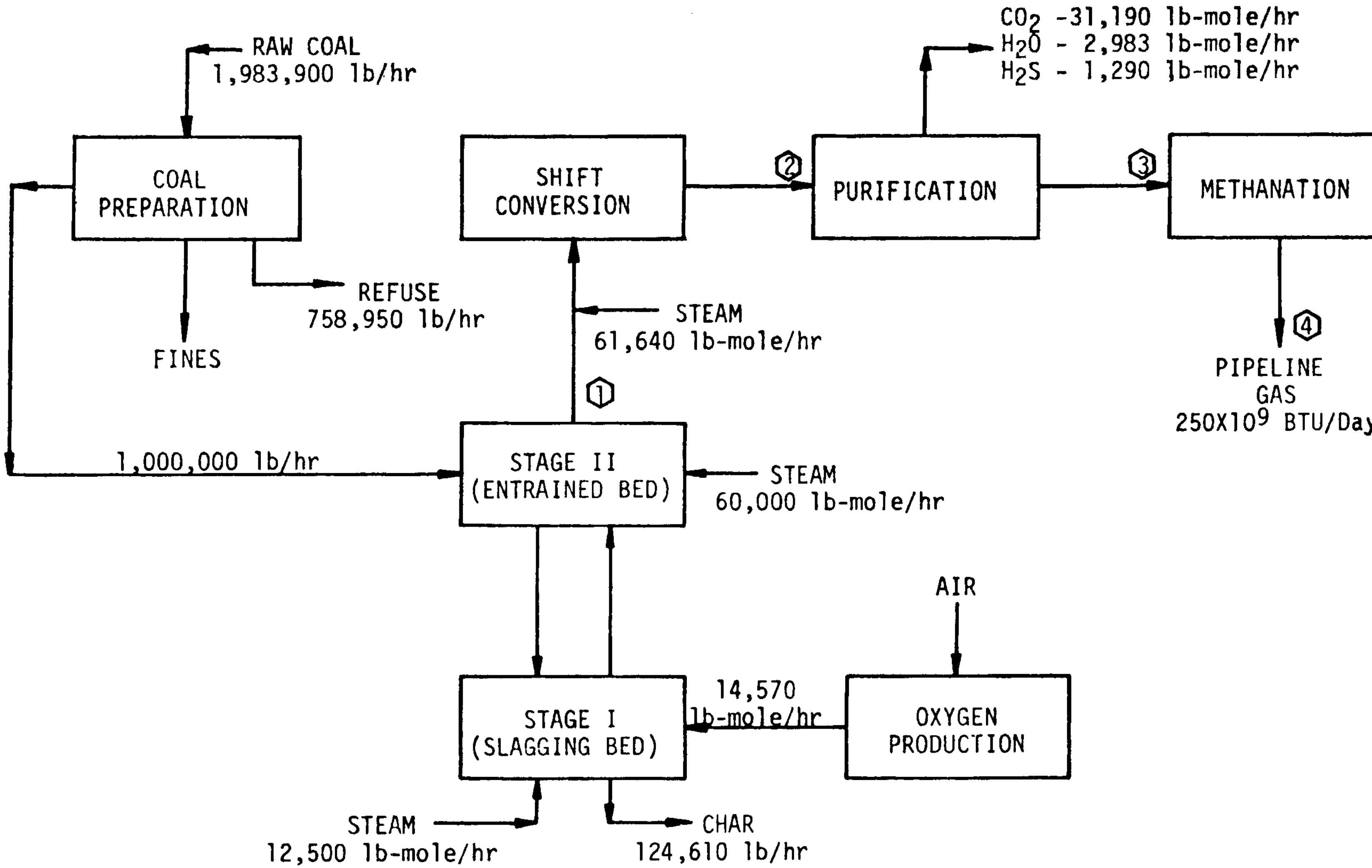

Figure VIII-4 Coal Gasification Process -- Alternate II-3

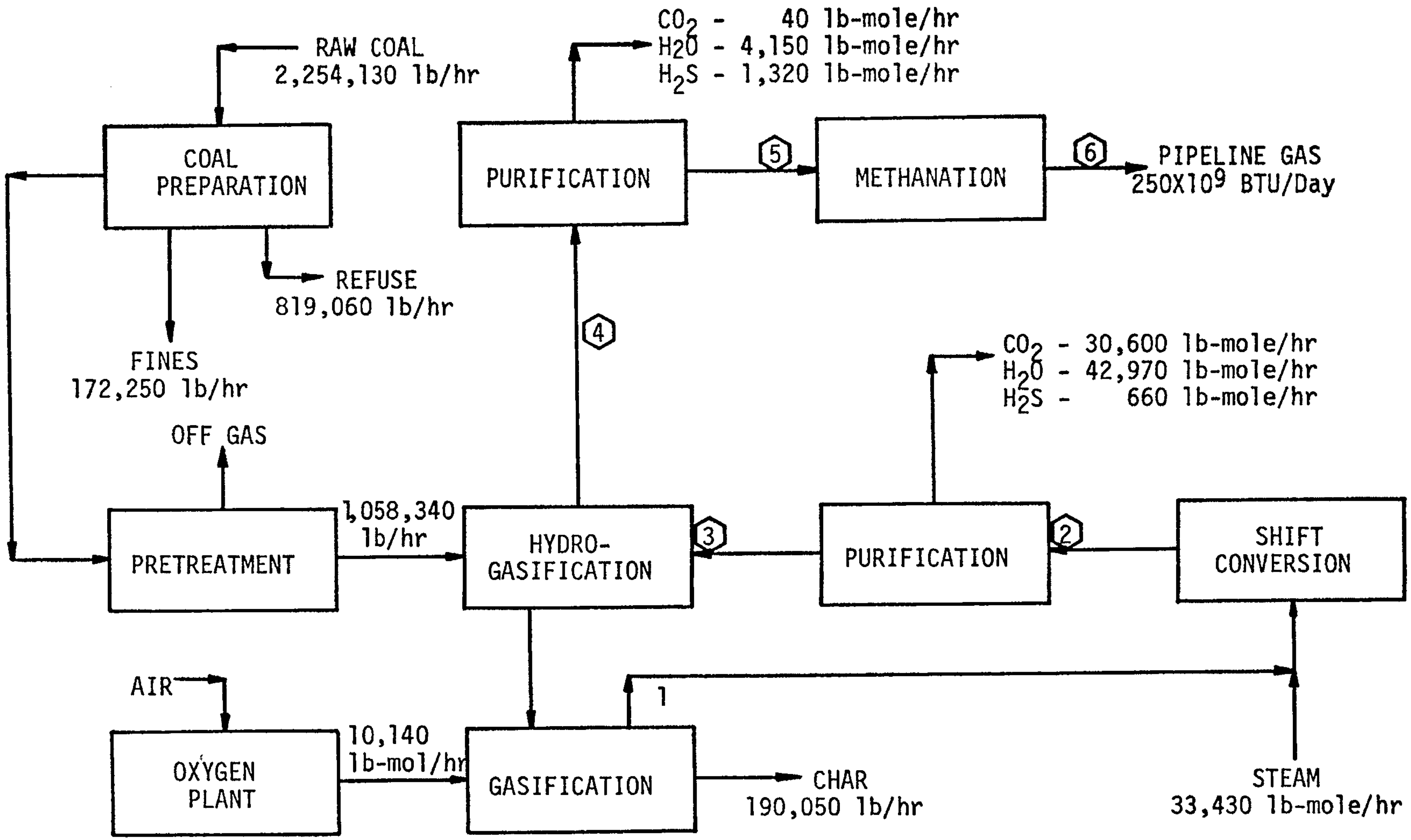

Figure VIII-5 Coal Gasification Process -- Alternate III from the hydrogasifier is processed through purification and methanation to meet pipeline gas quality.

1.4 Alternate IV

Depending on the type of fuel used in gasifier, this alternate scheme may be considered to represent the following two processes.

i. Alternate IV-1

A schematic flow diagram is shown in Figure VIII-6. The pretreated coal is fed into hydrogasofiers by slurry feeders. Coal particles are fluidized and reacted by the synthesis gas which is produced from the hydrogasifiers are transferred into the electrothermal gasifiers. In the electrothermal gasifiers, char reacts with steam, and the energy required for gasification is supplied by passing electric current through electrodes and the fluidized beds. The effluent gas of the hydrogasifiers is purified and methanated to produce pipeline gas.

ii. Alternate IV-2

A schematic flow diagram is shown in Figure VIII-7. This alternate is essentially the same process as Alternate IV-1 described in the previous section. The only difference is that lignite, which does not require pretreatment, is introduced to the hydrogasifier.

1.5 Alternate V

A schematic flow diagram of this alternate process is shown in Figure VIII-8. Lignite from the mine is crushed to proper sizes and dried in the preparation unit. Lignite is then preheated and is introduced through a lock hopper to the devolatilizer. In the devolatilizer lignite reacts with hydrogen-rich stream from the gasifier. The volatile matter from the lignite leaves the top of the devolatilizer as methane, carbon monoxide, and hydrogen. The devolatilized lignite (char) is withdrawn

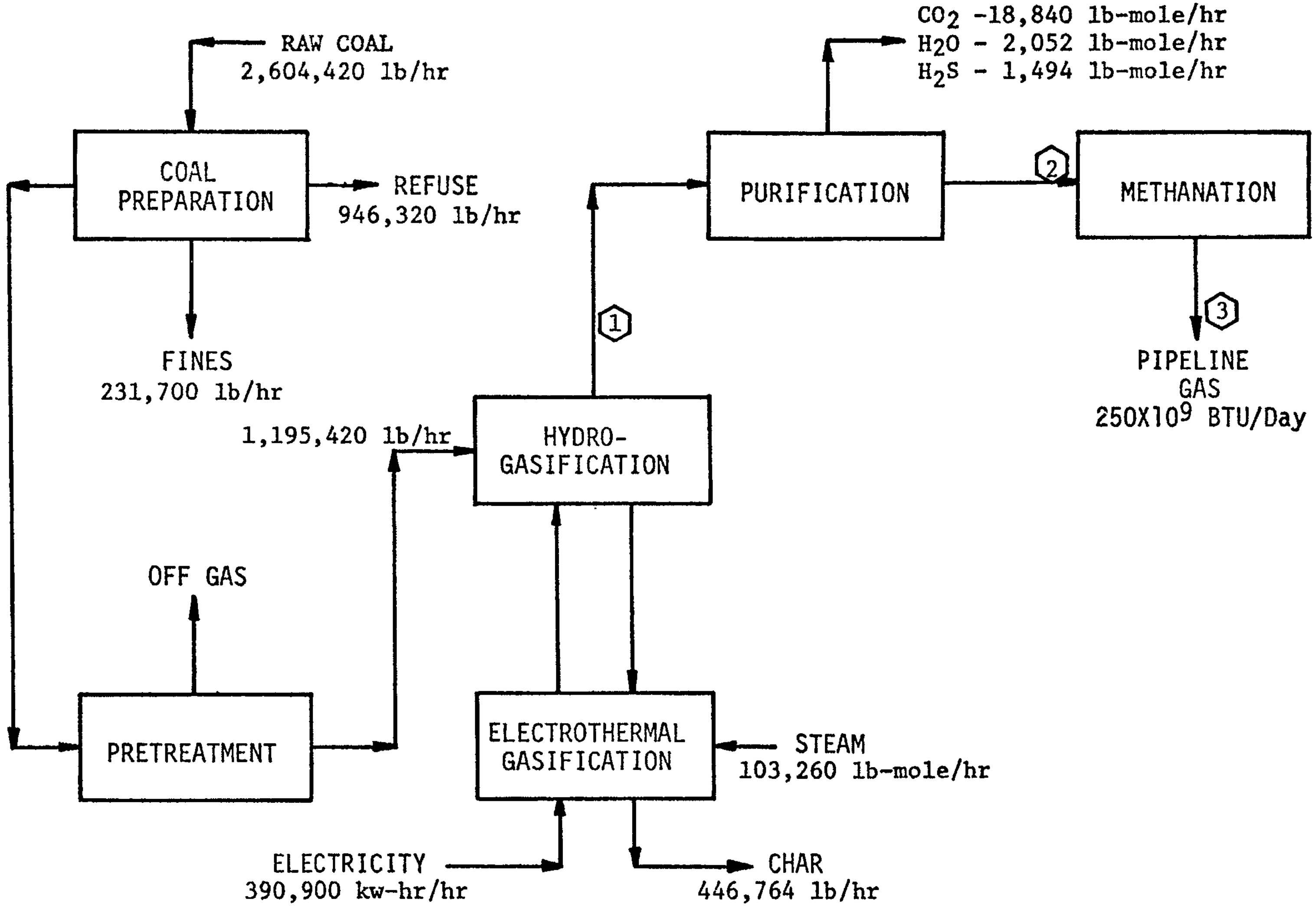

Figure VIII-6 Coal Gasification Process -- Alternate IV (Bituminus Coal)

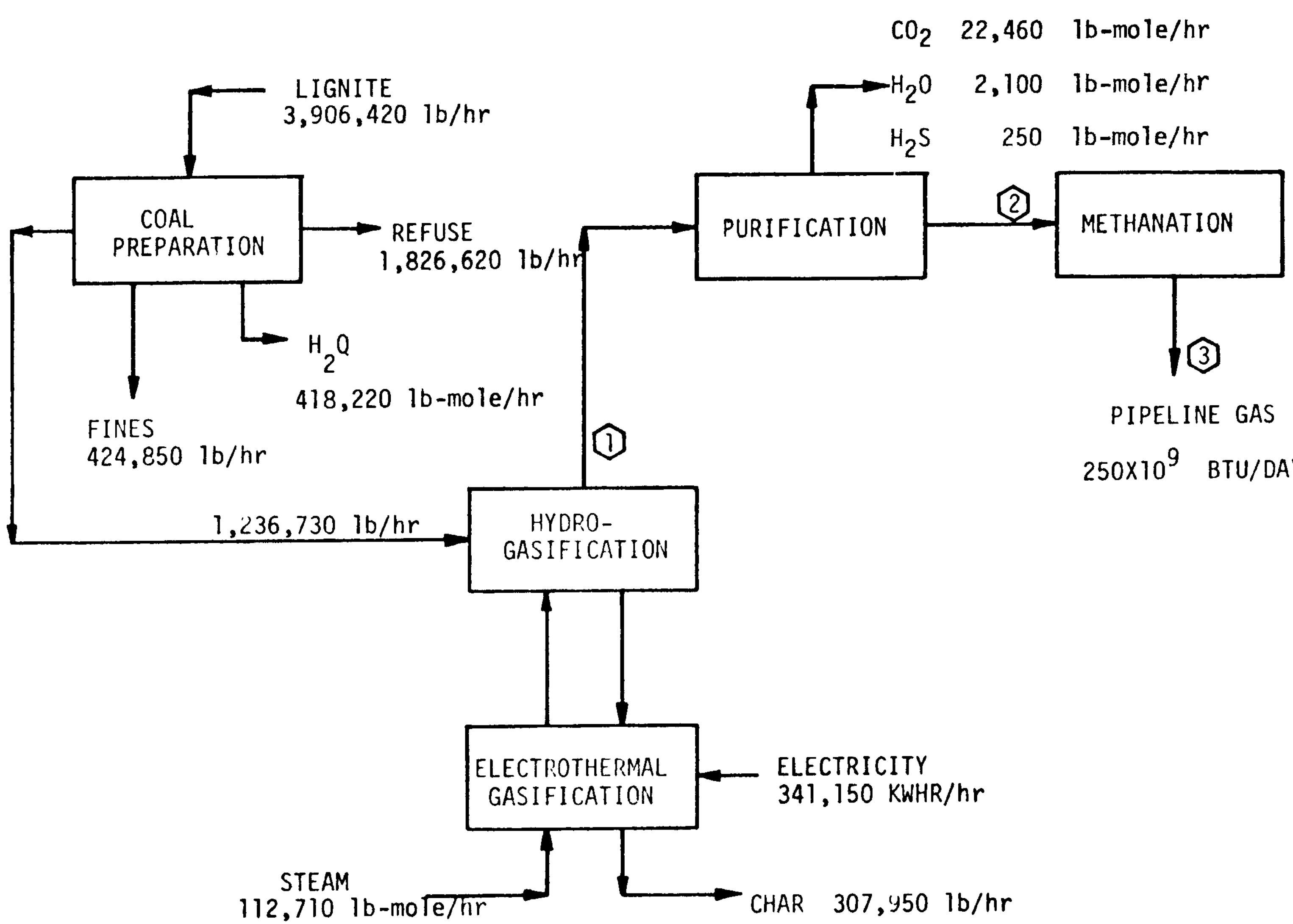

Figure VIII-7 Coal Gasification Process Alternate IV-2 (Lignite)

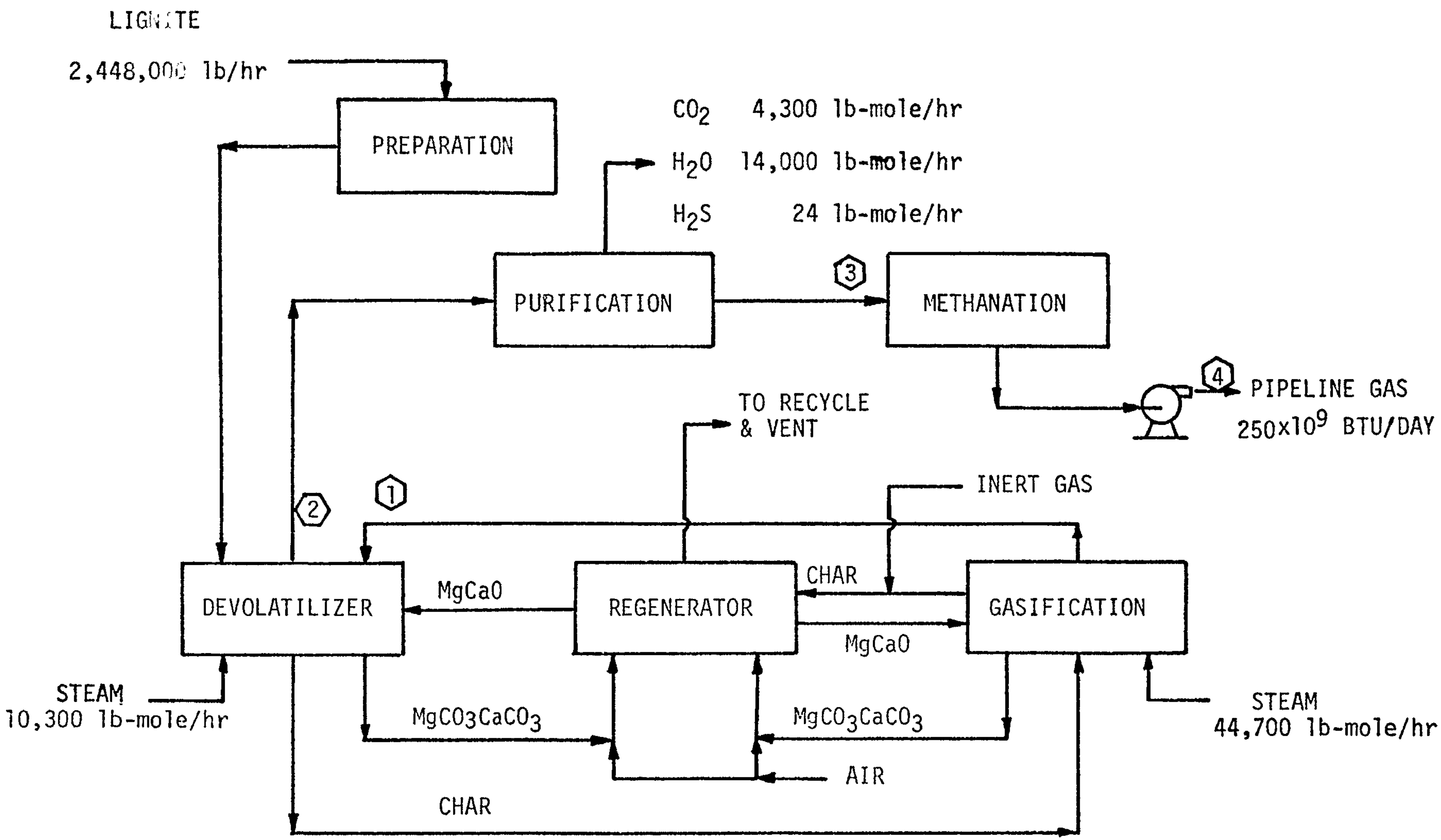

Figure VIII-8 Coal Gasification Process Alternate V from the reactor through a standpipe and lifted into the gasifier. Carbon in the char is gasified by reacting with steam in the gasifier. Residual char flows out of the gasifier by gravity and is lifted pneumatically to the regenerator. In the regenerator the carbon is burned with air to supply the heat needed for the calcination of dolomite. The dolomite in the regenerator comes from the devolatilizer and the gasifier through a dolomite circulation system. The calcined dolomite acts as a heat carrier, flows from the regenerator to the devolatilizer and the gasifier where it reacts with CO_2 and releases both of its sensible heat and heat of reaction to the gasifying lignite. The gaseous product of the devolatilizer is cooled, then sent to the gas purification unit, where CO_2, H_2S, C_6H_6 and other impurities are removed from the gas stream. The purified gas is introduced to the methanator, where CO reacts with H_2 to form more methane. The product gas from the methanator is cooled and compressed to the specified pressure of 1000 psig before it enters the pipeline.

2. Summary of Equipment Costs

In order to estimate the total equipment cost for different alternate processes of coal gasification to produce pipeline gas, the cost information developed for each phase in the previous chapters must be assembled in light of an integrated plant operation. This necessitates, in some instances, interpolation and extrapolation of performance data. The methods and results of the approach taken are briefly discussed in the following:

In Chapter III, costs of equipment for coal preparation and pretreatment are estimated based on information available in the literature, without performing detail design and computer optimization of this phase. Since sufficiently accurate information is available on this phase of operation, and the required cost of coal preparation and pretreatment affect the price of gas linearly, it is believed that the information presented in Figures III-5 and III-6 of Chapter III is adequate for the present purpose.

Results of thermodynamic and kinetic studies of gasification presented in Chapter IV, Sections 3,4, and 5 provide a guide to the reactor design procedure for different alternate gasification processes. In Section 5 of Chapter IV, the optimum reactor number, reactor size, as well as the costs of reactor and auxiliary equipment, are determined. Results of these calculations are presented in Figures IV-32 through IV-37.

In Chapter V, "Shift Conversion", the equipment costs are calculated based on different inlet gas compositions (or CO concentrations). Results of these calculations are listed in Tables V-6, V-10, and V-11. This information is summarized in Figure VIII-9 by plotting the optimum bare equipment cost of shift conversion vs. the amount of CO which must be shifted so that the H_2-CO ratio in the effluent is higher than 3, in order to achieve the pipeline gas production of 250 X 10^9 BTU/day. By using Figure V-9, optimum equipment costs of the shift conversion phase for streams with a given composition can be estimated. It should be noted that the equipment costs presented in Figure V-9 have been adjusted to the current cost index (1971).

In Chapter VI, different schemes of gas purification processes for various inlet gas compostions have been studied. As mentioned in Section 10.4 of the same chapter, scheme 5, the hot potash process followed by an amine process, is recommended as the best scheme among the various processes studied for removal of CO_2 and H_2S. To remove benzene and other

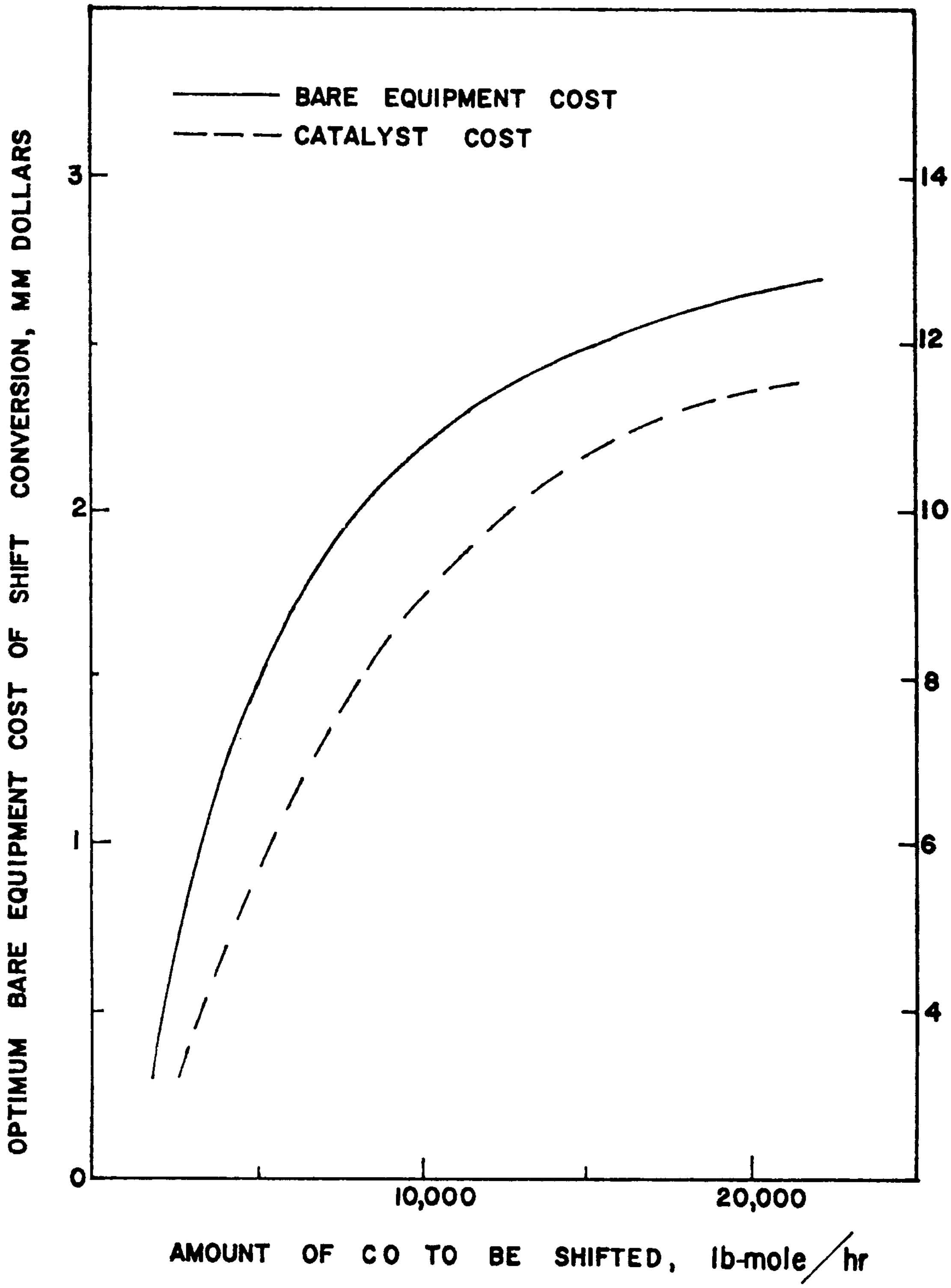

Figure VIII-9 Optimum Equipment Costs For Water Gas Shift Conversion Phase To Obtain Proper H_2-CO Ratio For Methanation impurities, an activated carbon tower is also required for a complete gas purification system. This information is summarized in Figure VIII-10 by plotting the optimum bare equipment cost vs. the amount of CO_2 [lb-mole/hr] which must be removed from the gas stream so that the CO_2 concentration is less than 1% in the product gas, in order to achieve the pipeline gas production of 250 X 10^9 BTU/day.

In Chapter VII, methanation with different inlet gas compositions is investigated. The equipment costs for different CO inlet gas concentrations are shown in Tables VII-8, VII-13, and VII-15. From this information, the equipment cost is summarized and is presented in Figure VIII-11 in terms of the molar percentage of CO of inlet gas. The discontinuity in the equipment cost appearing in this figure is due to the change in the optimum reactor system as discussed in Chapter VII. At high CO concentrations, because of the large heat of generation of methanation reaction, cold quench with gas recycle is used. By recycling the product gas to the methanator, the inlet gas is diluted and reactor overheating can be avoided.

3. Optimization and Gas Price Calculation

In Section 4 of Chapter II, the procedure for calculation of the revenue requirement was briefly discussed. Although the revenue requirement can be used as a criterion for comparison of the selected alternate processes, the cost of production of unit volume or unit thermal value of gas seems more convenient to use as the basis for the comparison. The procedure for computing the gas price, either in \$/M SCF or \$/MM BTU from the revenue requirement has been programmed

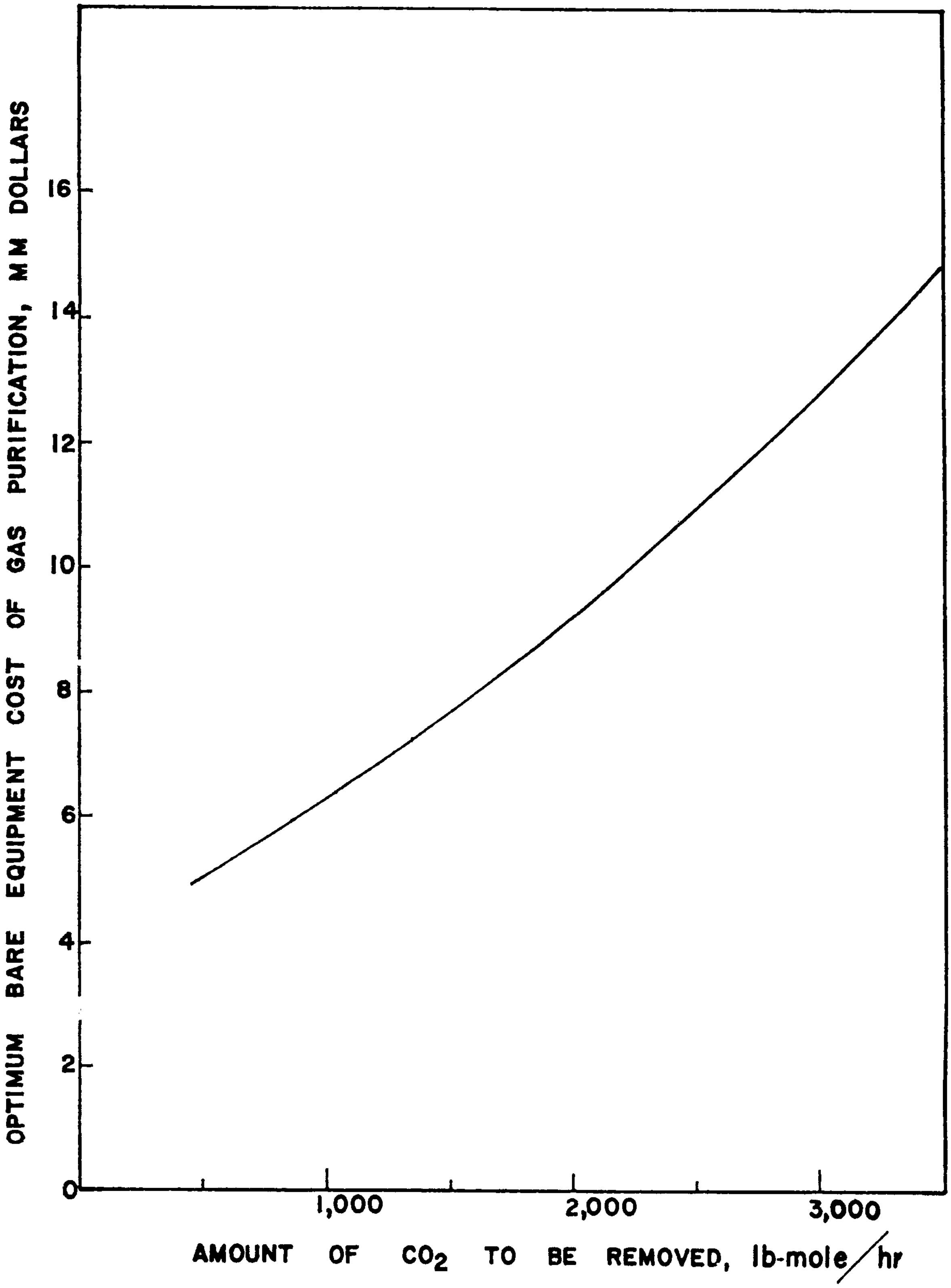

Figure VIII-10 Optimum Equipment Costs For Gas Purification Phase To Meet Pipeline Gas Quality

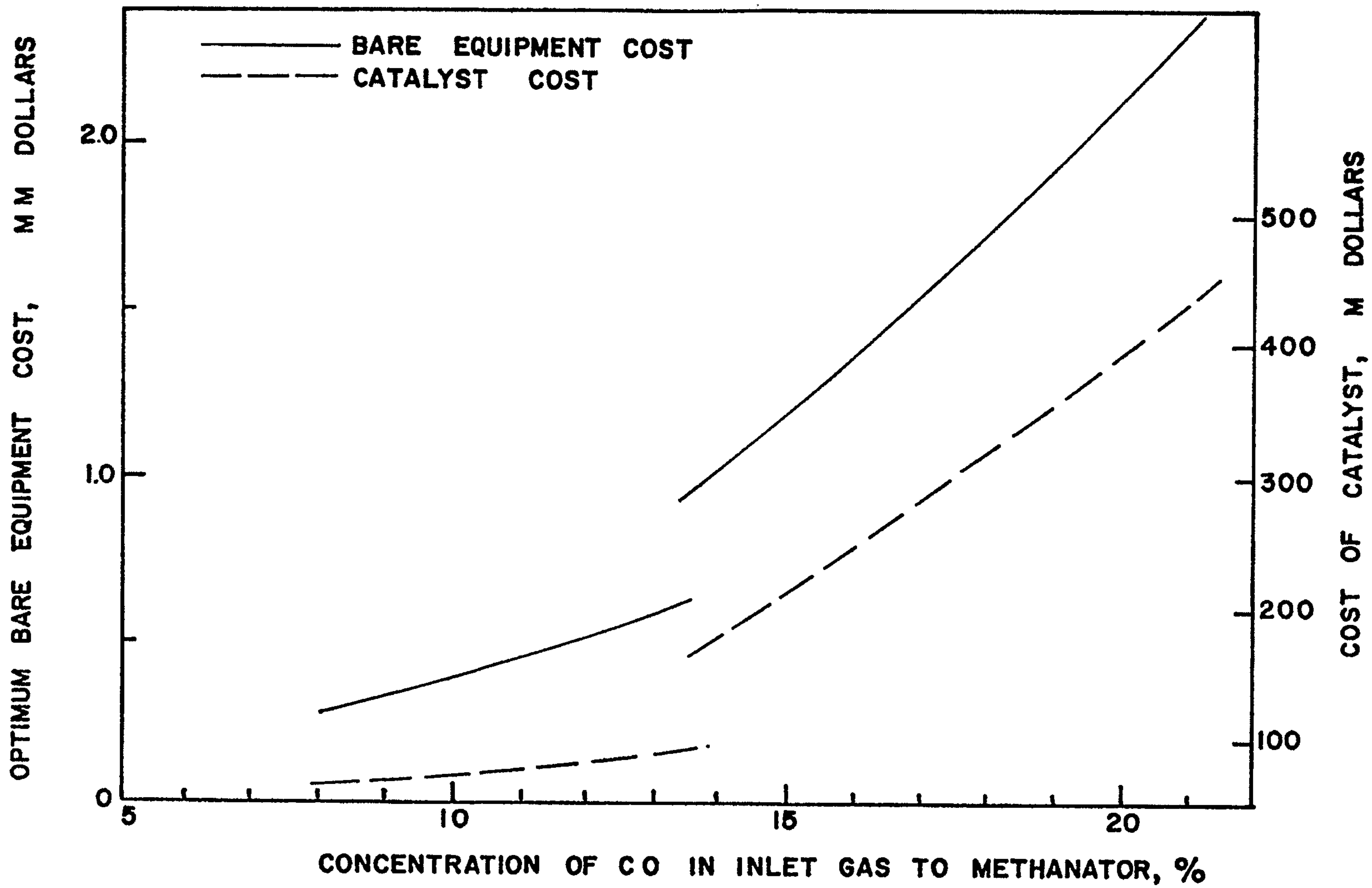

Figure VIII-11 Optimum Equipment Costs For Methanation Phase To Achieve Pipeline Gas Quality in the computer based on the O.C.R. accounting procedure. Assumptions and constants used in the program are listed in Chapter II. To use the computer program eight input data, as is indicated in the Appendix B, are necessary.

To obtain the total bare cost, the raw material cost, and the operating labor cost, the following procedure is adopted:

For each of the alternate processes, once the operating conditions of gasification are determined, (see Sections 2,3, and 4 of Chapter IV), the optimum size, the number of gasifiers, and the equipment cost of the gasification phase can be obtained. The optimum bare equipment costs of other phases involved in an integrated gas production plant can be evaluated directly from the figures provided in the previous section.

As has been discussed, in an integrated pipeline gas production plant, coal is used, not only to generate methane needed in the pipeline gas, but also to provide the steam, power, and heat necessary to produce methane. It is quite evident that, in an integrated plant, the amount of coal required will dominate the price of gas. Therefore, a thermodynamic model described in Chapter IV is first used to determine the optimum operating policy which can provide the minimum coal consumption for each of the alternates. A kinetic model, as described in Chapter IV, is then coupled with the thermodynamic model to calculate the composition of the gas from the gasification phase, and, simultaneously, to adjust the flow and the operating conditions to yield the desired gas distribution.

Based on the material balance, the amount of CO to be shifted, the amount of CO_2 to be removed in the purification phase, and the inlet CO concentration to the methanator are calculated. The optimum size of reactors and other units are then computed. The optimum bare equipment cost of shift conversion, gas purification, and methanation phases are determined based on Figures VIII-7, VIII-8, and VIII-9 respectively.

When oxygen is used in a coal gasification process, the bare equipment cost for the oxygen plant is estimated [1], and the six-tenth power of scale-up factor is applied.

Based on the total amount of coal required for the pipeline gas plant, the equipment cost associated with the coal preparation-pretreatment phase is estimated from Figures III-5, and III-6.

The toal bare cost is then computed by summing up the optimum bare cost of preparation-pretreatment, gasification, shift conversion, gas purification, methanation, oxygen generation, power generation and offsite facilities.

In the thermodynamic model, the steam generated in various parts of the process, i.e., the waste heat recovery system and gas product coolers are calculated from the energy balance. The amount of steam required for the overall process, such as the gasification phase, the shift conversion phase, the regeneration part of the gas purification phase and power generation are also determined. The overall steam balance is made from the steam generation and requirement of the plant. The amount of steam which must be supplied from a steam generation plant is then calculated. In this study, the low pressure steam required for the regeneration part of the gas purification phase is assumed to be adequately supplied by the low pressure steam generated from the waste heat recovery systems. The amount of treated water and cooling water for the pipeline gas plant is determined from the material and energy balance calculations.

The power required for oxygen production is estimated [3] from the total oxygen required for the pipeline gas plant. In the case of the electrothermal gasification process, the energy required for the gasification is calculated based on the material and energy balance taken around the gasifier. Power required for the coal preparation-pretreatment phase is estimated from Figure III-10, based on the total amount of coal required in the entire plant, including gasification, steam for process, and power generation.

The electric power required for the entire plant is then computed by summing up the power required for the coal preparation-pretreatment phase, the gasification phase including the feeding system and electrothermal process, the oxygen plant, and methanation product gas recycling pump.

From the annual coal consumption of the entire plant, the cost of the raw material is calculated based on the various costs of coal. The cost of coal depends on the location of the pipeline gas plant, the quality of coal, etc. Thus the cost of coal, in this study, is varied as a parameter so that the effect of this factor on the economy of pipeline gas production may be assessed.

The number of men needed for the normal operation of the plant is estimated from different sources [4] [1]. It ranges from 30 to 45 persons per shift. The wage of the operator is assumed to be $3.75 per man hour.

4. Results of Overall Plant Optimization

In this section, the results of optimization and an economic study of each of the alternate coal gasification processes considered are presented.

In all cases, the pipeline gas production rate is 250 X 10^9 BTU/day delivered at 1000 psig. The heating values of gas are at least 900 BTU/SCF, and vary slightly from process to process.

The results of material balance are shown in Figures VIII-1 through VIII- 8. The investment summary, the annual operating expense, and revenue requirement, as well as the gas compositions and gas flow rates, are shown in Tables VIII-1 through VIII-24 for each of the alternates separately. The annual operating expense and revenue requirement shown are based on the cost of coal at $4.00/ton and lignite at $1.50/ton. The effects of coal cost or lignite cost on the 20-year average gas price are shown in Figure VIII-12 through VIII-19. The effects of varying financial factors on the price of pipeline gas for different alternates are shown in Figure VIII-20 through VIII-27. It should be noted that in preparing those figures and tables relating Alternate V, detail process calculation and optimization were not performed since reliable thermal and kinetic data are lacking. The information presented in the report [2] by the Consolidation Coal Company on material balance, the gasification reactor design, and costs of lignite preparation and gasification was essentially adopted.

Table VIII-1 Investment Summary For Alternate I

		Bare Cost,$
Preparation and Storage		11,800,000
Pretreatment		6,180,000
Gasification		3,685,000
Shift Conversion		4,013,000
Gas Purification		19,000,000
Methanation		3,757,000
Oxygen Production Plant		32,219,000
Electric Power Plant		23,025,000
Offsite Facilities		18,296,000
Subtotal, Bare Cost		121,975,000
Contractor's Overhead and Profit		9,429,000
Interest During Construction		6,570,000
Total Fixed Investment		137,974,000
Working Capital		
30-Days Coal Inventory @ $4/Ton	4,009,000	
30-Days Other Direct Material Inventory	127,000	
Accounts Receivable	6,539,000	
Total Working Capital	10,675,000	10,675,000
Total Capital Investment		148,649,000

Table VIII-2 Annual Operating Expense and Revenue Requirement For Alternate I

	$/Year
Raw Material (@ $4/Ton)	45,706,000
Other Direct Materials	1,451,000
Direct Operating Labor	986,000
Maintenance	3,659,000
Supplies	549,000
Supervision	98,000
Payroll Overhead	108,000
General Overhead	2,646,000
Depreciation	6,899,000
Local Taxes and Insurance	4,139,000
Contingencies	1,325,000
Byproduct Credit	(1,150,000)
Operating Expense	66,416,000
Gross Return, 20-Year Average	5,334,000
Federal Income Tax, 20-Year Average	2,792,000
Total Revenue Requirement	74,542,000
20-Year Average Price of Gas, ¢/10^6 BTU	85.9

Table VIII-3 Gas Compositions (mole %) and Total Flow Rate of Alternate I

Stream No.*	1	2	3	4		
CO_2	12.33	28.56	1.00	2.98		
CO	29.41	14.64	22.12	0.08		
CH_4	5.07	5.25	7.93	89.17		
H_2O	23.27	4.78	0.09	0.09		
H_2	28.30	45.09	68.13	5.52		
H_2S	1.16	1.20	-	-		
N_2	0.46	0.48	0.73	2.16		
Flow Rate lb-mole/hr	138,920	134,210	88,820	29,900		

* See Figure VIII-1 for stream numbers

Table VIII-4 Investment Summary for Alternate II-1

		Bare Cost,$
Preparation and Storage		9,400,000
Pretreatment		5,650,000
Gasification		10,205,000
Shift Conversion		3,368,000
Gas Purification		12,840,000
Methanation		3,305,000
Oxygen Production Plant		31,939,000
Electric Power Plant		18,838,000
Offsite Facilities		16,861,000
Subtotal, Bare Cost		112,406,000
Contractor's Overhead and Profit		8,689,000
Interest During Construction		6,054,000
Total Fixed Investment		127,149,000
Working Capital		
30-Days Coal Inventory @ $4/ton	2,940,000	
30-Days Other Direct Material Inventory	97,000	
Accounts Receivable	5,324,000	
Total Working Capital	8,362,000	8,362,000
Total Capital Investment		125,511,000

Table VIII-5 Annual Operating Expense and Revenue Requirement For Alternate II-1

	$/Year
Raw Material (@ $4/Ton)	33,513,000
Other Direct Materials	1,109,000
Direct Operating Labor	986,000
Maintenance	3,372,000
Supplies	506,000
Supervision	99,000
Payroll Overhead	108,000
General Overhead	2,481,000
Depreciation	6,357,000
Local Taxes and Insurance	3,814,000
Contingencies	1,047,000
Byproduct Credit	-
Operating Expense	53,392,000
Gross Return, 20-Year Average	4,813,000
Federal Income Tax, 20-Year Average	2,494,000
Total Revenue Requirement	60,699,000
20-Year Average Price of Gas, ¢/10^6 BTU	70.0

Table VIII-6 Gas Compositions (mole %) and Total Flow Rate of Alternate II-1

Stream No.*	1	2	3	4		
CO_2	12.26	24.73	1.05	2.55		
CO	20.64	13.82	19.67	0.09		
CH_4	10.32	12.09	17.21	89.77		
H_2O	27.56	4.75	0.09	0.09		
H_2	27.95	43.11	61.37	6.02		
H_2S	0.91	1.07	-	-		
N_2	0.36	0.43	0.61	1.48		
Flow Rate lb-mole/hr	120,540	102,870	72,260	29,660		

* See Figure VIII-2 for stream numbers

Table VIII-7 Investment Summary For Alternate II-2

		Bare Cost, $
Preparation and Storage		10,620,000
Pretreatment		6,220,000
Gasification		12,837,000
Shift Conversion		3,675,000
Gas Purification		15,816,000
Methanation		2,220,000
Oxygen Production Plant		26,373,000
Electric Power Plant		15,373,000
Offsite Facilities		16,495,000
Subtotal, Bare Cost		109,965,000
Contractor's Overhead and Profit		8,500,000
Interest During Construction		5,923,000
Total Fixed Investment		124,388,000
Working Capital		
30-Days Coal Inventory @ $4/ton	3,401,000	
30-Days Other Direct Material Inventory	95,000	
Accounts Receivable	5,600,000	
Total Working Capital	9,096,000	9,096,000
Total Capital Investment		133,484,000

Table VIII-8 Annual Operating Expense and Revenue Requirement For Alternate II-2

	$/Year
Raw Material (@ $4/Ton)	38,774,000
Other Direct Materials	1,083,000
Direct Operating Labor	985,000
Maintenance	3,299,000
Supplies	495,000
Supervision	98,000
Payroll Overhead	108,000
General Overhead	2,439,000
Depreciation	6,219,000
Local Taxes and Insurance	3,732,000
Contingencies	1,145,000
Byproduct Credit	(1,798,000)
Operating Expense	56,579,000
Gross Return, 20-Year Average	4,773,000
Federal Income Tax, 20-Year Average	2,489,000
Total Revenue Requirement	63,841,000
20-Year Average Price of Gas, ¢/10^6 BTU	73.6

Table VIII-9 Gas Compositions (mole &) and Total Flow Rate of Alternate II-2

Stream No.*	1	2	3	4		
CO_2	18.50	33.15	1.02	2.03		
CO	25.03	10.12	16.65	0.11		
CH_4	17.59	17.49	28.51	89.93		
H_2O	18.98	4.75	0.09	0.09		
H_2	17.82	32.40	52.80	5.98		
H_2S	1.43	1.40	-	-		
N_2	0.57	0.57	0.93	1.85		
Flow Rate lb-mole/hr	95,682	96,220	59,040	29,614		

* See Figure VIII-3 for stream numbers

Table VIII-10 Investment Summary For Alternate II-3

		Bare Cost, $
Preparation, Storage and Drying		14,513,000
Pretreatment		-
Gasification		4,126,000
Shift Conversion		3,338,000
Gas Purification		15,816,000
Methanation		3,030,000
Oxygen Production Plant		30,325,000
Electric Power Plant		17,437,000
Offsite Facilities		15,633,000
Subtotal, Bare Cost		104,218,000
Contractor's Overhead and Profit		8,056,000
Interest During Construction		5,614,000
Total Fixed Investment		117,888,000
Working Capital		
30-Days Coal Inventory @ $4/Ton	2,896,000	
30-Days Other Direct Material Inventory	90,000	
Accounts Receivable	5,125,000	
Total Working Capital	8,111,000	8,111,000
Total Capital Investment		125,999,000

Table VIII-11 Annual Operating Expense and Revenue Requirement For Alternate II-3

	$/Year
Raw Material (@ $4/Ton)	33,011,000
Other Direct Materials	1,029,000
Direct Operating Labor	986,000
Maintenance	3,126,000
Supplies	469,000
Supervision	98,000
Payroll Overhead	108,000
General Overhead	2,340,000
Depreciation	5,894,000
Local Taxes and Insurance	3,537,000
Contingencies	1,012,000
Byproduct Credit	-
Operating Expense	51,610,000
Gross Return, 20-Year Average	4,488,000
Federal Income Tax, 20-Year Average	2,331,000
Total Revenue Requirement	58,429,000
20-Year Average Price of Gas, ¢/10^6 BTU	67.4

Table VIII-12 Gas Compositions (mole %) and Total Flow Rate of Alternate II-3

Stream No.*	1	2	3	4		
CO_2	16.50	30.13	1.05	2.43		
CO	17.97	12.24	18.94	0.10		
CH_4	10.53	12.94	20.01	89.91		
H_2O	30.53	4.75	0.09	0.10		
H_2	23.16	38.32	59.29	6.04		
H_2S	0.99	1.22	-	-		
N_2	0.32	0.40	0.62	1.42		
Flow Rate lb-mole/hr	130,160	105,894	68,440	29,620		

* See Figure VIII-4 for stream numbers

Table VIII-13 Investment Summary For Alternate III

		Bare Cost, $
Preparation and Storage		10,630,000
Pretreatment		6,500,000
Gasification		14,367,000
Shift Conversion		3,986,000
Gas Purification*		20,460,000
Methanation		360,000
Oxygen Production Plant		24,623,000
Electric Power Plant		14,065,000
Offsite Facilities		19,456,000
Subtotal, Bare Cost		114,447,000
Contractor's Overhead and Profit		8,847,000
Interest During Construction		6,164,000
Total Fixed Investment		129,458,000
Working Capital		
30-Days Coal Inventory @ $4/Ton	3,291,000	
30-Days Other Direct Material Inventory	45,000	
Accounts Receivable	5,449,000	
Total Working Capital	8,786,000	8,786,000
Total Capital Investment		138,244,000

* Primary Gas Purification: $15,660,000
Secondary Gas Purification: $4,800,000

Table VIII-14 Annual Operating Expense and Revenue Requirement For Alternate III

	$/Year
Raw Material (@ $4/Ton)	37,518,000
Other Direct Materials	513,000
Direct Operating Labor	986,000
Maintenance	3,434,000
Supplies	515,000
Supervision	99,000
Payroll Overhead	108,000
General Overhead	2,516,000
Depreciation	6,472,000
Local Taxes and Insurance	3,884,000
Contingencies	1,121,000
Byproduct Credit	(2,510,000)
Operating Expense	54,656,000
Gross Return, 20-Year Average	4,920,000
Federal Income Tax, 20-Year Average	2,554,000
Total Revenue Requirement	62,130,000
20-Year Average Price of Gas, ¢/10^6 BTU	71.7

Table VIII-15 Gas Compositions (mole %) and Total Flow Rate of Alternate III

Stream No.*	1	2	3	4	5	6
CO_2	13.64	38.21	0.66	0.76	0.77	0.93
CO	27.42	2.35	4.11	4.69	5.54	0.11
CH_4	-	-	-	61.81	72.98	94.71
H_2O	28.54	4.66	1.03	12.74	0.93	0.09
H_2	29.31	53.69	93.72	15.45	18.24	2.30
H_2S	0.82	0.81	-	3.24	-	-
N_2	0.27	0.28	0.48	1.30	1.54	1.86
Flow Rate lb-mole/hr	79,950	80,920	46,360	40,630	34,410	28,500

* See Figure VIII-5 for stream numbers

Table VIII-16 Investment Summary for Alternate IV-1

		Bare Cost,$
Preparation and Storage		11,200,000
Pretreatment		6,625,000
Gasification		33,952,000
Shift Conversion		-
Gas Purification		10,560,000
Methanation		1,635,000
Oxygen Production Plant		-
Electric Power Plant		42,603,000
Offsite Facilities		18,807,000
Subtotal, Bare Cost		125,382,000
Contractor's Overhead and Profit		9,692,000
Interest During Construction		6,754,000
Total Fixed Investment		141,828,000
Working Capital		
30-Days Coal Inventory @ $4/ton	3,802,000	
30-Days Other Direct Material Inventory	49,000	
Accounts Receivable	6,404,000	
Total Working Capital	10,255,000	10,255,000
Total Capital Investment		152,083,000

Table VIII-17 Annual Operating Expense and Revenue Requirement For Alternate IV-1

	$/Year
Raw Material (@ $4/Ton)	43,348,000
Other Direct Materials	556,000
Direct Operating Labor	986,000
Maintenance	3,761,000
Supplies	564,000
Supervision	99,000
Payroll Overhead	108,000
General Overhead	2,705,000
Depreciation	7,091,000
Local Taxes and Insurance	4,255,000
Contingencies	1,269,000
Byproduct Credit	-
Operating Expense	64,742,000
Gross Return, 20-Year Average	5,434,000
Federal Income Tax, 20-Year Average	2,832,000
Total Revenue Requirement	73,008,000
20-Year Average Price of Gas, ¢/10^6 BTU	84.2

Table VIII-18 Gas Compositions (mole %) and Total Flow Rate of Alternate IV-1

Stream No.*	1	2	3			
CO_2	14.40	1.03	1.82			
CO	5.59	14.47	0.12			
CH_4	14.26	36.92	90.40			
H_2O	46.29	0.09	0.08			
H_2	17.90	46.34	5.55			
H_2S	1.11	-	-			
N_2	0.45	1.15	2.03			
Flow Rate lb-mole/hr	134,545	51,977	29,503			

* See Figure VIII-6 for stream numbers

Table VIII-19 Investment Summary For Alternate IV-2 (Lignite)

		Bare Cost, $
Preparation, Storage and Drying		24,063,000
Pretreatment		-
Gasification		33,952,000
Shift Conversion		-
Gas Purification		12,000,000
Methanation		1,290,000
Oxygen Production Plant		-
Electric Power Plant		38,556,000
Offsite Facilities		19,387,000
Subtotal, Bare Cost		129,248,000
Contractor's Overhead and Profit		9,990,000
Interest During Construction		6,962,000
Total Fixed Investment		146,200,000
Working Capital		
30-Days Coal Inventory @ $1.5/Ton	2,139,000	
30-Days Other Direct Material Inventory	36,000	
Accounts Receivable	4,729,000	
Total Working Capital	6,904,000	6,904,000
Total Capital Investment		153,104,000

Table VIII-20 Annual Operating Expense and Revenue Requirement For Alternate IV-2 (Lignite)

	$/Year
Raw Material (@ $1.5/Ton)	24,382,000
Other Direct Materials	427,000
Direct Operating Labor	986,000
Maintenance	3,877,000
Supplies	582,000
Supervision	98,000
Payroll Overhead	108,000
General Overhead	2,772,000
Depreciation	7,310,000
Local Taxes and Insurance	4,386,000
Contingencies	899,000
Byproduct Credit	-
Operating Expense	45,827,000
Gross Return, 20-Year Average	5,344,000
Federal Income Tax, 20-Year Average	2,726,000
Total Revenue Requirement	53,897,000
20-Year Average Price of Gas, ¢/10^6 BTU	62.2

Table VIII-21 Gas Compositions (mole %) and Total Flow Rate of Alternate IV-2

Stream No. *	1	2	3			
CO_2	15.27	1.07	1.76			
CO	4.23	13.10	0.08			
CH_4	13.43	41.57	89.83			
H_2O	52.64	0.09	0.09			
H_2	13.99	43.30	6.82			
H_2S	0.16	-	-			
N_2	0.28	0.87	1.42			
Flow Rate lb-mole/hr	150,470	48,610	29,560			

* See Figure VIII-7 for stream numbers

Table VIII-22 Investment Summary For Alternate V

		Bare Cost,$
Preparation and Storage		10,980,000
Pretreatment		
Gasification		32,557,000
Shift Conversion		0
Gas Purification		21,900,000
Methanation		2,700,000
Oxygen Production Plant		1,330,000
Electric Power Plant		218,000
Offsite Facilities		12,297,000
Subtotal, Bare Cost		81,982,000
Contractor's Overhead and Profit		6,337,000
Interest During Construction		4,416,000
Total Fixed Investment		92,735,000
Working Capital		
30-Days Coal Inventory	1,374,000	
30-Days Other Direct Material Inventory	243,000	
Accounts Receivable	3,302,000	
Total Working Capital	4,919,000	4,919,000
Total Capital Investment		97,654,000

Table VIII-23 Annual Operating Expense and Revenue Requirement For Alternate V

	$/Year
Raw Material (@ 1.50/ton)	15,663,000
Other Direct Materials	2,770,000
Direct Operating Labor	986,000
Maintenance	2,459,000
Supplies	369,000
Supervision	99,000
Payroll Overhead	108,000
General Overhead	1,956,000
Depreciation	4,637,000
Local Taxes and Insurance	2,782,000
Contingencies	636,000
Byproduct Credit	0
Operating Expense	32,465,000
Gross Return, 20-Year Average	3,428,000
Federal Income Tax, 20-Year Average	1,755,000
Total Revenue Requirement	37,648,000
20-Year Average Price of Gas ¢/10^6 BTU	43.5

Table VIII-24 Gas Comositions (mole %) and Total Flow Rate of Alternate V

Stream No.*	1	2	3	4		
CO_2	4.24	5.18	0.45	1.00		
CO	7.55	14.32	18.34	0.10		
CH_4	7.22	17.62	22.55	92.40		
H_2O	29.65	17.36	0.40	0.01		
H_2	50.92	45.26	57.96	5.83		
H_2S	0.04	0.03	-	-		
N_2	0.38	0.23	0.30	0.66		
Flow Rate lb-mole/hr	49,350	81,750	63,830	28,840		

See Figure VIII-8 for stream numbers

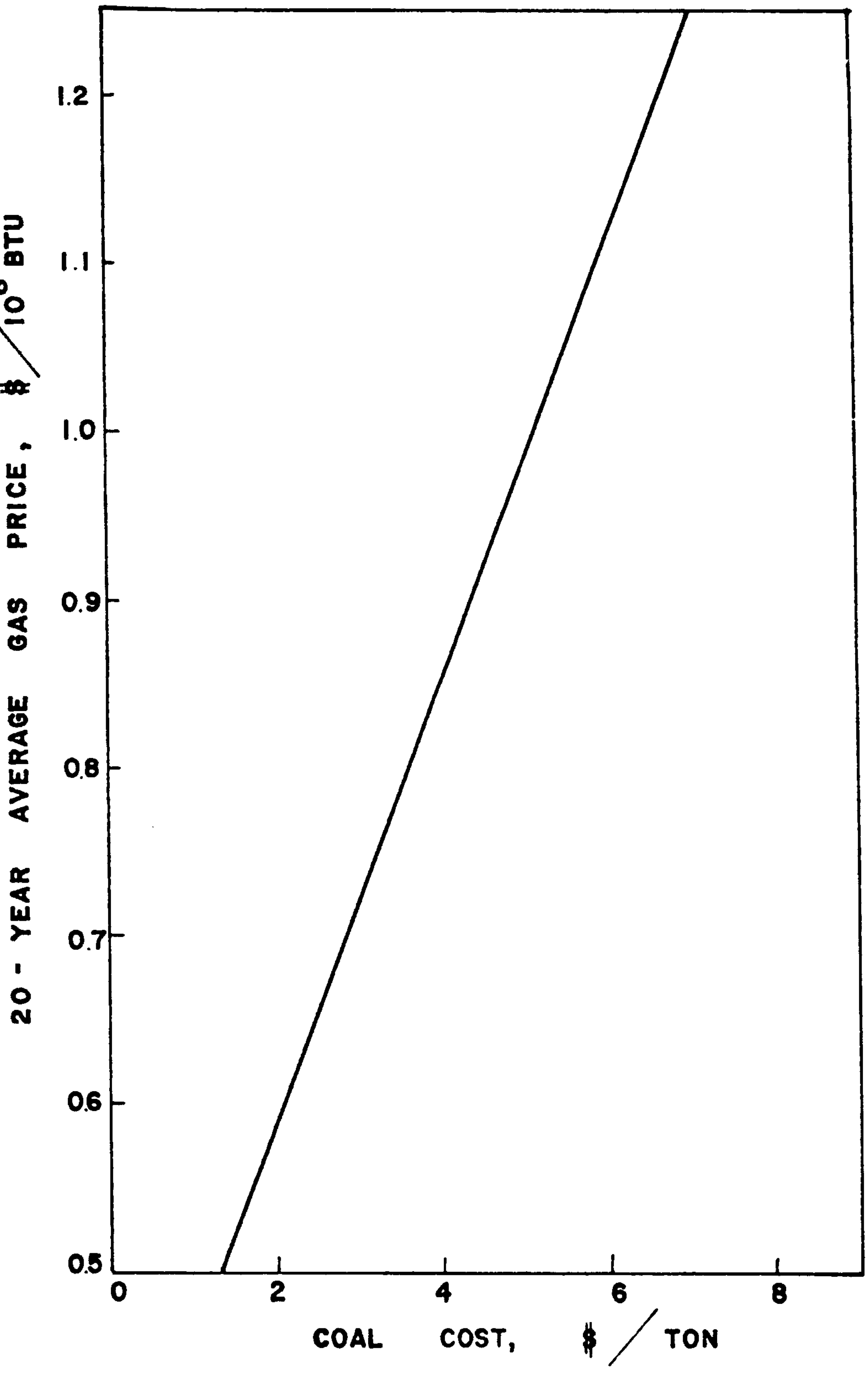

Fig. VIII-12 Price of Gas from Alternate I as a Function of the Cost of Coal

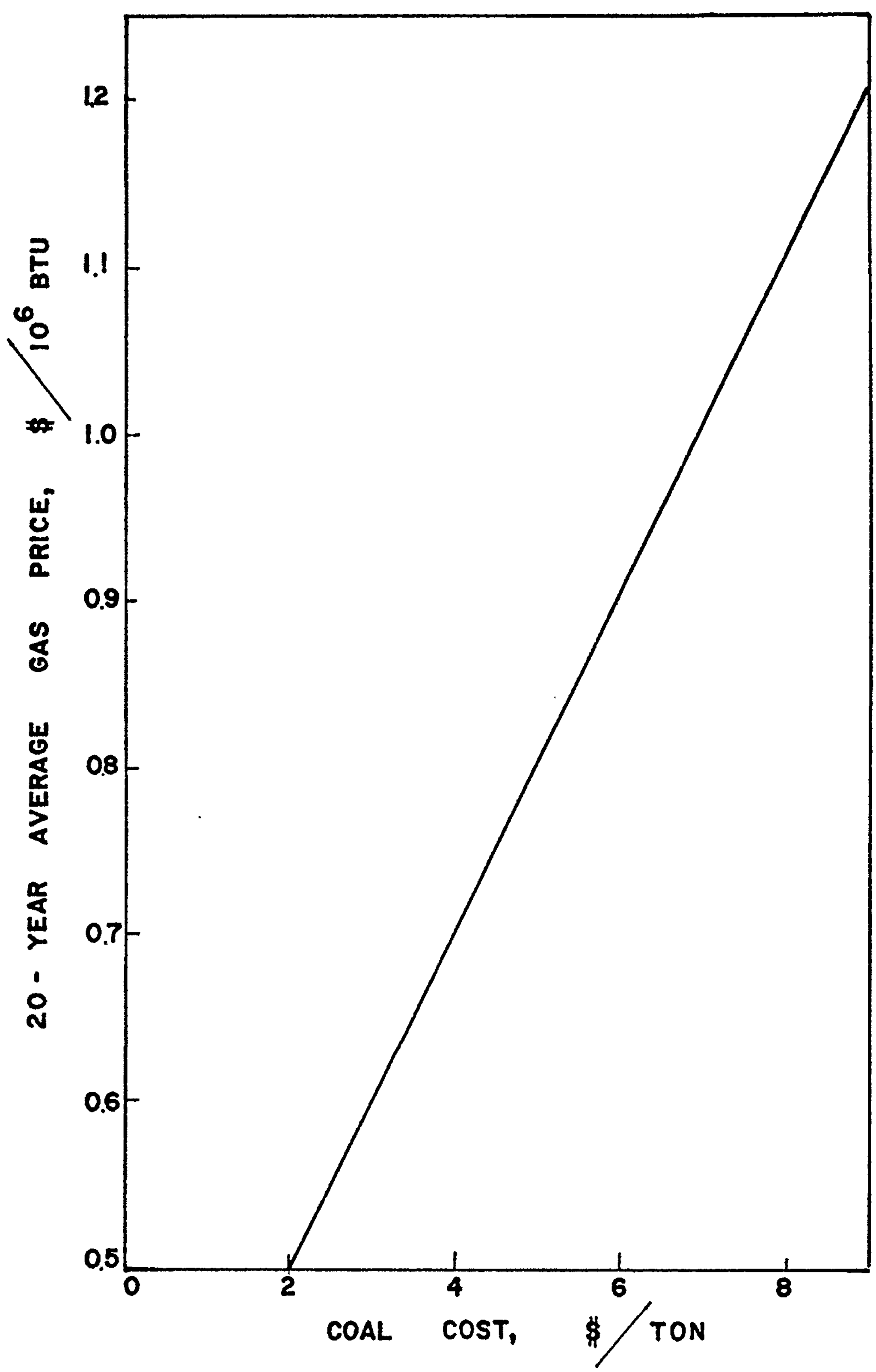

Fig. VIII-13 Price of Gas from Alternate II-1
as a Function of the Cost of Coal

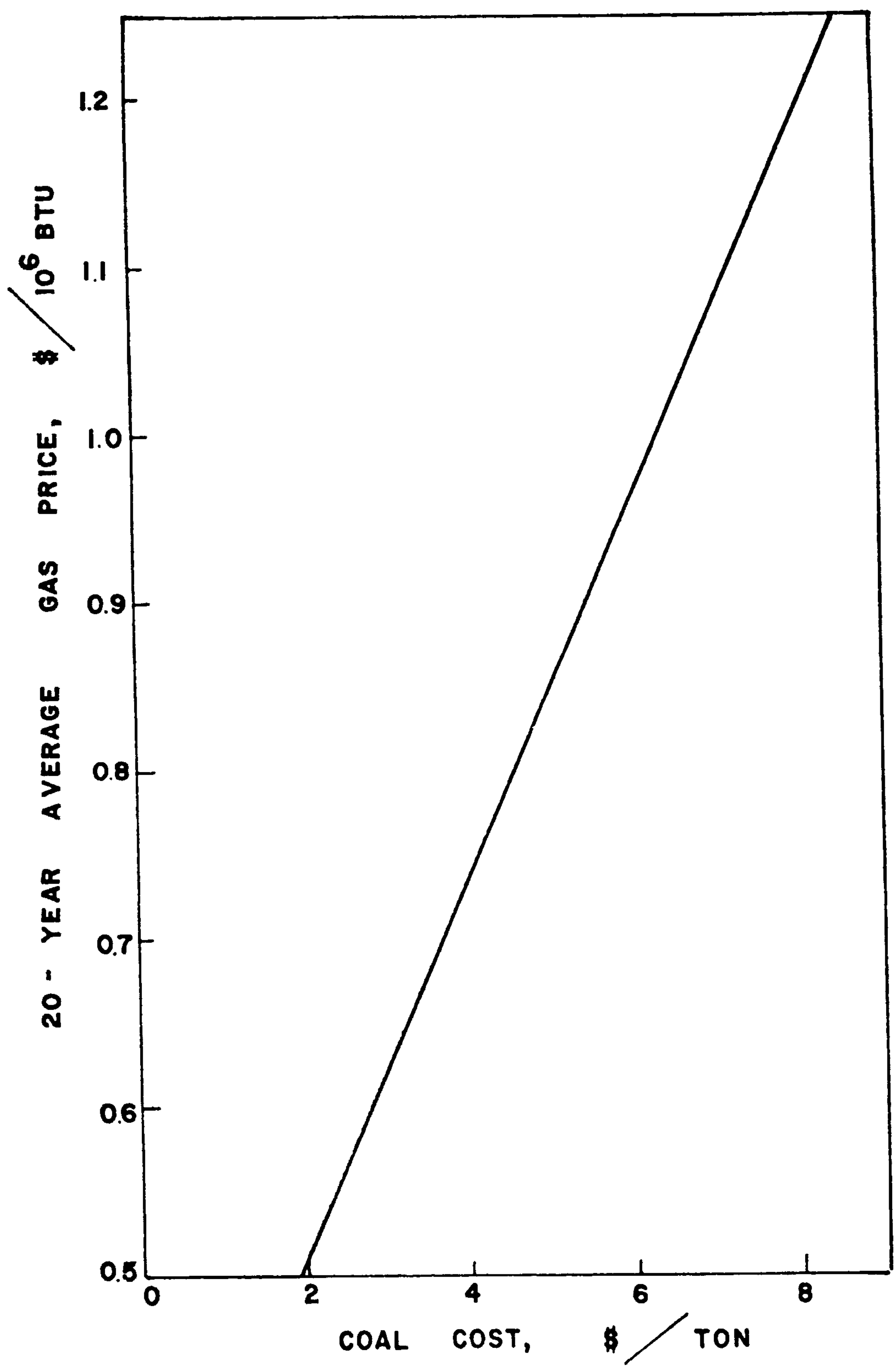

Fig. VIII-14 Price of Gas from Alternate II-2 as a Function of the Cost of Coal

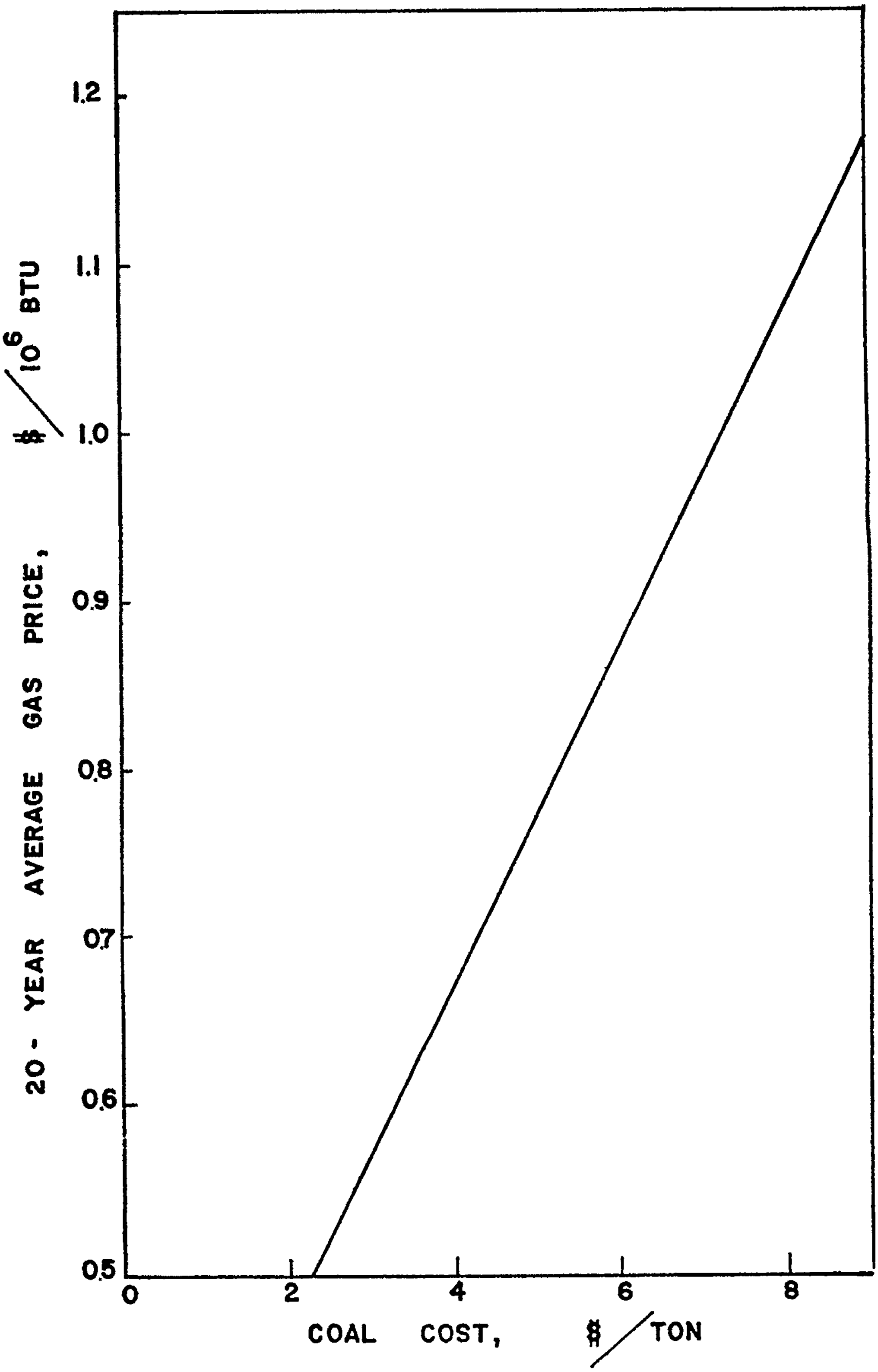

Fig. VIII-15 Price of Gas from Alternate II-3 as a Function of the Cost of Coal

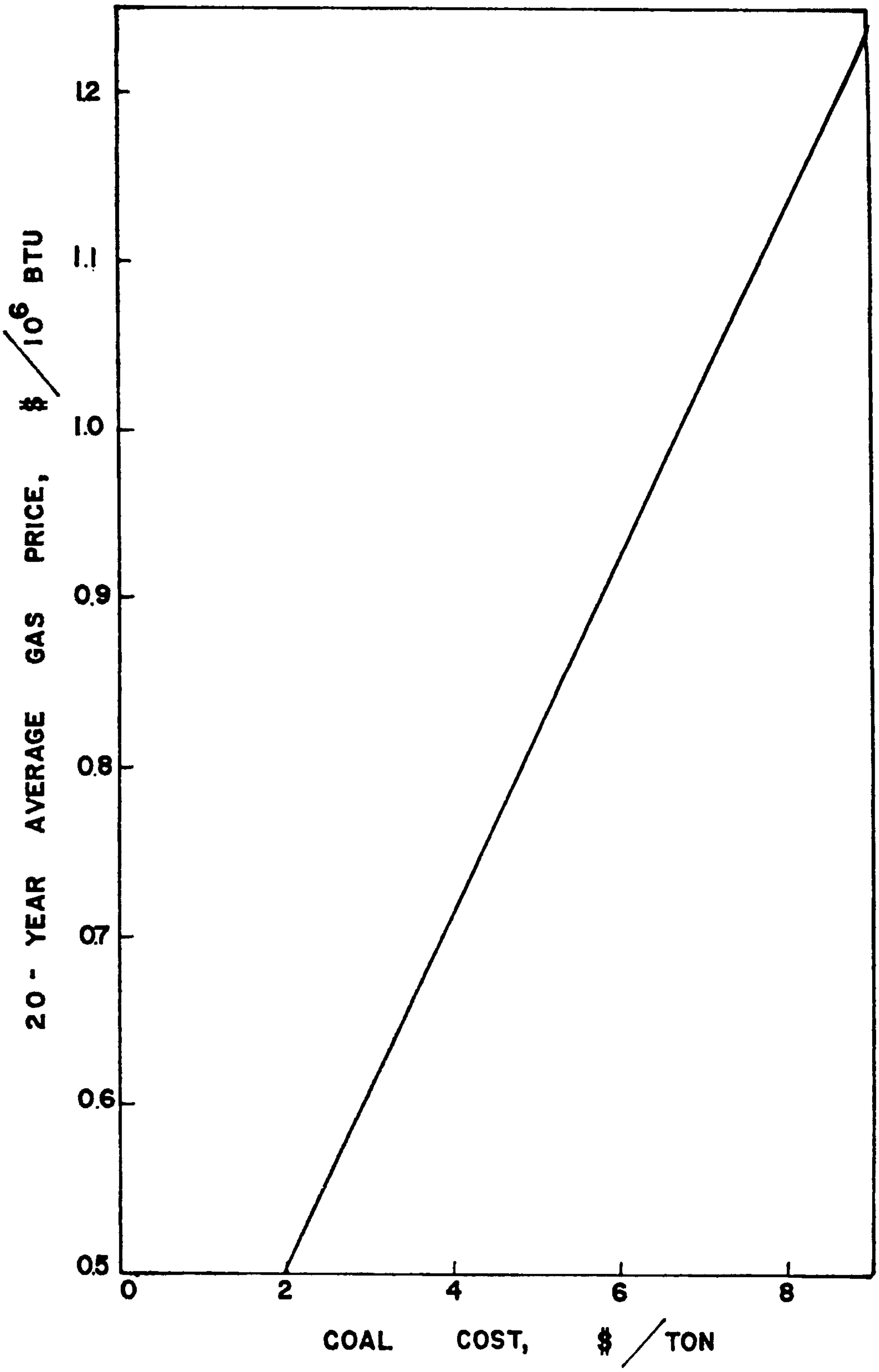

Fig. VIII-16 Price of Gas from Alternate III as a Function of the Cost of Coal

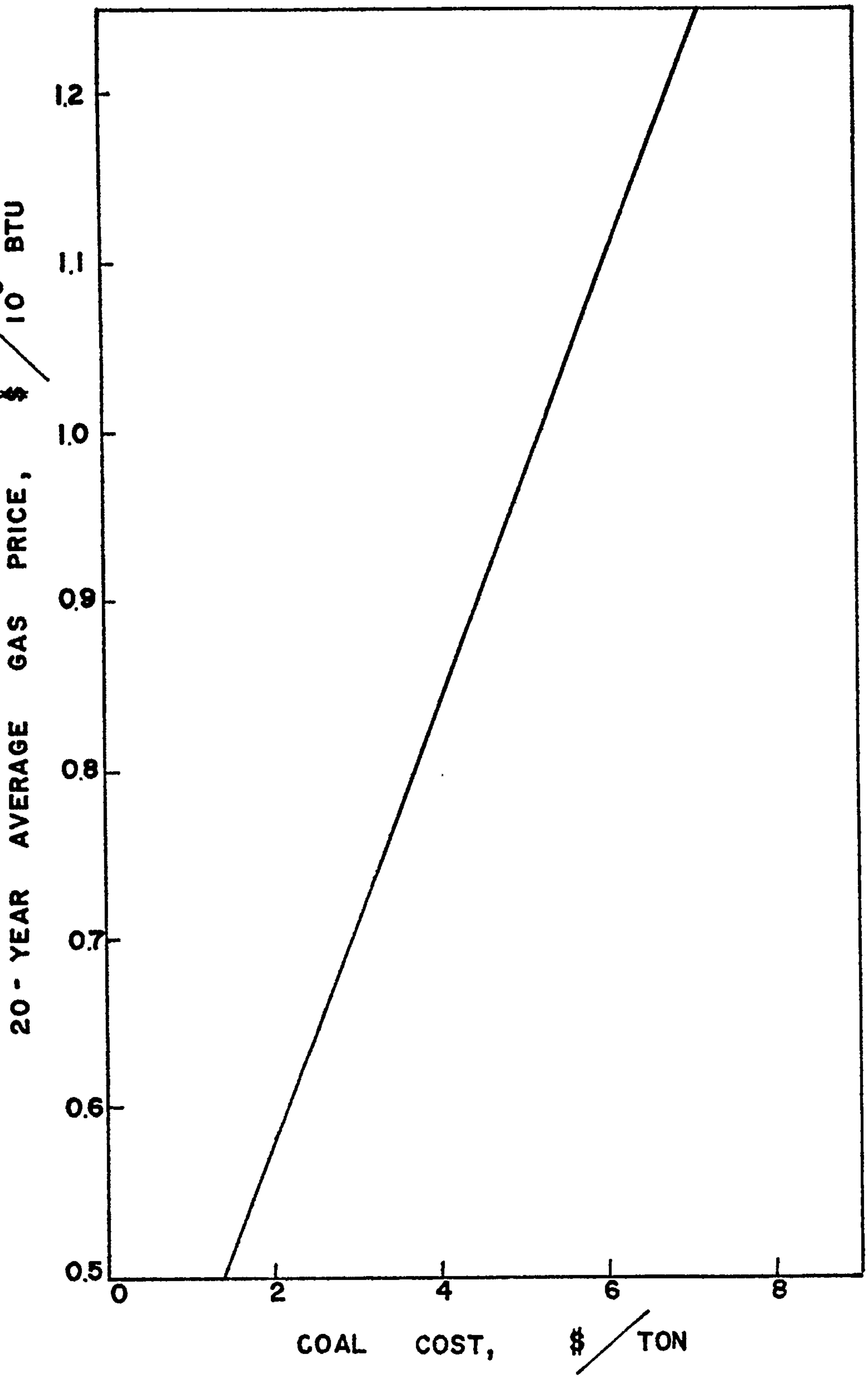

Fig. VIII-17 Price of Gas from Alternate IV-1 as a Function of the Cost of Coal

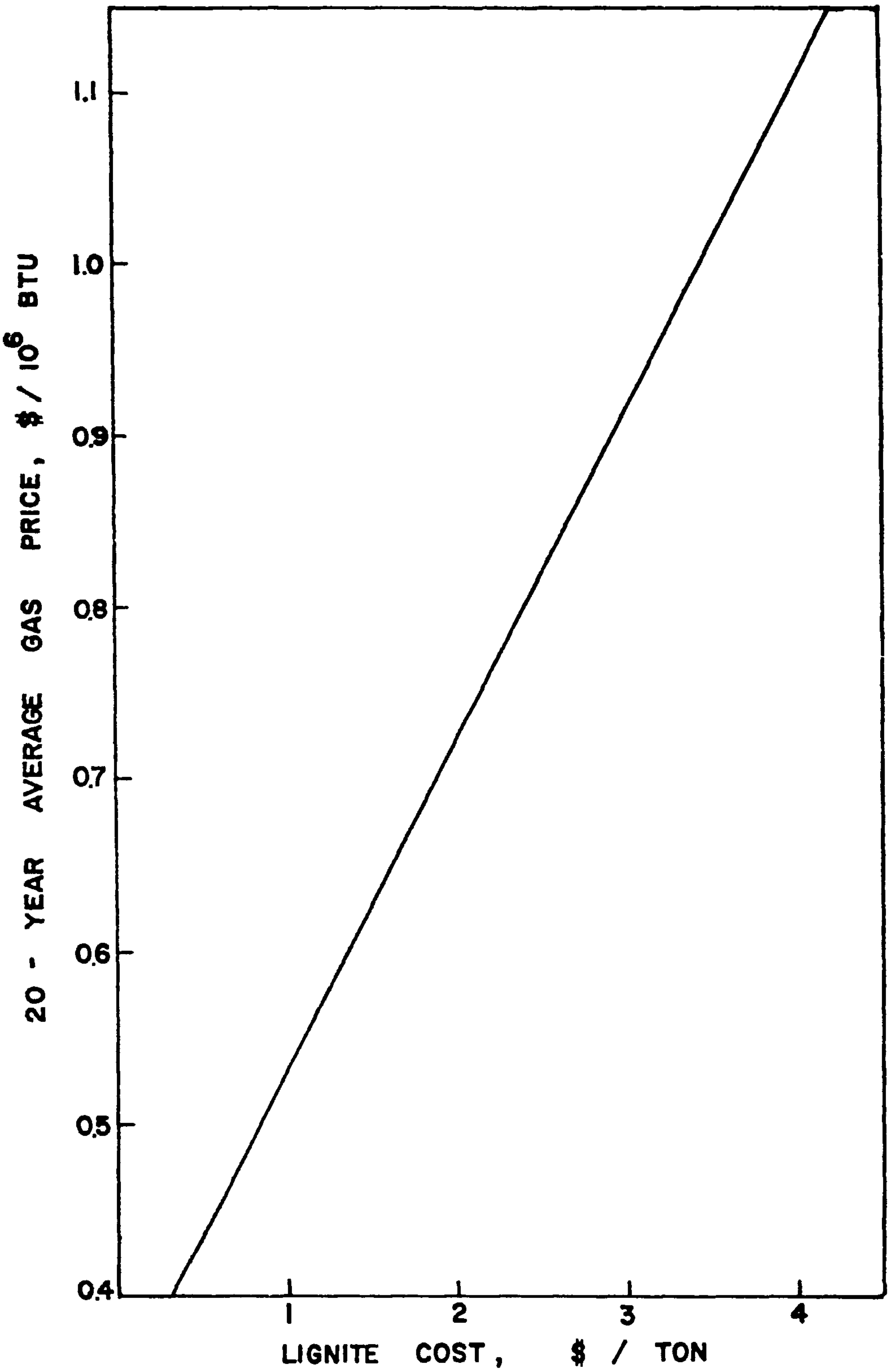

Fig. VIII-18 Price of Gas from Alternate IV-2 as a Function of the Cost of Lignite

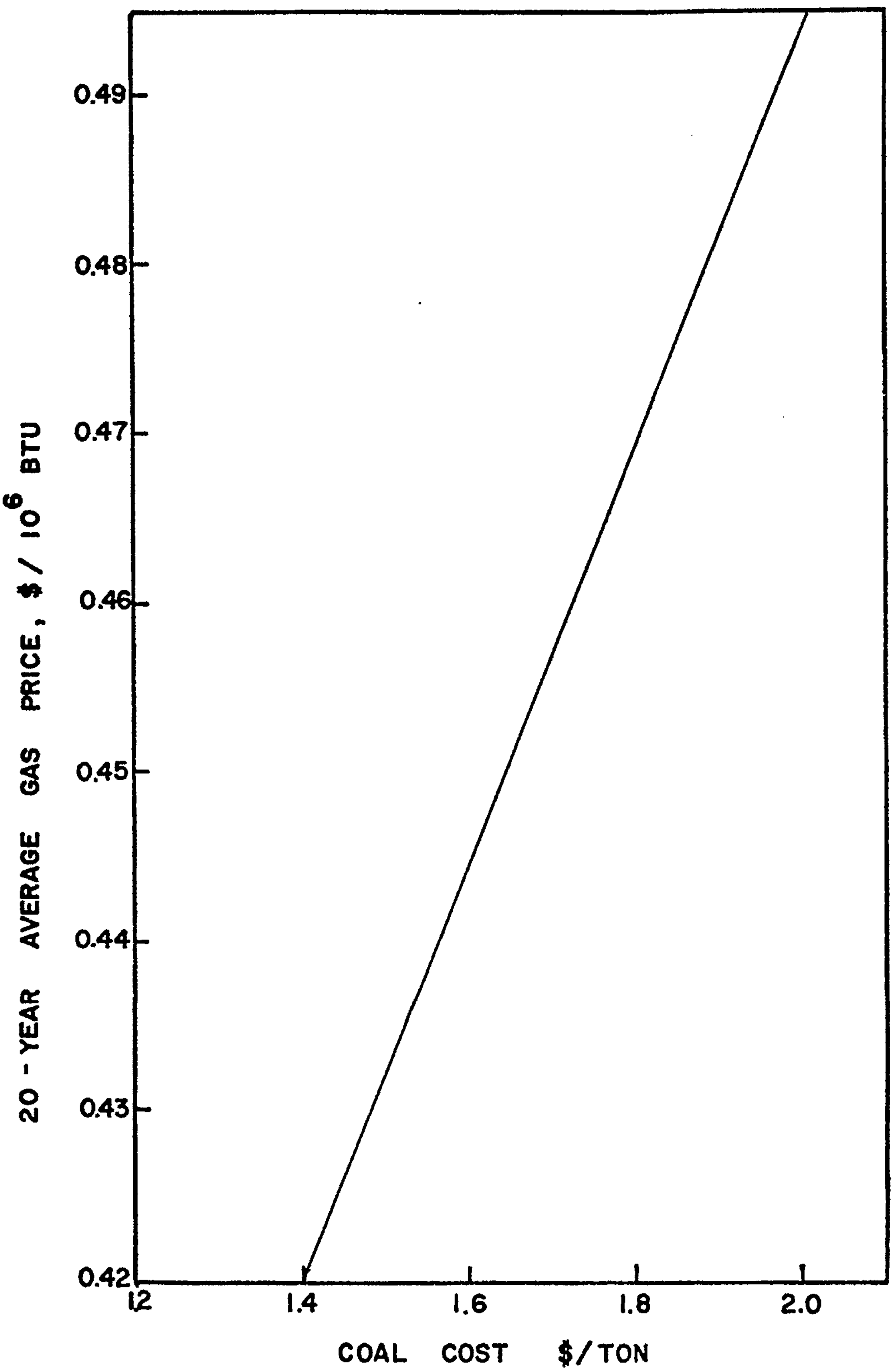

Fig. VIII-19 Price of Gas from Alternate V as a Function
Function of the Cost of Lignite

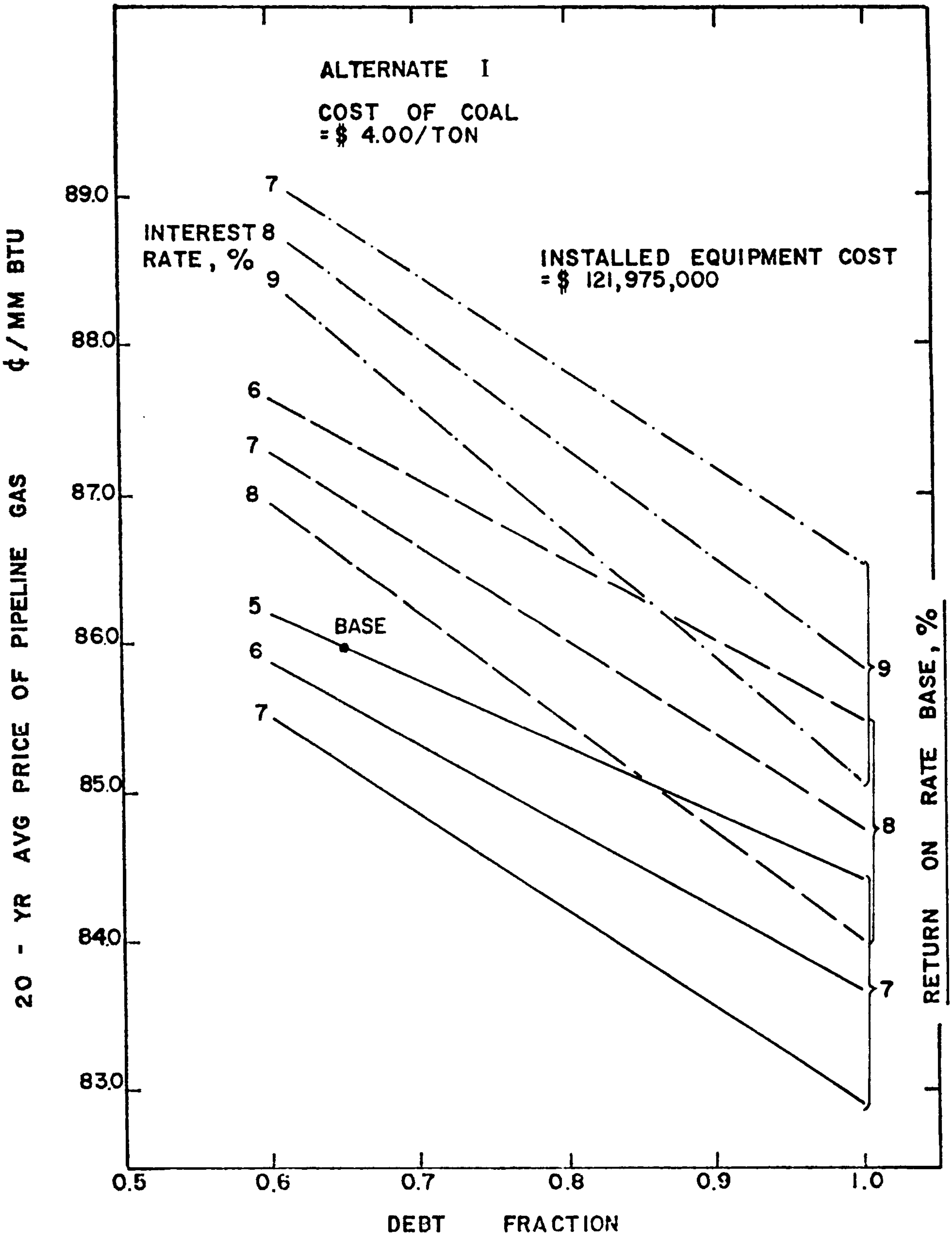

Figure VIII-20 Effect of Varying Financial Factors on the Price of Pipeline Gas-Alternate I

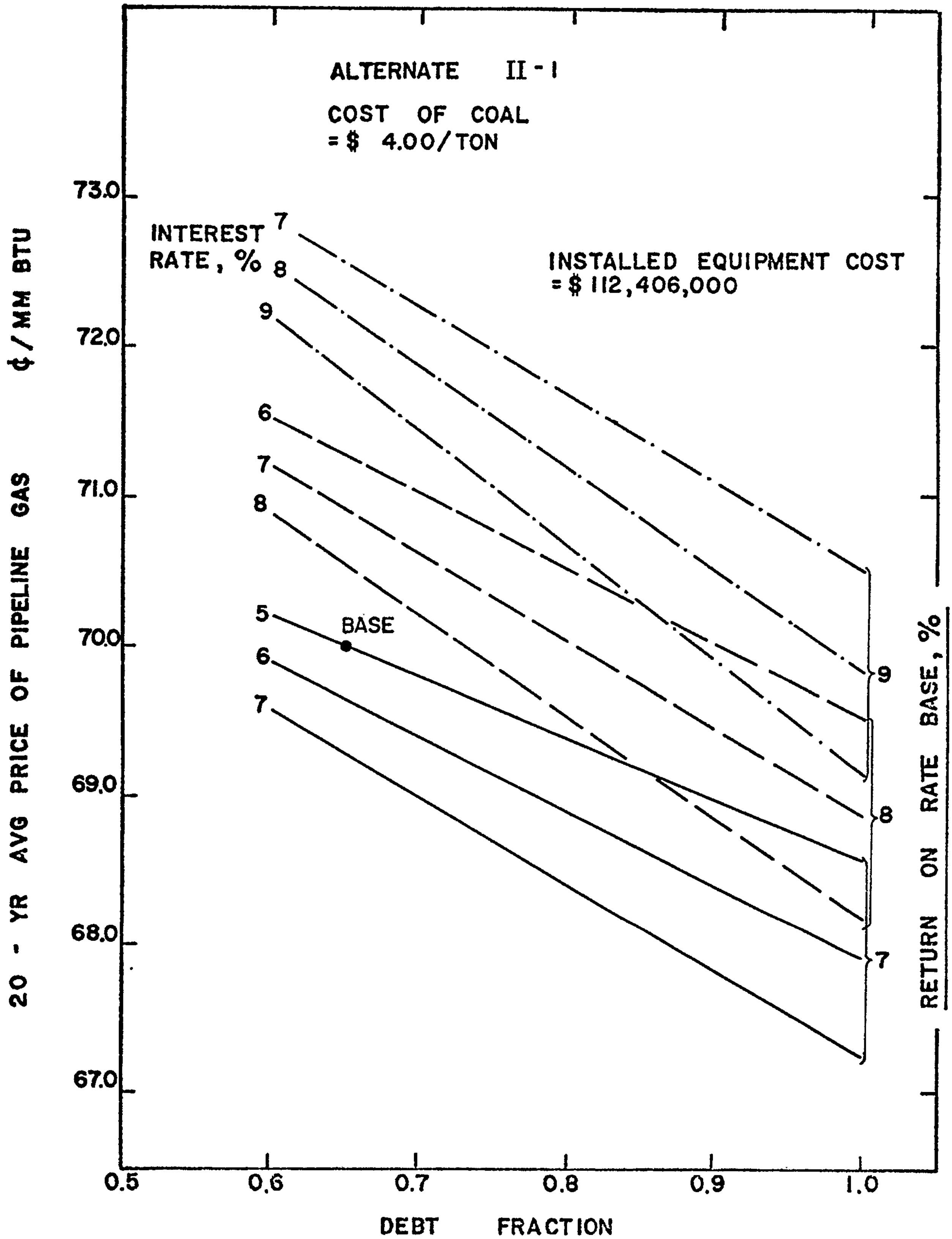

Figure VIII-21 Effect of Varying Financial Factors on the Price of Pipeline Gas - Alternate II-1

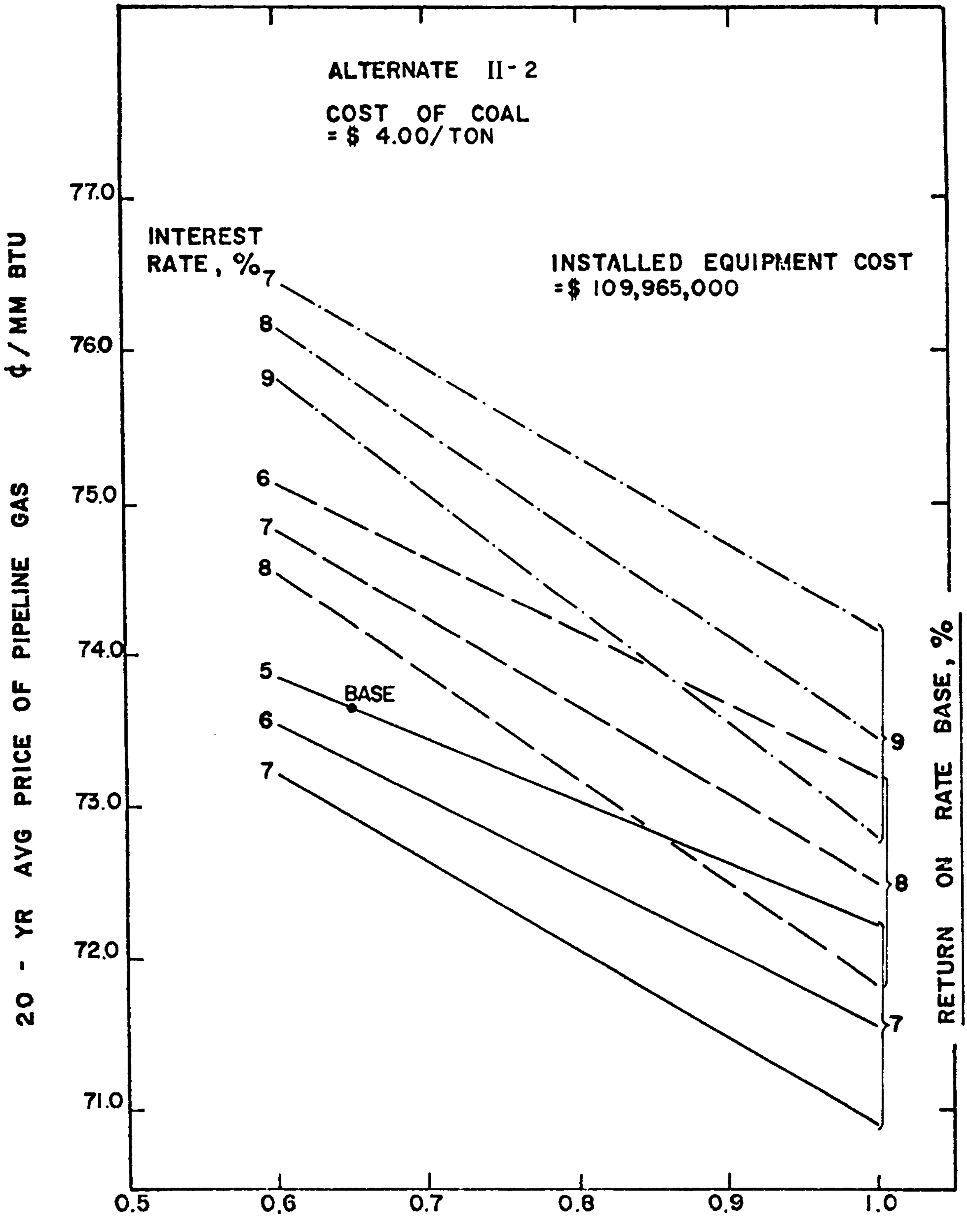

Figure VIII-22 Effect of Varying Financial Factors on the Price of Pipeline Gas - Alternate II-2

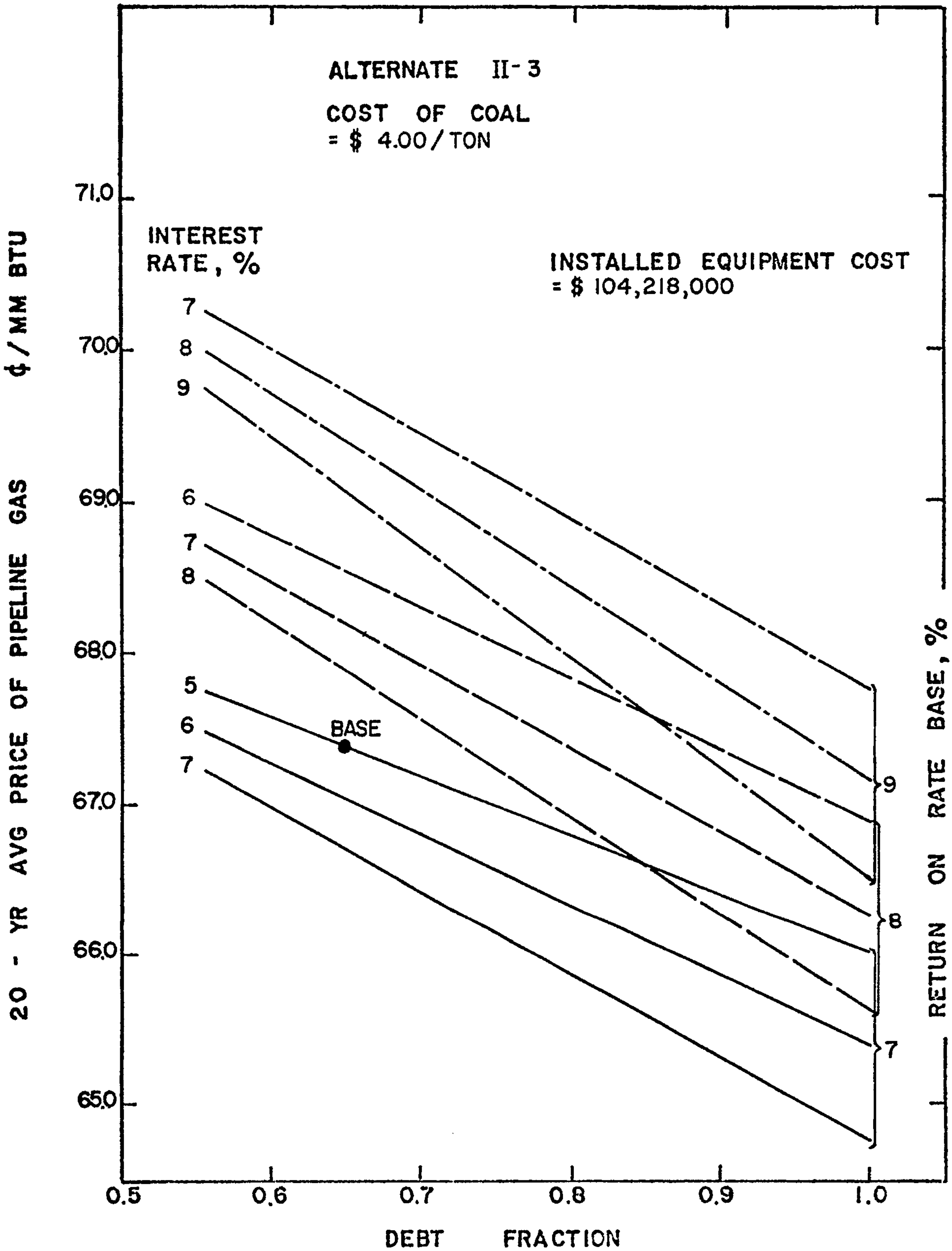

Figure VIII-23 Effect of Varying Financial Factors on the Price of Pipeline Gas - Alternate II-3

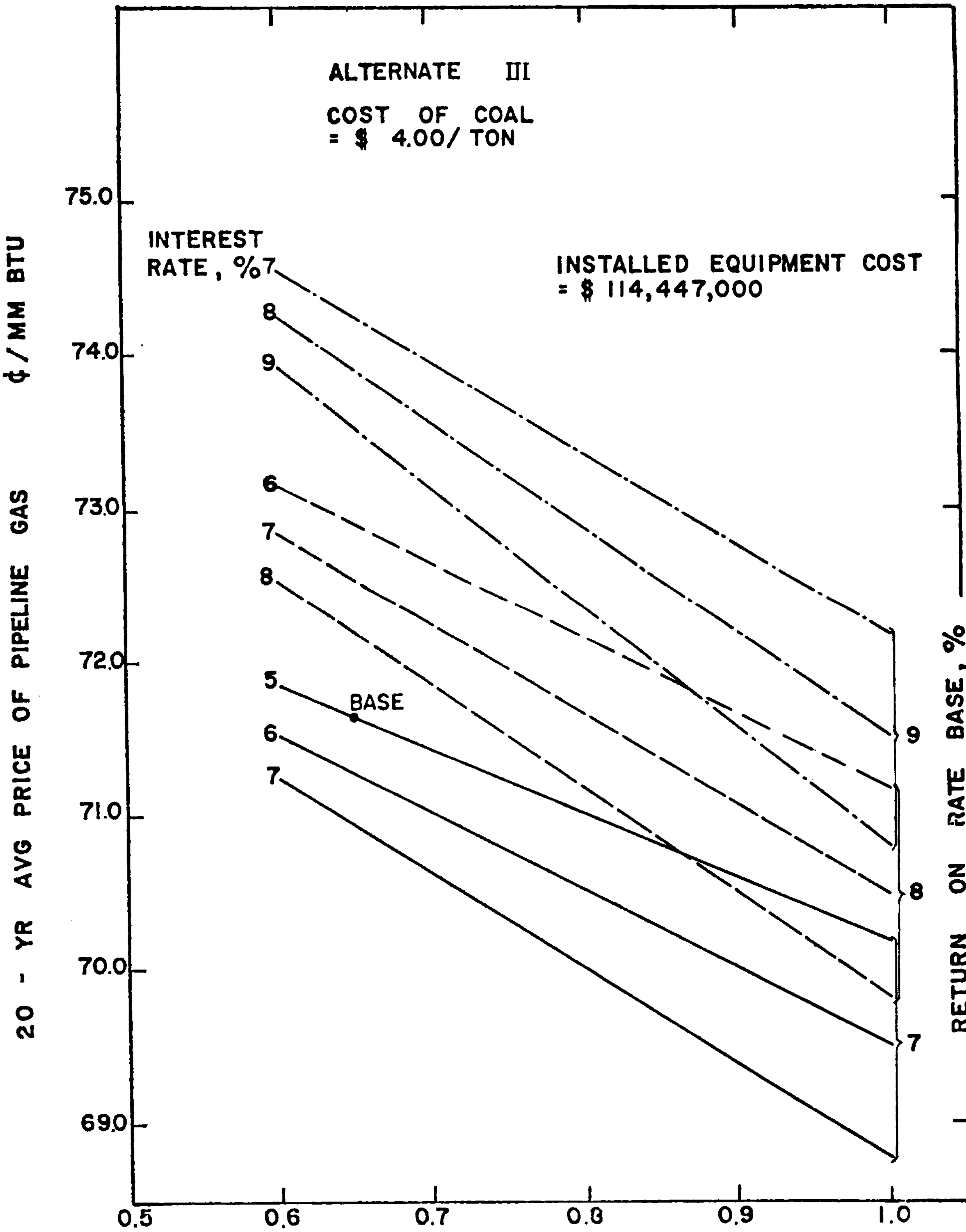

Figure VIII-24 Effect of Varying Financial Factors on the Price of Pipeline Gas - Alternate III

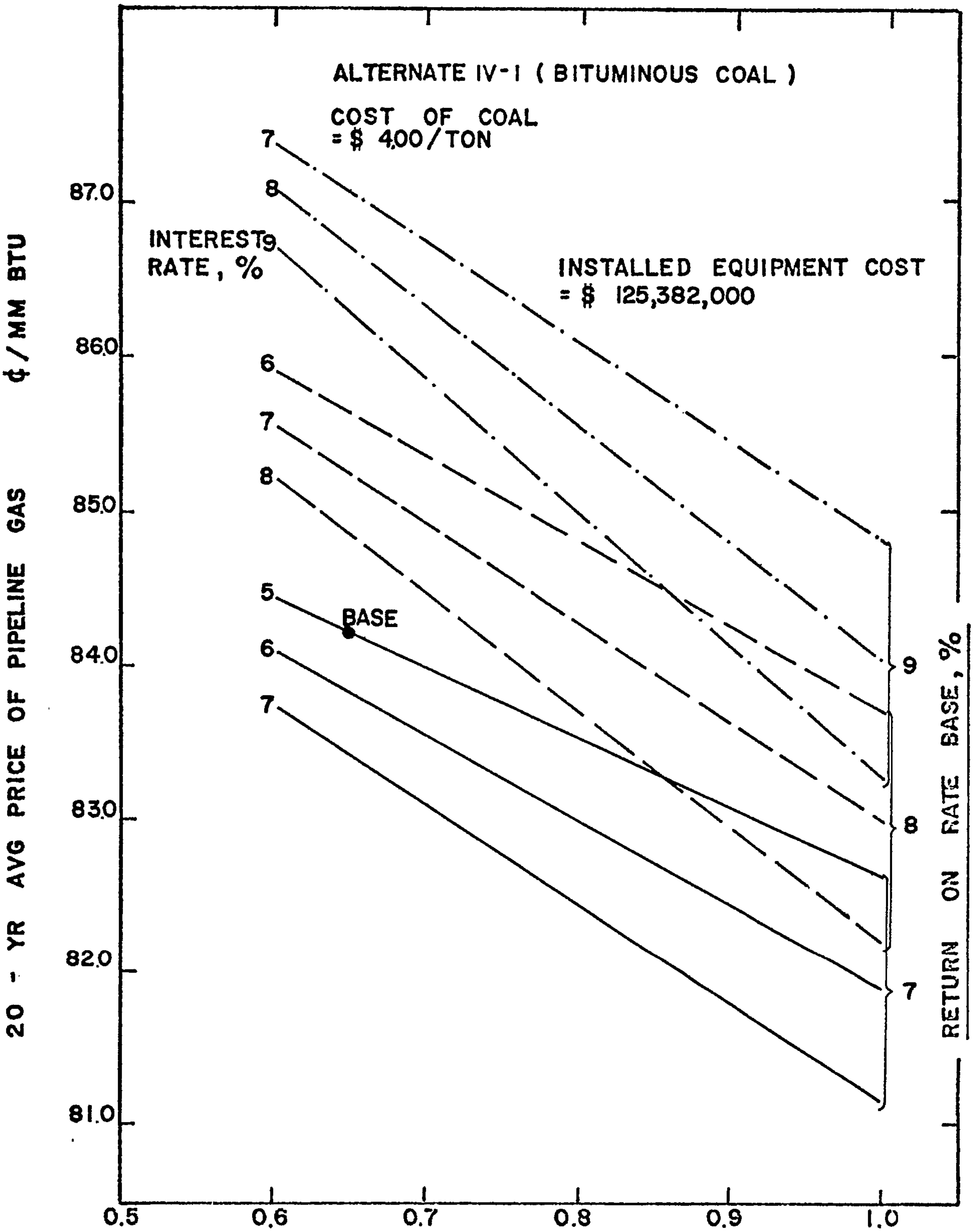

Figure VIII-25 Effect of varying Financial Factors on the Price of Pipeline Gas - Alternate VI-1

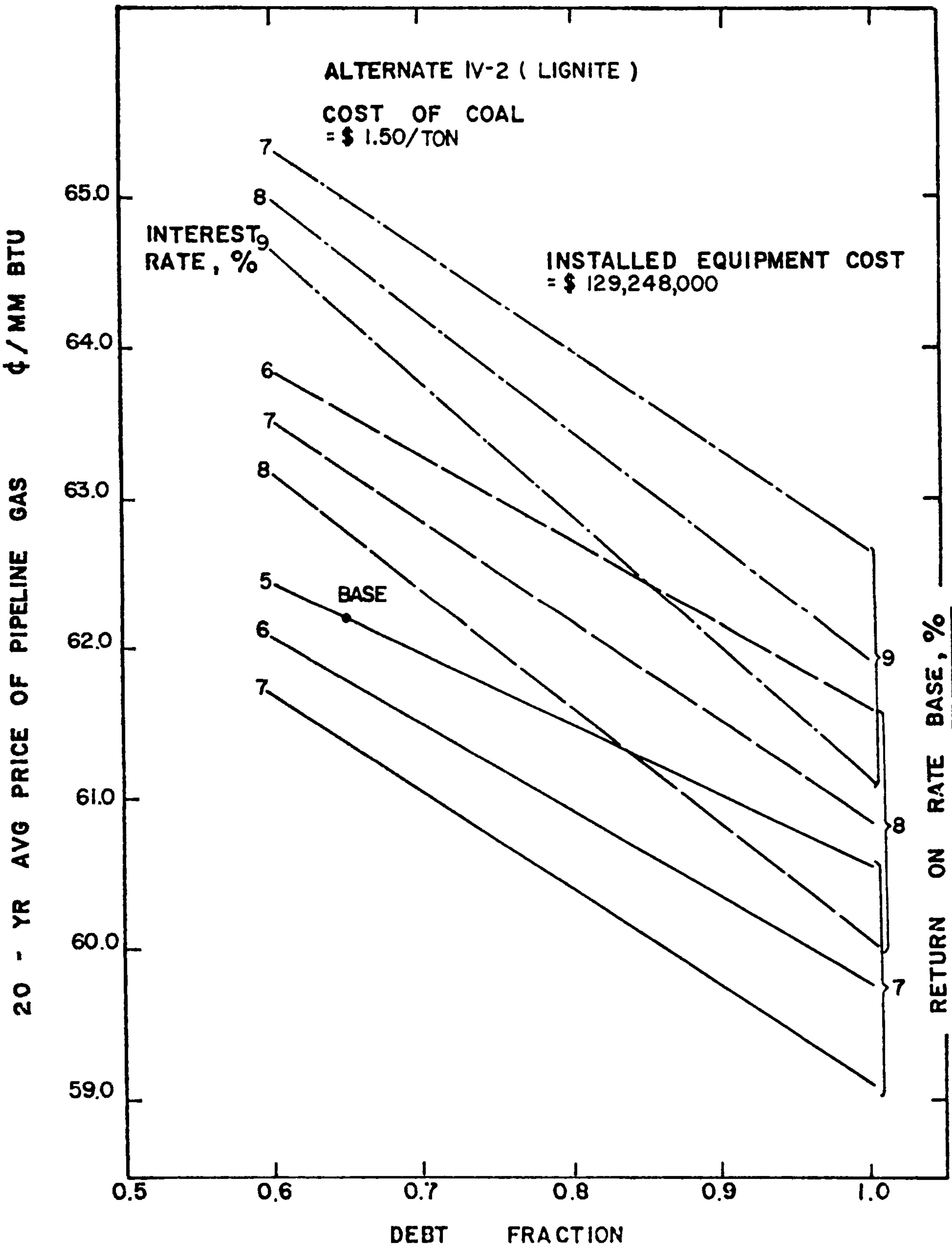

Figure VIII-26 Effect of Varying Financial Factors on the Price of Pipeline Gas - Alternate IV-2

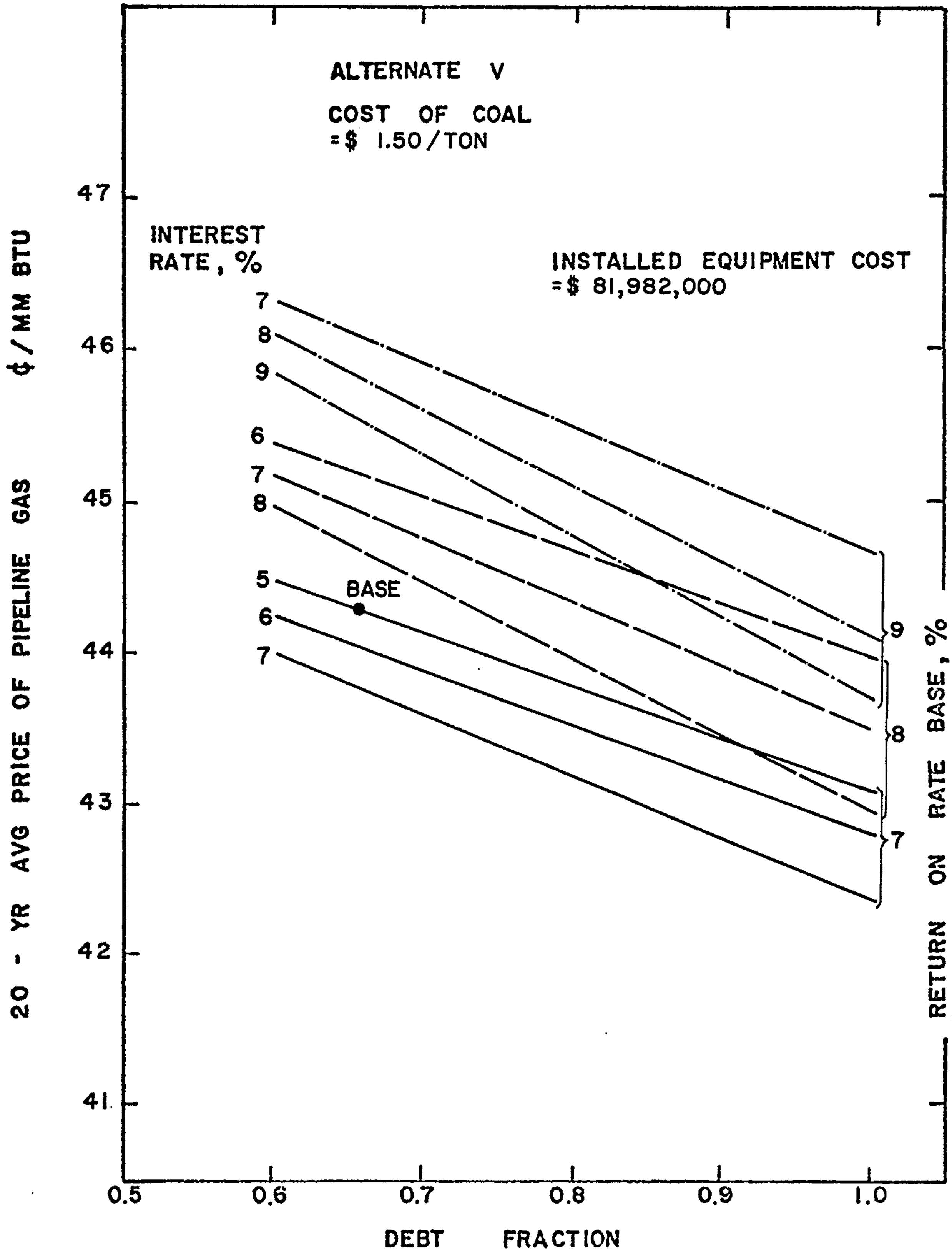

Figure VIII-27 Effect of Varying Financial Factors on the Price of Pipeline Gas - Alternate V

The equipment costs of the gas purification phase and the methanation phase were estimated based on the procedure presented in Section 2 of this chapter.

5. Conclusions and Recommendations

From the result of overall plant optimization presented, the following conclusions and recommendations can be made.

1. The price of gas is most significantly affected by the amount and cost of coal required for the integrated plant. Depending upon the coal cost, roughly 40% to 60% of the gas price may be associated with the cost of coal.

2. Pretreatment of coal to prevent agglomeration in the gasifiers would result in approximately 6 to 19 percent weight losses of coal. Not only the reactive carbon, but also hydrogen is reduced in the pretreatment of bituminous coal. Research efforts directed towards the development of gasification systems which utilize raw coal or lesser pretreated coal seem desirable.

3. The lower gas price shown by Alternate II-3 is primarily the result of direct use of raw coal without pretreatment in the gasifier. The evaluation is based on the assumption that the entrained bed reactor of Alternate II-3 can handle raw coal without agglomeration. More extensive pilot testing and additional design data are needed.

4. Although most of the processes considered operated at approximately 1000 psig in order to produce methane at the pipeline

pressure, the investigation of gasification at a higher pressure indicates that reaction cost increases with increase-pressure above 1000 psig. Since most of the gasification reactions are favored when the pressure is increased, higher pressure operation reduces the reactor size and improves the gas purification efficiency. However, the equipment costs for these two phases of operation are significantly affected by the pressure and thus, the advantage of a higher pressure operation is offset by the requirement of thicker reactor walls. The operation at pressures lower than 1000 psig will require compression cost to bring it to the pipeline gas condition.

5. The technology of the coal feeding system to provide uniform distribution of coal in a large diameter gasifier without causing agglomeration has not been fully developed. Additional efforts are needed to devise operational and more economic coal feeders for high pressure and high temperature gasifiers.

6. Because of the lack of performance data, the design of slag bed reactors is based on estimated approximate residence time requirements, and, therefore, may not be accurate. However, as the effect of reactor size on the resultant gas price is rather small. More reliable engineering data on slag bed reactors will be needed.

7. From the thermodynamic point of view, for the production of methane, direct hydrogen coal reactions utilizing devolatilization

and hydrogenolysis are more efficient than the carbon monoxide-hydrogen reaction (methanation reaction). Therefore, if the water-gas shift reaction is needed in the process, the shift reaction should be carried out, if possible, before the coal gasification reaction so as to maximize the hydrogen-coal reaction in the gasifier, and minimize the methanation reaction needed to achieve pipeline quality.

8. Since the volatile portion of coal contains valuable hydrogen, it is more effective to preserve this hydrogen as much as possible for methane production. Therefore, the gasification process should be arranged so as to subject coal to rapid devolatilization in a reduced condition during the initial period of contact in order to avoid formation of stable tar.

9. The highest gas price, shown by Alternate I, is due to the inefficient use of carbon and hydrogen in coal by reacting coal with oxygen during the initial period and by extensive water-gas shift reaction and methanation required later in the process.

10. In gasification processes requiring oxygen, the cost of the oxygen plant and the associated power generation plant is the largest portion of the total equipment cost; occupying roughly 40% of the total.

11. The high gas price of Alternate IV is due to the high operating cost of the electrothermal gasifier.

12. The equipment cost for the gasification phase or for the gas purification phase seem to be the second largest item among

equipment costs, depending on the alternate considered.

13. Gas prices from gasification processes with lignite feeds are lower than that with bituminous coal feeds. However, more detail study based on different ranks of coal and lignite is desirable.

14. The price of gas presented does not include the by-product credit obtainable from the gas purification phase, such as H_2S or elemental sulfur, etc.

15. In view of the large exothermic heat of reaction produced in the methanation reactor, it is desirable to operate the methanator in a state of fluidization for rapid heat removal. Catalysts rugged enough to sustain attrition in fluidized beds and less sensitive to sulfur poisoning should be developed.

16. The technology of the solids feedings and removal systems to and from a high temperature and pressure gasifier has not been fully developed. Additional efforts are needed to devise operational and more economical solid feeders which can provide uniform distribution of coal in a large diameter gasifier without agglomeration.

The results presented above are an engineering estimate based on a number of simplifying assumptions and thus are subject to certain variations. Particularly, in view of the future development of new techmology, some of the engineering problems which hinder an otherwise sound process may be solved, and could alter the economic picture of the process. Therefore, the price of gas shown in this report should be regarded as the relative estimates which are subject to change depending on economic climate and only be used for comparison among the alternates studied. However, it is believed that a measure of effectiveness of a number of coal gasification processes in relationship to their costs has been established which will be useful in economic evaluation of future potential for the commercialization of the various alternates considered.

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