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COMPARATIVE COAL TRANSPORTATION COSTS:
AN ECONOMIC AND ENGINEERING ANALYSIS
OF TRUCK, BELT, RAIL, BARGE AND COAL
SLURRY AND PNEUMATIC PIPELINES

VOLUME 3

COAL SLURRY PIPELINES

Prepared for

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
and the
FEDERAL ENERGY ADMINISTRATION

by

Center for Advanced Computation
University of Illinois
at Urbana Champaign
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FINAL REPORT

on

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U.S. Department of the Interior
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FOREWARD

This report was prepared by the Center for Advanced Computation of the University of Illinois at Urbana-Champaign under USBM Contract No. JO166163. The contract was initiated under the Office of University Relations. It was administered under the technical direction of the Division of Interindustry Analysis with Mr. Ronald Balazik acting as the Technical Project Officer. Mr. Robert Carpenter was the contract specialist for the Bureau of Mines.

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Subject Inventions

This is to certify that, to the best of my knowledge and belief, there were no Subject Inventions made or have resulted from the performance of this contract.

August 1977

A handwritten signature in cursive script, appearing to read "Michael Rieber".

Michael Rieber
Principal Investigator

CAC Document No. 223

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by

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3. COAL SLURRY PIPELINES

3.1 INTRODUCTION

An analysis of coal slurry pipelines was presented in our May 1976 study, Route Specific Cost Comparisons: Unit Trains, Coal Slurry Pipelines and Extra High Voltage Transmission [4]. The present study extends that analysis.

The earlier work included technical and economic cost descriptions of the Black Mesa and ETSI pipelines as well as some hypothetical pipeline routes. Water problems, safety and environment, required resources, and labor impacts were discussed at some length. Additionally, pipeline impacts on competing railroads, slurry-rail comparisons, and cost escalation were analyzed. The difference in pipeline profitability to an owner-operator versus a promoter-builder was suggested. These aspects are not redone in this study. Here, we present a synopsis of the previous results and a general statement of coal slurry pipelines. Extensions of the arguments are presented where they appear warranted. New material is developed in the area of pipeline branching and tapping. This would appear necessary if slurry pipelines are to function as more than private lines; if they are, for example, to be responsive to common carrier requirements.

Except for the availability of water, pipelines are not geographically limited. To date, commercially proposed pipelines have had a generally north-south orientation with points of origin in the great plains and mountain states. West to east and west to Pacific pipelines are feasible. They are also feasible along the east coast and for shipments out of Appalachia. In fact, the water problem there may be a relatively small deterrent. We have found no reason to expect that costing, other than for problems associated with land values and terrain, differs significantly by geographic region. A list of some proposed and hypothetical coal slurry pipelines appears in Table 3.1. Cost estimates are those proposed by the listed source at the time of submission. They have not been escalated.

A coal slurry pipeline is an available alternative to unit train transportation. While the process is not new, it was not until 1957 that a major coal slurry pipeline was built. The 10" diameter pipeline extended 108 miles from Cadiz, Ohio to the East Lake Power Station of the Cleveland Illuminating Company on Lake Erie. It operated until 1963 when changes in ICC rate making policies permitted the competing railroad to offer cheaper unit train rates on all

coal carrying unit trains in the region. Apparently the cost structure of the pipeline did not allow the meeting of the new rates and the pipeline was closed. Since then the line has remained inoperative. An engineering proposal was formulated by Bechtel, sponsored by the former Federal Water Pollution Control Administration, for the inactive pipeline to ship garbage from Cleveland to the Cadiz area [1]. This proposal was not carried out because of local opposition to garbage dumping at Cadiz. The incident, however, has been denied in testimony by E. J. Wasp at a House Subcommittee hearing on January 29, 1976 [2].

A second coal slurry pipeline was not built until 1970. It extends between the Black Mesa coal fields near Kayenta, Arizona and the Mohave power plant in southern Nevada. This 273 mile, 18" line was built as a cost efficient alternative to the construction of 150 miles of new railroad. The circumstances were ideal for the use of a slurry pipeline. The distance between the Black Mesa coal mines, located 120 miles north of the nearest railroad, and the Davis Dam, located 30 miles north of the nearest railroad, gave the pipeline a 2:3 distance advantage. The availability of an adequate water supply with which to move the coal, without the need for water return, further reduced the relative costs.

A coal slurry pipeline system requires that the coal go through a number of processing stages before it is used by the power plant. Once mined, the coal is delivered to a preparation plant where it is pulverized to sizes between 18 and 325 mesh and then suspended in about an equal weight of water. This 50-50 slurry mixture has a consistency approximating toothpaste. It is pushed through the pipeline via electric pumping stations 70 to 100 miles apart [3,p.3]. Flow velocity through the line must be maintained within a narrow range. For example, if a 3.5 mph design is used at 5 mph, the system must be able to withstand double the horsepower, peak pressure, and wear [4,p.59]. Minimum flowrate must be maintained to avoid particle settling and plugging. If an emergency situation occurs, a maximum of three days shutdown is possible before the coal particles settle in the line. However, in general, once a pipeline system has been designed, because of economic considerations on the one hand and design limits on the other, flowrate is rather inflexible.

Pipelines may be routed through and around mountains, cities and other obstacles. However, routing and terrain are reflected in construction costs, pipeline pressure, and required pumping power. If access to route paths is difficult, additional pipeline construction costs accrue. Elevation changes put more stress on pumps than level

movement.

Two pipeline hazards are breakage and plugging. While plugging does not occur on liquid or gas pipelines, line breaks and leaks are not unknown. System reaction is nearly the same for both cases. Stations upstream of the plug or break must dump slurry into holding ponds and introduce water for flushing. For a 1000 mile line with 100 mile station spacing, this means dumping slurry into a holding pond equivalent to one acre by 100 feet deep. Complete flushing of the line would take 30 hours [4,p.75]. Downstream of the plug or break the slurry presents a different problem. In the case of a plug, the slurry between it and the downstream station cannot be moved. If plug removal or other repair takes more than a week, the slurry may deposit in the pipe and lose fluidity. In the case of breakage, the downstream slurry can be moved if the leak is not too large. In that case there will still be sufficient pressure remaining to flush the downstream mass. Spillage however, creates environmental hazards, especially if near or in a populated area. This procedure calls for flushing water storage as well as holding pond storage. For a 25MMTY, 3.5 mph, 1000 mile line station, the requirement is 20,000 gal/min. of flushing water and 42 million cubic feet of holding pond storage space. Subsequent to the operation, disposal of the dumped slurry remains. After the coal has settled it must be dredged and removed. Unless a sufficient number of ready buyers, with facilities capable of burning the finely divided coal are available, the dumped coal is valueless. Reinjection is possible from established holding ponds. This requires provision for agitators and injection pumps. To date no slurry line proposal includes this option. During the interim period, the ponds themselves may cause an environmental hazard. Dredged coal may be carried away by the wind as coal dust. If the pond water is allowed to evaporate, coal dust may be carried from the margins. The flushing water is too dirty to dump into rivers or streams and contains too little coal to justify dewatering. Pipeline safeguards include the addition of standby pumps, an emergency power source, and pipe overdesign. Standby pumps are needed in case of main pump failure or if extra power is needed for moving the slurry. Pipeline overdesign minimizes the chance of breakage.

Pipeline failure is not a unique event. For example, there were 1,373 failures of natural gas pipelines in 1975; a better record than the 1,477 failures in 1974 [13]. While natural gas leaks are more dangerous than coal slurry leaks, and there are many more miles of natural gas pipelines, coal lines are more difficult to restart. There can be no guarantee against breakage. The use of 3/8"

thick 38" diameter pipe for coal slurry at 1000 psi suggests at least the same probability of breakage as that for a natural gas pipeline. The seven year old Black Mesa pipeline burst in two places on February 8, 1977 [23,24]. According to the newspaper report, slurry escaped into the desert east and west of Kingman, Arizona. The amount of escaped slurry was not reported. However, the Burlington-Northern has taken color photographs of the extent of the residue.

Inherent in pipeline movement is friction and the resulting abrasion of both the coal particles and the pipeline wall. While coal particles become smaller along the line, increasing slurry viscosity somewhat, the lack of specific data shows that this may not be significant. Normally, abrasion is not a problem when slurry moves at low velocities.

Coal fines of less than 40 micronmeter size ($<40\mu\text{m}$), a result of the grinding process during shipment, cannot be avoided. Use of these fines is a matter of concern. At the present time, no solutions exist. An attempt to dewater them has had limited success [6]. To reduce the moisture in the slurry cake from 20 percent to 10 percent, a minimum of 1 percent of the heat of the coal has to be used. Recent attempts at using natural gas or oil to dry the coal cake appear to be an uneconomic engineering practice. Retention of 20 percent moisture in coal mined with that amount already contained is less objectionable. Returning the transport water to the mine area after dewatering may solve both the problem of the fines and the acquisition of scarce water in the mining area. The increase in total cost, however, is considerable.

Pipelines that have a slowly moving throughput and a water carrier may be subject to freezing in northern areas during periods of severe cold. Most of the pipeline will be underground but some portions must be exposed. Heated sections or heavy insulation provides a solution at an added cost. If the slurry freezes, expansion would result in a pressure increase of more than 300 psi. More importantly, a frozen section can act as a plug. Even the presence of a slush may reduce pipeline slurry velocity to unacceptably low speeds. Freezing may also cause uneven concentration of the coal in the pipe as the outer portions freeze first. When this melts, also unevenly, a natural settling of the coal particles in the slush will occur. Estimation of the danger of pipeline freezing is similar to that of, for example, the estimation of the probability of low water conditions on a river or drought. In the latter case we estimate (regionally or locally), from past records, the probability of a ten day low water flow during

a given period of years; anywhere from ten to one hundred years depending on our needs. For a pipeline with a given life expectancy we can similarly estimate the probability of a ten day period of temperatures below any given arbitrary point.

The receiving plant centrifuges the slurry at high speeds. This separates most of the coal from the water leaving about a 25 percent total moisture content in the coal. This remaining moisture causes about a 2.5 percent loss in heating value compared to dry coal. This is adequate for power plant use. Further drying is possible but may be unnecessary [4, pp.10-11]. Here, power plant design is the determining factor.

One of the problems associated with slurry pipeline analyses is the lack of operating experience. With only one, relatively small, system presently in operation, new proposals for lines three to four times longer with throughputs of four to five times the quantity mean that the analyses are subject to some speculation. Furthermore, the Black Mesa pipeline is ideally located; other systems modeled upon it must be analyzed carefully. As the Black Mesa coal slurry system has been used as a prime source of current technical information, some review is in order.

The contract pumping rate at Black Mesa is between 560 and 660 tons/hour, or 4.9-5.78MMTY, respectively. However, the general literature indicates that the line moves 4.8 million tons of coal per year. The slurry is about 48 percent coal by weight. Coal is delivered by conveyor belt to the preparation plant. Once it is crushed and mixed with water, it is sent to one of four 630,000 gallon storage tanks. The slurry is agitated to prevent settling. Four electrically powered pumping stations located 65 miles apart move the slurry at about 3.5 mph. Actual trip duration for a ton of coal is about three days. The effect of terrain on operating pressure is seen in the Black Mesa pipeline. There, the pressure drop due to pipe flow friction and hydrostatic head produces a maximum pressure of 1500 psig. Pipe flow friction was deliberately introduced at the delivery end to deal with this problem. By decreasing the pipe diameter, the flow velocity is sufficiently reduced as it enters the separation facility [5].

A report prepared by M.L. Dina, plant engineer, Mohave Generating Station, [6] provides an indication of some technical problems and solutions. The major areas of concern are centrifuging and coal slurry temperature. Centrifuging problems include: 1) underflow; 2) excess coal cake moisture; and 3) wear on centrifuge linings. The

underflow, which contains an average of 80 percent water and 20 percent solids (95 percent of which are <40 μ m size), when introduced into the centrifuge results in a 6 percent moisture increase. For every one percent increase in fines of <40 μ m a one percent increase in cake moisture was noted. The 400,000 tons of underflow that Mohave has produced entirely fill a waste water pond 35 acres in area to a depth of 10 feet. Studies concerning the use of these fines are continuing.

By rerouting the underflow, added moisture was eliminated. However, the power station design specified the use of coal with a lower moisture content than could be obtained by centrifuging. The initial design called for 25 percent moisture in the coal instead of the 28 percent received. The first solution tried was to air dry this coal cake. However, the system temperature was too low. Subsequently, gas burners were installed to heat the air from 650^oF to 750^oF. This proved sufficient and did not affect other processing operations. Given the cost and scarcity of natural gas, experimentation is underway to convert to fuel oil. In the long-run, a coal fired heating system is probably desirable given the plant input.

An inherent problem of centrifuging is wear. Slurry abrasiveness required overhauling the centrifuge every 500 to 1000 hours. Experimentation resulted in the use of new materials. Alumina ceramic centrifuge flites were found to have a life span of 15,000 hours. Hardened stainless steel cone liners lasted approximately 10,000 hours. These changes have significantly improved the Mohave operation.

TABLE 3.1: Proposed and Hypothetical Coal Slurry Pipelines

Origin Destination	Distance (Miles)	Capacity (MMTY)	Pipe (inches)	Total Cost (\$10 ⁶)	\$/ton	mills/ ton-mile	Source
Wyo-Ark	1000	25	38	750	7	7	ETSI
Colo-Tex Alamosa- Houston	961	15		509	12.2		Houston Natural Gas
Wyo-Tex Powder River Region-Houston	1260 1200	25 (22-38) 25	36-48	1200	12.5	1¢ 6.9-9.5	Brown & Root CAC
NM-Ariz Star Lake - St. Johns	200	10					Nev. Power Co. Ariz. Pub. Service Co.
Utah-Nev. Aerton - Arrow Canyon	175	10					Nev. Power Co.
Wyo-Oregon Gillette- Boardman	800	10	20,24	500		8-10	Gulf Interstate-NW Pipeline
Wyo-Ida.	1100			700			Gulf Interstate-NW Pipeline
WV-NY Fairmont - Staten Island	355	2.6	12	75.5		1.9¢	ERDA Prepared by Consolidated Edison Co. of New York and the Lummus Co., a subsidiary of Combustion Engineering, Inc.
Mont-Wash Spokane Seattle	333 574	4.55 4.55	24,18	209.6	14.97		Bureau of Mines
Mont-Wash Spokane Seattle	333 574	9.1 9.1	36,24	413.7	14.36		Bureau of Mines
Mont-Wash Seattle	574	9.1	24	244.4	13.56		Bureau of Mines
Mont-Wash Seattle	574	18.2	36	503.4	13.51		Bureau of Mines

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3.2 SLURRY PIPELINE COSTS

Slurry pipeline costs as summarized in reference [4] appear in Table 3.2. Also, material and labor parameters are found in Tables 3.3 and 3.4. The pipeline is capital intensive and the capital costs are front-ended.

The pipeline costs developed here are understated. The relative cost of U.S. pipeline construction rose from an index of 235 in 1973 to 343 in 1975 (1947=100). Between 1974 and 1975, alone, it rose 64 points. Similarly, pumping equipment (stationary engines, reciprocating pumps and speed increasers) rose from an index of 273 in 1973 to 370 in 1975. Of this, 66 points were accounted for in the last year [14]. The 800 mile Aleyeska pipeline, on which the Bechtel Corporation had construction management control until 1975 [15,16] and responsibility for welding quality control until early 1976 [17, 18], was originally costed in 1968 at \$900 million. The price was \$6 billion by October 1974, \$6.375 billion by June 1975 and about \$7 billion by February 1976 [19]. By July 1976, reported costs were \$7.7 billion or somewhat less than \$10 billion if interest costs are added [20]. It is possible that in projecting the ETSI slurry pipeline the original cost estimate of \$750 million was an understatement. It is probable that our escalation of this to \$1.034 billion is also understated. A current estimate of at least \$1.1 billion is in order.

Documentation of the present slurry pipeline systems are found in several sources [3,4,6]. The Black Mesa pipeline consists of one mine supplying one destination with 5MMTY by a 273 mile, 18 inch pipeline. The Wyoming-Arkansas, 1040 mile, 38-inch pipeline, would supply 25MMTY [7,p.20]. Major costs accrue to the preparation plants and dewatering stations. Right of way costs for buried pipelines are assumed to be similar to oil and gas lines. The present value of removing the pipeline after its useful life has not been included. Annual fixed charges are estimated on the same basis as those for unit trains, however, high utilization is relatively more important. If coal throughput must be dropped at the supply or demand end, below minimum design capacity, the only method to decrease coal shipment is to introduce excess water into the system [4,pp.68-69]. The alternative of large coal inventories at the supply end is expensive, at the demand end even more so.

Figure 3.1 shows route specific costs for some hypothetical routes [4] in dollars/ton for slurry pipelines assuming water costs of \$1 per 1000 gallons and \$2.50 per 1000 gallons and for both cases of no return and where the

water is returned including piping and pumping equipment cost at both a low level of \$240,000 per mile (denoted RL) for the 27" diameter return water pipe and \$480,000/mile as a conservative high value (RH). The figure of \$240,000 per mile was close to that suggested by Bechtel and is believed to be the lowest possible cost including pipes, pumps, and motors but no new excavation or other route preparation. Depending on current prices of equipment, this figure might buy only the pipe. The figure of \$480,000/mile accounts for the necessary uphill pumping and a pump designed to handle inky water after separation of the coal from the slurry. When water is returned, the unit cost in cents/ton-mile (Figure 3.1) does not decrease over distance as much as in those cases when water is not returned. Also included in Figure 3.1 are the multipliers for converting the unit costs to costs per million Btu (MMBtu). Two multipliers are provided for each source, the 'dry' basis (D) and the 'as mined' basis (M).

The availability of water is a major concern. The point has been sufficiently emphasized by the present drought in the states where the proposed lines originate. Although the water for the proposed slurry lines may be brackish, it can be used for some irrigation or other purposes when mixed with sweet water. Sources of water at pumping stations enroute are unlikely to be all brackish. Presently there are no plans to build a pipeline with a return water system. Pipeline water requirements are found in Table 3.3. To this should be added the ETSI estimate of 3.66MM ft³ for a dumping pond at each station. However, a holding pond of ten times this capacity might be needed at the delivery point. Flushing water amounting to 27.4MM gallons will be needed (the ETSI specification of 18.7MM gallons does not include the volume of coal to be filled by water.) Hence, the water reservoir should also be 3.66MM ft³ instead of the 2.5MM ft³ estimated by ETSI.

Water costs vary over a wide range. Some estimates for the ETSI line are presented in Volume 1, Section 1.9.2. Costs are subject to such factors as accessibility and alternative use by farmers and industry. Existing or potential drought conditions in the supply end make water and water rights a critical element. One way to reduce the heavy reliance on an adequate water supply is to provide for a return system. For the ETSI system, equipment for this would cost about \$257,000 per mile for 27" piping diameter (approximately $38\sqrt{2}$ " although the pipe could be 24" diameter if the pumping velocity were suitably increased) and \$514,000 per mile as a conservative value. Return pumping would require more power in order to move the waste water. The benefits of long distance shipping economics are not felt as much in a water-return system.

But it offers a solution to the problem of fines as exemplified by the Black Mesa receiving facility [6]. With return water, fines could be returned for use in land reclamation projects at the mine site.

If water could burn, a slurry line would be ideal. On the east and west coasts, oil may be an available substitute as a carrier, particularly for south-north shipments. The idea dates back to World War II and has lately been somewhat revived [21]. The oil source would probably be imports, but the coal content would reduce total oil consumption. With the entire slurry burned, transport costs are low. Particle deposition in oil takes weeks not days as it does in water. Total costs may not be lower than burning coal alone if scrubbing is unnecessary. If crude oil is used as the carrier, the differential profit that could have been made from the sale of the refined products must be added to the transport costs.

TABLE 3.2: Itemized Capital Costs of Black Mesa and Wyoming-Arkansas Coal Slurry Pipelines (1976 Prices)

<u>Preparation</u>	Black Mesa	Wyoming-Arkansas
	273 miles <u>5 x 10⁶ tons/yr</u>	1,040 miles <u>25 x 10⁶ tons/yr</u>
1. Transport from mine -----	1.5	7.5
2. Truck hopper	0.05	0.25
3. Initial crushing and cleaning	1.0	5.0
4. Stocking conveyor	0.2	1.0
5. In-active storage -----	1.0	5.0
6. Raw storage	0.68	3.4
7. Active storage	1.0	5.0
8. Dozers and scrapers	0.6	3.0
9. Conveyor transfer tower	0.2	1.0
10. Transfer tower -----	0.3	1.5
11. Conveyor to bunkers	0.15	0.75
12. Bunkers and feeders	0.15	0.75
13. Operating plant	1.0	5.0
14. Vibrator	0.2	1.0
15. Impactor -----	0.5	2.5
16. Rod mill	1.5	7.5
17. Vibrator	0.15	0.75
18. Slurry holding tank	0.6	3.0
19. Slurry test loop	0.05	0.25
20. Land -----	0.05	0.25
21. Wells and water pumps	1.25	6.25
22. Water working storage	0.35	1.75
23. Water reservoir and pipe	0.3	1.5
24. Water piping and rust inhibitor injectors	0.1	0.5
25. First pumping station -----	5.0	25.0
TOTAL: Preparation -----	17.88	89.4
 <u>Pipeline</u>		
26(a) Mainline	45.6	26 (b) 700
27. Collecting and branch lines		190
28(a) Coal in pipelines	0.23	28 (b) 4.4
TOTAL: Pipeline -----	45.83	894.4

TABLE 3.2: Itemized Capital Costs of Black Mesa and Wyoming-Arkansas Coal Slurry Pipelines (1976 Prices) (Continued)

<u>Separation</u>	Black Mesa	Wyoming-Arkansas
	273 miles <u>5 x 10⁶ tons/yr</u>	1,040 miles <u>25 x 10⁶ tons/yr</u>
29 (a) Permanent storage	4.8	29 (b) 13.0
30. Holding tanks	2.1	10.5
31. Dewatering centrifuges	4.0	18
32. Pulverizers	0.9	4.5
33. Flocculating tanks	0.7	3.5
34. Piping	0.15	0.75
TOTAL: Separation -----	12.65	50.25
TOTAL CAPITAL COST -----	76.36	1034.0

Notes to Table 3.2:

1. Five 125-ton trucks for transport from the mine @ \$30,000 each.
2. Truck hopper @ \$50,000
3. Two 28 ft by 14 ft diameter rotary breakers, \$1,000/ton/hr x 660 ton/hr x 1.5 [4a]
4. Movable stacking conveyor, \$800/ft x 250 ft [4b]
5. 200,000 tons coal @ \$5/ton in-active storage
6. 35,000 tons coal @ \$5/ton raw storage + feeder and site development @ \$500,000 [4c,5]
7. 38,000 tons coal @ \$5/ton active storage + rotary plow, structure above, and site development @ \$810,000 [4c,5]
8. Four bulldozers or scrapers @ \$150,000
9. 400 ft by 30 in. conveyor, \$250/ft equipment x 400 ft x 1.28 labor and material/material x 1.6 [4d,6a]
10. Transfer tower with 300 ton bin; coal sampled and weighed @ \$300,000
11. 300 ft x 30 in. conveyor, \$250/ft equipment x 300 ft x 1.28 labor and material/materials x 1.6 [4d,6a]
12. Three 590 ton bunkers with feeders @ \$50,000
13. Operating plant @ \$1,000,000
14. Three 6 ft x 10 ft twindeck vibrators, 3 x \$1,100/ft² x 60^{0.58} ft² x 1.32 installation x 2.4 stainless steel x 1.5 [6a]
15. Three impactors, 290 tons/hr, 3 x \$85/ton/hr x 290^{1.2} tons/hr x 1.57 installation x 1.5 [6a]
16. Three 18 ft x 13 ft I.D. rod mills, 1,500 hp, 150 tons of rods, 3(150 tons x 2,000 lb x \$1/lb + \$20,000/motor x 8.5 installation) [7,8]
17. Three 3.5 ft x 4 ft wedge wire screen vibrator, 3 x \$900/ft² x 14^{0.58}/ft² x 1.32 installation x 2.4 stainless steel x 3 wedge wire x 1.5 [6a]

TABLE 3.2: Itemized Capital Costs of Black Mesa and Wyoming-Arkansas Coal Slurry Pipelines
(1976 Prices)
(Continued)

18. Four 650,000 gallon tanks with 10 ft 125 hp agitator, 4(\$60,000/tank x 1.75 inflation + \$350/hp x 125^{0.5} hp x 1.62 installation x 1.5 inflation) + \$100,000 slurry tower
19. 206 ft test loop, 4,200 gpm @ \$50,000
20. 100 acres @ \$500/acre
21. Five 3,400 ft wells and pumps @ \$250,000 [9]
22. 150 ft diameter x 48 ft high, 6.3 x 10⁶ gal water storage tank, \$200,000 x 1.75 [6b]
23. 3 x 10⁶ gal plastic lined tank and 14 in., two-mile pipe, \$150,000 x 1.75 + \$40,000 pipe [6b]
24. Piping and rust inhibitor injectors @ \$100,000
25. Three 1,750 hp, 330 tons/hr coal equivalent slurry pumps, 1,000 psi discharge, 3 x \$1,330,000 + \$1,000,000 accessories [6c]
- 26a. \$7,120,000 pumping x 5 x 10⁶ tons/9 x 10⁶ tons x 1.65 inflation + \$37,590,000 mainline x 273 miles/344 miles x 5 x 10⁶/9 x 10⁶ tons x 2.1 inflation - \$5,000,000 first pumping station [10]
- 26b. (\$13,000,000 + \$3,400,000) x 5 pipeline valuation in Niobrara and Goshen Counties, Wyoming, x 1,040 miles/106 miles x 0.91 deflation - \$25,000,000, first pumping station [9]
27. (\$20,800,000 + 3,600,000) x 5 collecting pipeline valuation in Campbell and Converse Counties, Wyoming, x 2 destination supply lines as well as collecting lines x 0.91 deflation [9]
- 28a. 46,000 tons coal in pipe @ \$5/ton
- 28b. 875,000 tons coal in pipe @ \$5/ton
- 29a. Two 36 x 10⁶ gal storage tanks in a ground plastic lined, 90 tons coal each, 2(\$200,000 for 6 x 10⁶ gal tank item 22 x 6^{0.8} size factor x 1.75 inflation + 90,000 tons coal x \$10/ton) [6b,8]
- 29b. 1 x 10⁶ tons coal hauled by train and stored dry @ \$10/ton + \$3,000,000 for facilities
30. Three 6 x 10⁶ gal holding tanks, 15,500 tons of coal, 3(\$200,000/tank x 1.75 inflation + \$200,000 agitator and accessories + 15,500 tons x \$10/ton) [6b,8]
31. Twenty centrifuges, 20 x \$35,000/centrifuge x 3.1 process plant cost ratio x 1.9 [8,11b]
32. Ten pulverizers, \$520/lb x (660 tons/hr x 2,000 lb/ton)0.35 x 1.59 installation x 1.8 [6a]
33. Two 200 ft I.D. tanks @ \$350,000 [6b]
34. Piping @ \$150,000

Source: [4]

TABLE 3.3: Major Items Required for Operation and Maintenance
of Energy Facilities (1976 \$)

(Quantities per Year)

COAL SLURRY PIPELINE
(includes slurry preparation and dewatering)

Thousands
of Dollars

I. MATERIALS

A. Major Raw Materials, Volume, Energy Content:

25 x 10⁶ tons fine coal/year;
405 x 10¹² Btus/year

B. Other Materials and Supplies

1. Lumber and Wood Products (20,21):*	
Lumber	122
2. Paper and Paper Products (24-26)	31
3. Chemicals and Allied Materials (27-32):	
Corrosion retardants	1,378
Other	62
Subtotal	<u>1,440</u>
4. Stone, Clay, and Glass Products (35,36):	
Negligible	
5. Nonferrous Metals (38): Aluminum, copper products	122
6. Metal Products (39-42): Pipe, valves, and fittings	298
7. Miscellaneous: Negligible	
8. TOTAL	2,013

II. MACHINERY AND EQUIPMENT

1. Nonelectrical machinery (43-50,52): Negligible
2. Electrical Equipment (53-58): Negligible
3. Transportation Equipment (59-61): Negligible
4. Instruments and Controls (62,63): Negligible

TABLE 3.3: Major Items Required for Operation and Maintenance
of Energy Facilities (1976 \$)
(Continued)

5. Miscellaneous (64):	
Machinery (pumps, pulverizers, etc.); controls, electrical instruments, communication equipment	2,986
6. TOTAL	2,986

III. UTILITIES

1. Power and Light (68): (1.5¢/kWh)	
Coal preparation 420 x 10 ⁶ kWh (49,020 KW)	6,300
Pipeline movement 847 x 10 ⁶ kWh (98,856 KW)	12,700
2. Fuel (68):	
3. Water (68): 6.43 x 10 ⁹ gal (\$1/1000 gal)	6.43 x 10 ⁶
4. TOTAL	19,161

*Bureau of Economic Analysis industry category numbers
are in parentheses.

Source: [4]

TABLE 3.3: Major Items Required for Operation and Maintenance
of Energy Facilities (1976 \$)
(Continued)

5. Miscellaneous (64):	
Machinery (pumps, pulverizers, etc.); controls, electrical instruments, communication equipment	2,986
6. TOTAL	2,986
<u>III. UTILITIES</u>	
1. Power and Light (68): (1.5¢/kWh)	
Coal preparation 420 x 10 ⁶ kWh (49,020 KW)	6,300
Pipeline movement 847 x 10 ⁶ kWh (98,856 kW)	12,700
2. Fuel (68):	161
3. TOTAL [ex Water]	19,161

*Bureau of Economic Analysis industry category numbers
are in parentheses.

Source: [4]

Note: Water costs, a separable item, may be estimated
on the basis of \$1/1000 gallons, with
6.43 x 10³ gallons required, or \$6,430.

TABLE 3.4: Manpower Required for Operation of Energy Facilities

(Average Man-Years per Year)

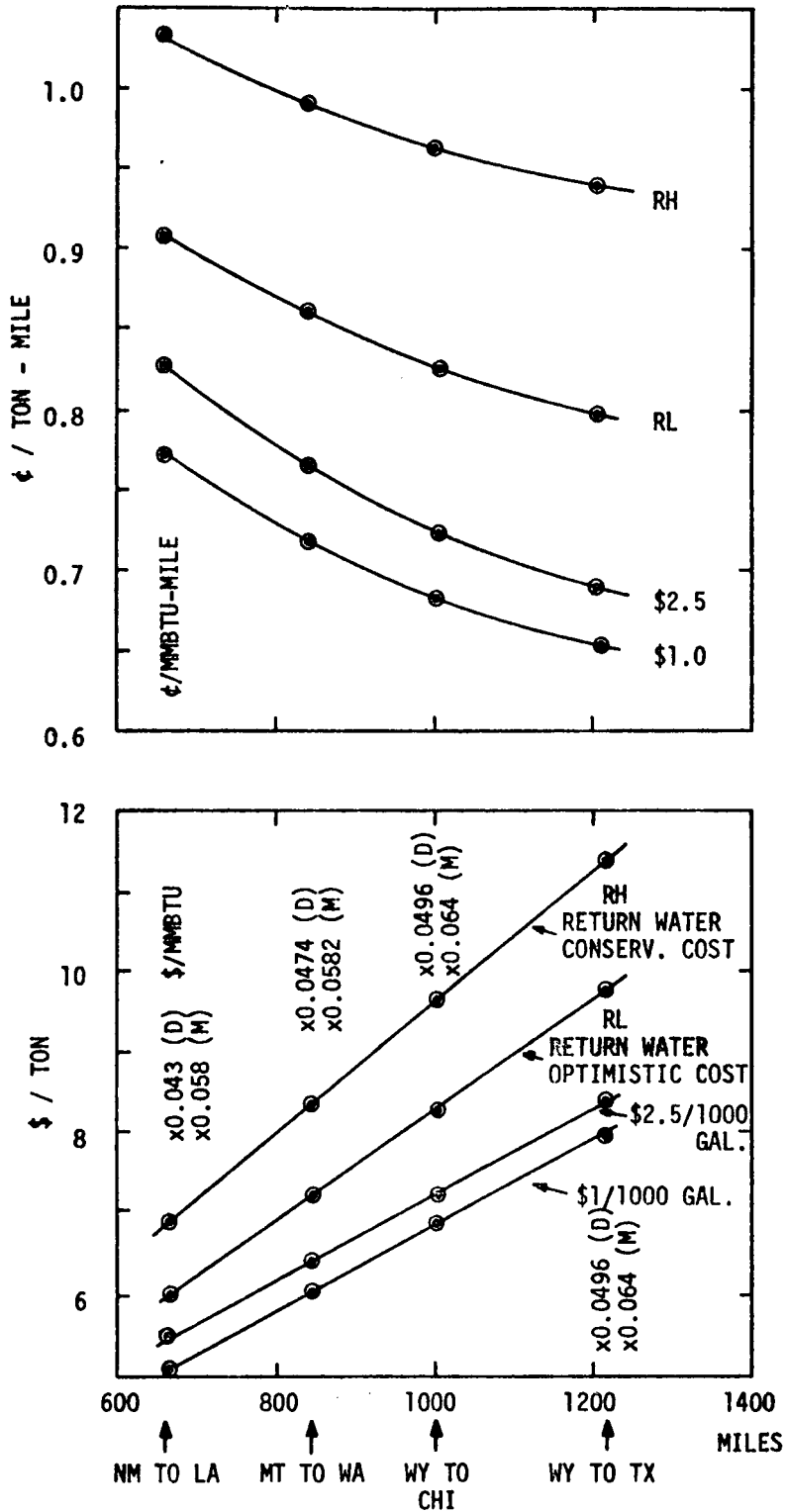
Coal Slurry Pipeline
(includes slurry preparation and dewatering)

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<u>A. NONMANUAL</u>		<u>B. MANUAL</u>	
1. Technical		1. Craftsmen	
a. Engineers:		a. Critical skills:	
Chemical	1	Pipefitter/welder	8
Designers and draftsmen	0	Electrician	8
c. Supervisors and managers	4	Operator, station engineer, pumpman	16
d. Other technical:		Mechanic helper	16
Office employees	2	Mechanic	72
e. Total technical	7	Subtotal	120
2. Nontechnical:		b. Other	0
Foreman	52	c. Total craftsmen	120
3. Nonmanual, TOTAL	59	2. Teamsters and laborers	32
		3. Manual, TOTAL	152

Source: [4]

FIGURE 3.1: Unit Cost - Slurry Pipelines



3.3 PIPELINE FLEXIBILITY AND BRANCHING

A slurry pipeline does not have the same advantage of monotonic cost reduction with increases in throughput that railroads do in the range from 5MMTY to 70MMTY. The reason is that in moving from, say, 25MMTY to 70MMTY, increasing pipe diameters on a single line from 38" to 64" is not desirable because 70MMTY represents a generating capacity of at least 14000 MW. Because electric generating stations must be designed to handle powdered coal, rather than larger sizes, a pipeline failure would be too costly. The result of a prolonged blockage or disruption would be a regional blackout. Good planning would call for three 38" pipelines or, perhaps, two 46" pipelines as a safeguard against total interruption of regional coal supply. An alternative would be a very large standby inventory of caked coal powder. This presents environmental and safety hazards.

One alternative is to operate a 3.5 mph line at, say, 5 mph to gain throughput. The undesirability of operating a pipeline designed for 3.5 mph at 5 mph is seen in the doubling of pumping power and a pipeline pressure at 143 percent of design capacity. For example, each pumping station on the Black Mesa pipeline is equipped with 3 pumps with one as a spare. If this practice is applied, operating at 122 percent capacity is feasible provided the line can take a 50 percent increase in operating pressure. In this case the unit transportation cost would be reduced by 18 percent. Similarly, operating at the minimum flow velocity of 3 mph gives a transfer capacity of 86 percent for the same slurry but at 75 percent of the power need. In this case, unit costs are increased by 15 percent.

Another option is to design a pipeline for 5 mph thus giving the flexibility of a reduced load at 3.5 mph or 3 mph. For purposes of comparison, a case was calculated (Table 3.5), showing changes in costs for such a pipeline operating at 3.5 mph. Note that while a pipeline designed for 5 mph may have a unit cost only 5 percent higher than a 3.5 mph line, when the former is operated at 3.5 mph the unit cost will be 40 percent higher, for a 40 percent capacity range.

If coal slurry pipelines are to become an important factor in coal transportation, they cannot remain in the class of single user or special case pipelines. A 273 mile line with a throughput of only 5MMTY (Black Mesa) may serve a single power station, but economics precludes extending a 5MMTY line to 750 or 1000 miles. On the other hand, even if the economics of a 25MMTY, 1000 mile pipeline, is

attractive, single users of such throughput are nonexistent. Were they to exist, the risk of shutdown of the line on the consumer or of a shutdown of the consumer on the line suggests major economic penalties. The consumer may gain some protection by holding large (and costly) inventories. But this must be considered a part of the transport cost. The pipeline seeks protection by long term take or pay agreements. (These prior agreements also aid in financing the line.) Currently, the largest producing mine is Decker No. 1 in Montana which had a 1975 output of 9.2 MMTY. The next three largest mines produced less than 7 MMTY. The grouping after that falls well below 5 MMTY per mine. As companies, only Peabody and Consolidation Coal produced more than 25 MMTY in 1975. In 1975, only six states used more than 25 MMTY in the production of electricity. Of these only two, Ohio and Pennsylvania, consumed considerably more. Among coal fired utilities, the largest in 1975 was the Monroe plant of Detroit Edison at 6.9 MMTY. The Four Corners plant in New Mexico and the Labadie plant in Missouri consumed 5.9 and 5.7 MMTY, respectively. As coal use grows, both mine and plant sizes may be expected to grow. They are unlikely to grow to 25 MMTY. Hence, some form of slurry pipeline gathering and distribution system is indicated.

One solution is to branch the pipeline to serve multiple users. Each user must have its own dewatering and other ancillary facilities. If the coal slurry pipeline is to be a common carrier in more than name only, a branching system is required unless a very large service depot handling finely powdered coal is envisioned. Movement of the powder or dewatered cake from the depot to the consumer would not be simple and may be environmentally hazardous. Dewatering equipment, however, is a major cost of a slurry pipeline. Such plants are probably beyond the reach of all but large consumers. Long-term agreements are not entirely necessary as the customer will have to amortize the plant in any event. Customers of the requisite size in a given location, even with branching, are apt to be few. Branching does allow for flexibility due to market conditions but because, unlike gas or oil lines, the slurry is subject to settling, a branched operation is not simple.

Branching increases pipeline flexibility because instead of slurry transport from a point of origin to a point of delivery, distribution along the pipeline route can take place. However, unlike gas or liquid pipelines, the flow velocity of a coal slurry line cannot be arbitrarily varied. The pipeline must operate at a flowrate above that required to keep the slurry from settling, and below that permitted by the maximum design

pipeline pressure. For a 3.5 mph design, the operating speed of the slurry cannot fall below 3.0 mph, or run above 4.3 mph (for a 50 percent design margin).

Given these considerations, the following is a general analysis of a branching point along a pipeline. The case of a single branching line is illustrated in a series of tables. Cases of multiple branching are shown in Figure 3.2. These include double branching in 3.2(a) and single branching segments in 3.2(b) and 3.2(c). Table 3.6 shows the capacity range for branching under normal conditions. Here, it is assumed that the design specifications for slurry flow, W , are: 3.5 mph normal, 3.0 mph minimum, 4.3 mph maximum, and 5.0 mph maximum for a specially designed line. For a given segment of pipeline under normal conditions, the range of safe operation is -14 percent to +23 percent of the design flowrate. This is written as $W + 23\% - 14\%$ (-14 percent to +43 percent for 5 mph). The flowrate $W + 23\%$ is the maximum permissible to avoid line burst, while $W - 14\%$ is the slowest rate possible that avoids slurry settling and plugging.

The effect of varying the branching flow W_C , is shown in Table 3.7. the minimum flow is theoretically, zero when the line is completely shut off. This is possible only if shutting off the designed flow, W_C , does not cause the flow, W_B to exceed its maximum. The resulting effects are shown in Table 3.8. These general cases indicate that the flexibility of the system depends heavily on the size of the branching line. The smaller the branch line, the easier it is for the main line to compensate for variations in flowrate. In order for a branching system to have the capability of total shutdown, it must be able to first clear the line by flushing through with water. This required pumping and storage adds significantly to the cost of the system.

The originally proposed Houston Natural Gas pipeline may serve as an example for application to the general formulas. Their proposed branching scheme is shown in Table 3.9. It should be noted that their latest proposal is to use barges for distribution rather than branching laterals. They have already merged with a major barge line. Using mainline D, Tables 3.10 and 3.11 were developed. For example, we can show the flexibility of each line when the flowrate of the branching line is at its maximum and minimum design capacity. For normal operation, in millions of tons per year, and the range of flow variation:

$$\bar{W}_F = 6 (+ .14/-1.71) = 6 (+ 2\%/-29\%)$$

$$\bar{W}_D = 13.5 (+ 1.71/-1.07) = 13.5 (+ 13\%/-8\%)$$

$$\bar{W}_E = 7.5 (+ 1.71/-1.07) = 7.5 (+ 23\%/-14\%)$$

Note that 6 (+ .14/-1.71) means an increase of 0.14MMTY above the 6MMTY design or a decrease of 1.71MMTY. The second equality gives the same variation but in percentages. For a specially designed line capable of 5 mph speeds, the equivalent throughputs are:

$$\bar{W}_F = 6 (+ 1.14/-1.71) = 6 (+ 19\%/-29\%)$$

$$\bar{W}_D = 13.5 (+ 3.20/-1.71) = 13.5 (+ 24\%/-29\%)$$

$$\bar{W}_E = 7.5 (+ 3.20/-1.07) = 7.5 (+ 43\%/-14\%)$$

The 20 percent increase in branch flowrate still leaves room for flexibility. With respect to the maximum and minimum branch flowrates, the maximum of 6.14MMTY can be handled by simply increasing the flow in the source pipe. The amount of slurry delivered to other points by the main pipeline remains unchanged. However, operation at minimum branch flowrate is impossible without decreasing the flow to other points downstream:

Design Case

$$\bar{W}_F = 5.0$$

$$\bar{W}_D = 12.5$$

$$\bar{W}_E = 7.5$$

Minimum Case

$$\bar{W}_F = 4.29; \bar{W}_F \text{ decreased by } 14\%$$

$$\bar{W}_D = 10.7; \bar{W}_D \text{ decreased by } 14\%$$

$$\bar{W}_E = 6.4; \bar{W}_E \text{ decreased by } 15\%$$

Maximum Case

$W_F = 6.14$; W_F increased by 43%

$W_D = 12.64$; W_D increased by 1%

$W_E = 6.5$; W_E remains constant

Because stopping the branching flowrate causes the downstream section to exceed its allowable maximum, the branch cannot be shut off. Halting this line would require the main line to operate below the minimum flowrate of 3.0 mph, which is also not allowable.

Obviously, any changes in the main line will be felt at other branching points. Similar analyses using the technique employed above will determine conditions at other points. With many branching points, the number of variables increases at a very rapid rate. Nevertheless, if coal slurry pipelines are to be truly common carriers rather than private carriers under a public label, this form of analysis must be repeated for each line and for a number of potential customers. It would appear from the above, however, that the ability to branch a coal slurry pipeline to serve several major customers is severely limited.

Akin to branching is tapping a slurry line. This is different because there is no change in the original diameter of the main pipeline. Branching would be designed into a pipeline system. Tapping occurs when a consumer, not one of the original customers, wishes to establish a branch line to take advantage of the existing main line. This is shown in Table 3.12. If tapped, the upstream line's flowrate must increase to compensate for this loss of slurry at the tap. Table 3.13 shows the resulting flowrate variations. As an example, it is helpful to use a situation similar to that of our branching example (Table 3.6). The normal main line flow conditions of 10MMTY are close to those of the branching case. Table 3.14(a) shows the maximum tap situation for a 10MMTY line while Table 3.14(b) shows this for a 25MMTY line. A major drawback to tapping is the effect on the main line. A tap can draw 25 percent of the main line while still allowing the design throughput downstream. However, the upstream line will be operating at its maximum capacity. This rules out further tapping unless one is willing to sacrifice downstream throughput by adding water to maintain the flowrate. Compared to the branching case, tapping lacks flexibility. One may design for branching but one must adapt for tapping; branching is preferred. This suggests that

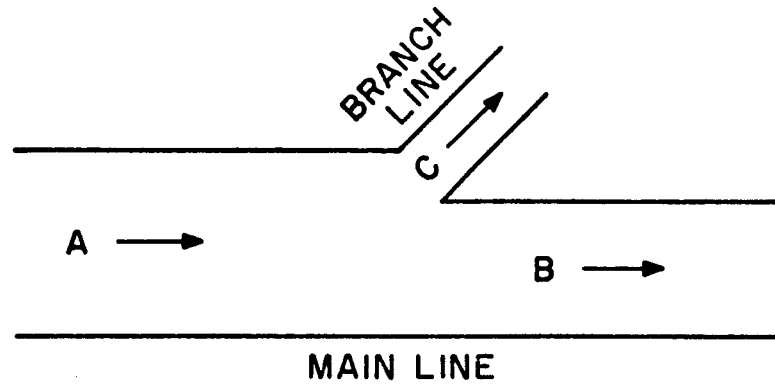
additional customers, at a later date, may not be served. An analysis of branching and tapping as a gathering system from dispersed mines into a coal slurry trunk line may be found in reference [22].

TABLE 3.5: Changes in Costs per 1000-Mile Pipeline
 Designed for 5 MPH Flow at 5 MPH and
 3.5 MPH as Compared to One Designed
 for 3.5 MPH
 (in million dollars)

Design	5 mph Line		3.5 mph Line
	5 mph	3.5 mph	3.5 mph
Operating Flow			
Operating Capacity, MMTY	36	25	25
Capital Costs:			
Gathering	22.3	22.3	15.5
Preparation	117.9	117.9	81.9
Piping & Pumping	1300	1300	860
Separation	72.4	72.4	50.3
Total	1512.6	1512.6	1007.7
Annual Costs:			
Fixed Charges			
Rate Base	93.8	93.8	62.5
Federal Tax	26.3	26.3	17.5
State Tax	30.3	30.3	20.1
Depreciation	50.4	50.4	33.6
Total	200.8	200.8	133.7
Operating Costs			
Labor	6.9	6.9	6.9
Material	6.25	5	5
Power	34.1	19	19
Water (\$1/1000 gal)	9.3	6.4	6.4
Total Annual Cost	258.6	239.3	171.0
Unit Cost:			
\$/ton	7.18	9.57	6.85
¢/ton-mile	.72	.96	.69
¢/MMBtu	36	48	33.9
¢/MMBtu/mile	.036	.048	.034

Source: [4]

TABLE 3.6: Pipeline Branching Under Normal Conditions



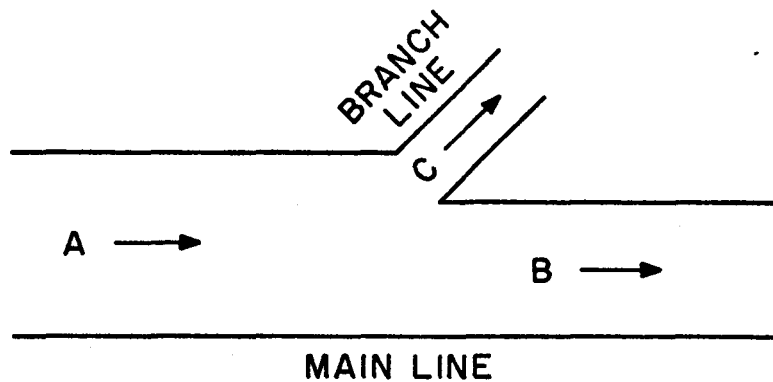
PIPELINE SECTION	FLOWRATE			
	NORMAL (3.5 mph)	MINIMUM (3.0 mph)	MAXIMUM (4.3 mph)	SPECIAL DESIGN (5.0 mph)
A	w'_A	$.857 w'_A$	$1.23 w'_A$	$1.43 w'_A$
B	w'_B	$.857 w'_B$	$1.23 w'_B$	$1.43 w'_B$
C	w'_C	$.857 w'_C$	$1.23 w'_C$	$1.43 w'_C$

w' = design flowrate

In all cases: $W + 23\%/-14\%$

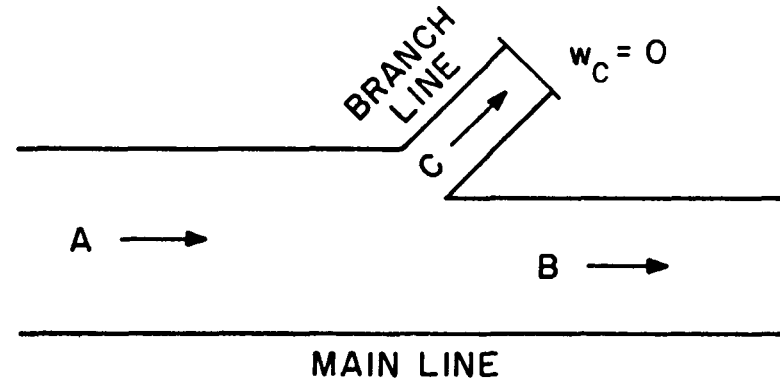
For special pipeline design: $W + 43\%/-14\%$

TABLE 3.7: General Effect of Varying Branch Flowrate, w_C



PIPELINE SECTION	FLOWRATE			
	NORMAL (3.5 mph)	MINIMUM (3.0 mph)	MAXIMUM (4.3 mph)	SPECIAL DESIGN (5.0 mph)
A		$\max \begin{cases} .857 w_A' \\ .857 w_B' + w_C \end{cases}$	$\min \begin{cases} 1.23 w_A' \\ 1.23 w_B' + w_C \end{cases}$	$\min \begin{cases} 1.43 w_A' \\ 1.43 w_B' + w_C \end{cases}$
B		$\max \begin{cases} .857 w_B' \\ .857 w_A' - w_C \end{cases}$	$\min \begin{cases} 1.23 w_B' \\ 1.23 w_A' - w_C \end{cases}$	$\min \begin{cases} 1.43 w_B' \\ 1.43 w_A' - w_C \end{cases}$
C	w_C	$.857 w_C$	$\begin{matrix} \leq \\ \geq \end{matrix} \begin{cases} 1.23 w_C' \\ 1.23 w_A' - .857 w_B' \end{cases}$	$\begin{matrix} \leq \\ \geq \end{matrix} \begin{cases} 1.43 w_C' \\ 1.23 w_A' - .857 w_B' \end{cases}$

TABLE 3.8: General Case of Branch Line Shutdown



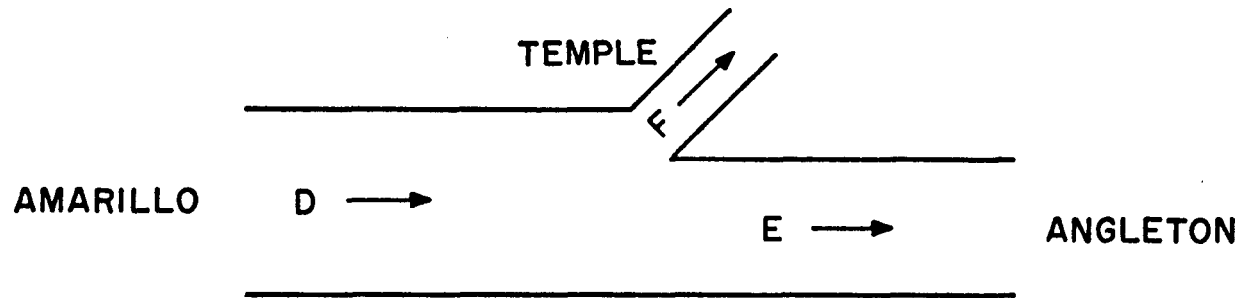
PIPELINE SECTION	FLOWRATE			
	NORMAL (3.5 mph)	MINIMUM (3.0 mph)	MAXIMUM (4.3 mph)	SPECIAL DESIGN (5.0 mph)
A		$.857 w'_A$	$1.23 w'_B$	$1.43 w'_B$
B		$.857 w'_A$	$1.23 w'_B$	$1.43 w'_B$
C	0	—	—	—

TABLE 3.9: Houston Natural Gas Branching Pipeline

<u>Segment</u>	<u>Route</u>	<u>Annual Throughput Capacity (tons)</u>
A	Farmington to Walsenburg	5,000,000
B*	Walsenburg to Amarillo	15,000,000
C	Amarillo to Plant X	1,250,000
D*	Amarillo to Temple	12,500,000
E*	Temple to Angleton	7,500,000
F	Temple	5,000,000

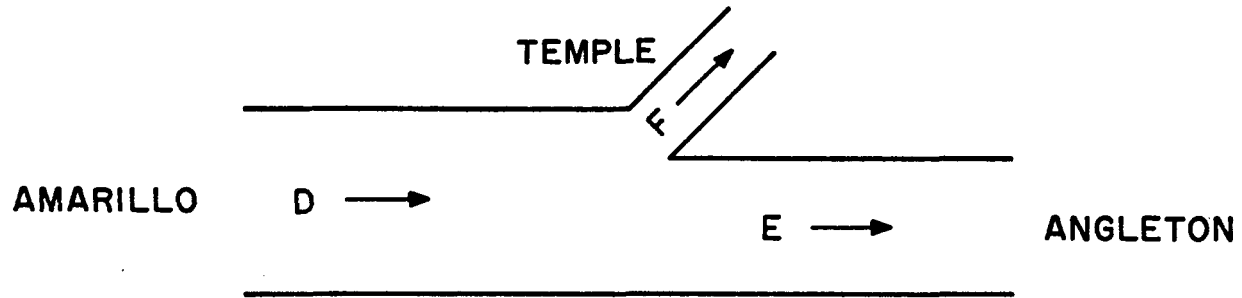
*Mainline Segments

TABLE 3.10: Houston Natural Gas Pipeline,
Proposed Normal Operation



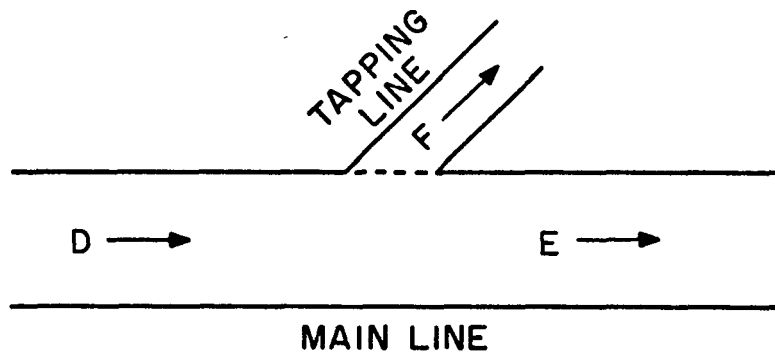
PIPELINE SECTION	FLOWRATE (MMTY)			
	NORMAL (3.5 mph)	MINIMUM (3.0 mph)	MAXIMUM (4.3 mph)	SPECIAL DESIGN (5.0 mph)
D	12.5	10.7	15.4	17.9
E	7.5	6.43	9.21	10.7
F	5.0	4.29	6.14	7.14

TABLE 3.11: Houston Natural Gas Pipeline Variable Branching Flowrate, w_F



PIPELINE SECTION	FLOWRATE (MMTY)			
	NORMAL (3.5 mph)	MINIMUM (3.0 mph)	MAXIMUM (4.3 mph)	SPECIAL DESIGN (5.0 mph)
D		$\max \begin{cases} 10.7 \\ 6.43 + w_F \end{cases}$	$\min \begin{cases} 15.4 \\ 9.21 + w_F \end{cases}$	$\min \begin{cases} 17.9 \\ 10.7 + w_F \end{cases}$
E		$\max \begin{cases} 6.43 \\ 10.7 - w_F \end{cases}$	$\min \begin{cases} 9.21 \\ 15.4 - w_F \end{cases}$	$\min \begin{cases} 10.7 \\ 17.9 - w_F \end{cases}$
F	w_F	4.29	6.14	7.14

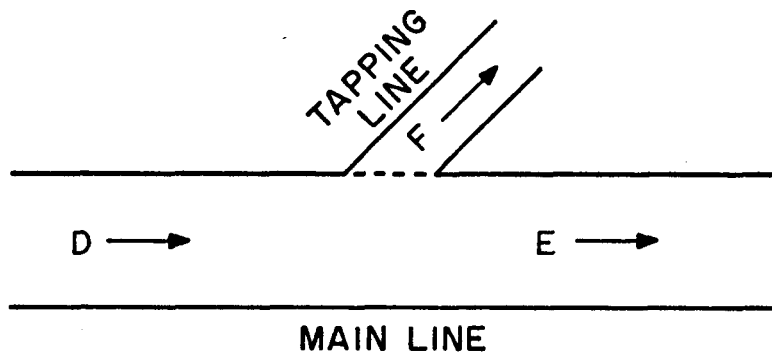
TABLE 3.12: Example of Pipeline Tapping, Normal Operation



PIPELINE SECTION	FLOWRATE (MMTY)			
	NORMAL (3.5 mph)	MINIMUM (3.0 mph)	MAXIMUM (4.3 mph)	SPECIAL DESIGN (5.0 mph)
D	10.0	8.57	12.3	14.3
E	10.0	8.57	12.3	14.3
F	0	$.857 w_F^i$	$1.23 w_F^i$	$1.43 w_F^i$

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TABLE 3.13: Example of Pipeline Tapping, Varying Tap Flowrate



PIPELINE SECTION	FLOWRATE (MMTY)			
	NORMAL (3.5 mph)	MINIMUM (3.0 mph)	MAXIMUM (4.3 mph)	SPECIAL DESIGN (5.0 mph)
D		$.857 w_E' + w_F'$	$1.23 w_E'$	$1.43 w_E'$
E		$.857 w_E'$	$1.23 w_E' - w_F'$	$1.43 w_E' - w_F'$
F	w_F'	$.857 w_F'$	$1.23 w_F'$	$1.43 w_F'$

TABLE 3.14: Examples of Pipeline Tapping

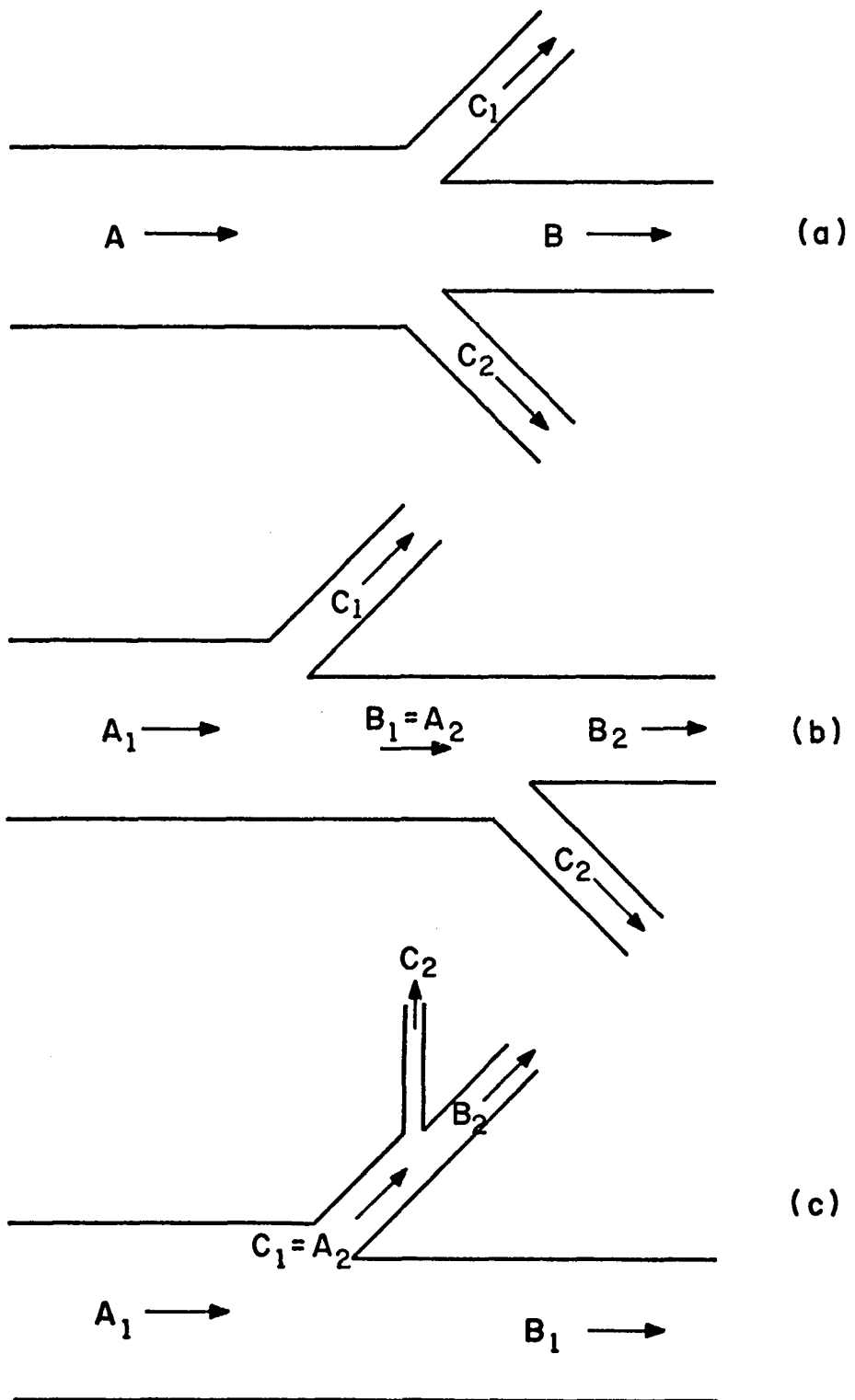
(a)

PIPELINE SECTION	FLOWRATE (MMTY)			
	NORMAL (3.5 mph)	MINIMUM (3.0 mph)	MAXIMUM (4.3 mph)	SPECIAL DESIGN (5.0 mph)
D	12.3	10.9	12.3	14.3
E	10.0	8.57	10.0	12.0
F	2.3	1.97	2.83	3.29

(b)

PIPELINE SECTION	FLOWRATE (MMTY)			
	NORMAL (3.5 mph)	MINIMUM (3.0 mph)	MAXIMUM (4.3 mph)	SPECIAL DESIGN (5.0 mph)
D	30.71	27.14	30.71	35.71
E	25.00	21.43	25.00	30.00
F	5.71	4.90	7.02	8.16

FIGURE 3.2: Branching Examples



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COSTS AND RESOURCES FOR SLURRY PIPELINE

MILLION DOLLARS - 25 MMTY - 3.5 MPH

ROUTE - GENERALIZED PIPELINE - 195.0 MILES

CCOST OF WATER 1.07 DOLLARS/1000 GAL

CAPITAL COSTS		ANNUAL COSTS			UNIT COSTS		
		ANNUAL FIXED CHARGE ON DEBT	OPERATING COSTS				
PREPARATION	104.2	AVERAGE RATE BASE	179.6	OPERATING LABOR	3.1	\$/TON	3.17
PIPING	201.2	RATE BASE	22.3	ADMINISTRATION	1.6	/TON-MILE	1.63
SEPARATION PLANT	53.8	FEDERAL TAX	5.2	MATERIAL	5.3	/MMBTU	15.39
		STATE TAX	7.2	POWER	14.6	/MMBTU-MILE	0.079
		DEPRECIATION	12.0	WATER	6.9		
TOTAL CAPITAL COST	359.3	TOTAL DEBT RETIREMENT	47.7	TOTAL OPERATING COST	31.6		
		TOTAL ANNUAL COST	79.2				
TOTAL COST (30 YRS) =		4412.69 (MILLION DOLLARS)					

CALCULATION FOR RETURN WATER

CAPITAL COSTS		ANNUAL COSTS			UNIT COSTS		
		ANNUAL FIXED CHARGE ON DEBT	OPERATING COSTS				
PREPARATION	104.2	AVERAGE RATE BASE	236.0	OPERATING LABOR	3.1	\$/TON	3.66
PIPING	313.9	RATE BASE	28.3	ADMINISTRATION	1.6	/TON-MILE	1.88
SEPARATION PLANT	53.9	FEDERAL TAX	8.2	MATERIAL	5.3	/MMBTU	17.76
		STATE TAX	9.4	POWER	18.6	/MMBTU-MILE	0.091
		DEPRECIATION	15.7	WATER	0.0		
TOTAL CAPITAL COST	472.0	TOTAL DEBT RETIREMENT	62.6	TOTAL OPERATING COST	28.8		
		TOTAL ANNUAL COST	91.5				
TOTAL COST (30 YRS) =		4601.44 (MILLION DOLLARS)					

COSTS AND RESOURCES FOR SLURRY PIPELINE

MILLION DOLLARS - 25 MMTY - 3.5 MPH

ROUTE - GENERALIZED PIPELINE - 195.0 MILES

COST OF WATER 2.68 DOLLARS/1000 GAL

CAPITAL COSTS		ANNUAL COSTS		UNIT COSTS			
		ANNUAL FIXED CHARGE ON DEBT	OPERATING COSTS				
PREPARATION	104.2	AVERAGE RATE BASE	179.6	OPERATING LABOR	3.1	\$/TON	3.58
PIPELINES	201.2	STATE TAX	22.3	ADMINISTRATION	1.6	/TON-MILE	1.84
SEPARATION PLANT	53.8	FEDERAL TAX	6.2	MATERIAL	5.3	/MMBTU	17.40
		STATE TAX	7.2	POWER	14.6	/MMBTU-MILE	0.089
		DEPRECIATION	12.0	WATER	17.2		
TOTAL CAPITAL COST	359.3	TOTAL DEBT RETIREMENT	47.7	TOTAL OPERATING COST	41.9		
		TOTAL ANNUAL COST	89.6				
TOTAL COST (30 YRS) =	5390.56 (MILLION DOLLARS)						

COSTS AND RESOURCES FOR SLURRY PIPELINE

MILLION DOLLARS - 25 MMTY - 3.5 MPH

ROUTE - GENERALIZED PIPELINE - 390.0 MILES

COST OF WATER 1.07 DOLLARS/1000 GAL

CAPITAL COSTS		ANNUAL COSTS			UNIT COSTS		
		ANNUAL FIXED CHARGE ON DEBT	OPERATING COSTS				
PREPARATION	104.2	AVERAGE RATE BASE	280.3	OPERATING LABOR	3.6	\$/TON	4.43
PIPING	402.5	RATE BASE	34.8	ADMINISTRATION	1.8	/TON-MILE	1.14
SEPARATION PLANT	53.8	FEDERAL TAX	9.7	MATERIAL	5.3	/MMBTU	21.50
		STATE TAX	11.2	POWER	18.8	/MMBTU-MILE	0.055
		DEPRECIATION	18.7	WATER	6.9		
TOTAL CAPITAL COST	560.5	TOTAL DEBT RETIREMENT	74.4	TOTAL OPERATING COST	36.4		

		TOTAL ANNUAL COST	
TOTAL COST (30 YRS) =	5665.61 (MILLION DOLLARS)		110.7

CALCULATION FOR RETURN WATER

CAPITAL COSTS		ANNUAL COSTS			UNIT COSTS		
		ANNUAL FIXED CHARGE ON DEBT	OPERATING COSTS				
PREPARATION	104.2	AVERAGE RATE BASE	323.0	OPERATING LABOR	3.6	\$/TON	5.68
PIPING	627.9	RATE BASE	48.7	ADMINISTRATION	1.8	/TON-MILE	1.46
SEPARATION PLANT	53.8	FEDERAL TAX	13.6	MATERIAL	5.3	/MMBTU	27.58
		STATE TAX	12.7	POWER	27.0	/MMBTU-MILE	0.071
		DEPRECIATION	26.2	WATER	0.0		
TOTAL CAPITAL COST	785.9	TOTAL DEBT RETIREMENT	104.3	TOTAL OPERATING COST	37.7		

		TOTAL ANNUAL COST	
TOTAL COST (30 YRS) =	6693.02 (MILLION DOLLARS)		142.0

COSTS AND RESOURCES FOR SLURRY PIPELINE

MILLION DOLLARS - 25 MMTY - 3.5 MPH

ROUTE - GENERALIZED PIPELINE - 390.0 MILES

COST OF WATER 2.68 DOLLARS/1000 GAL

CAPITAL COSTS		ANNUAL COSTS			UNIT COSTS		
		ANNUAL FIXED CHARGE ON DEBT	OPERATING COSTS				
PREPARATION	184.2	AVERAGE RATE BASE	280.3	OPERATING LABOR	3.6	\$/TON	4.84
PIPING	402.5	PIPE RENT	34.8	ADMINISTRATION	1.8	/TON-MILE	1.24
SEPARATION PLANT	53.8	FEDERAL TAX	9.7	MATERIAL	5.3	/MMBTU	23.51
		STATE TAX	11.2	POWER	18.8	/MMBTU-MILE	0.060
		DEPRECIATION	18.7	WATER	17.2		
TOTAL CAPITAL COST	560.5	TOTAL DEBT RETIREMENT	74.4	TOTAL OPERATING COST	46.7		
		TOTAL ANNUAL COST			121.1		
TOTAL COST (30 YRS) =	6643.48 (MILLION DOLLARS)						

COSTS AND RESOURCES FOR SLURRY PIPELINE

MILLION DOLLARS - 25 MMTY - 3.5 MPH

ROUTE - GENERALIZED PIPELINE - 585.0 MILES

COST OF WATER 1.07 DOLLARS/1000 GAL

CAPITAL COSTS		ANNUAL COSTS			UNIT COSTS			
		ANNUAL FIXED CHARGE ON DEBT	OPERATING COSTS					
PREPARATION	104.2	AVERAGE RATE BASE	380.9	OPERATING LABOR	4.0	\$/TON	5.69	
PIPING	603.7	RAIL BASE	47.2	ADMINISTRATION	2.0	/TON-MILE	0.97	
SEPARATION PLANT	53.8	FEDERAL TAX	13.2	MATERIAL	5.3	/MMBTU	27.62	
		STATE TAX	15.2	POWER-	22.9	/MMBTU-MILE	0.047	
		DEPRECIATION	25.4	WATER	6.9			
TOTAL CAPITAL COST	761.8	TOTAL DEBT RETIREMENT	101.1	TOTAL OPERATING COST	41.1			
		TOTAL ANNUAL COST		142.2				
TOTAL COST (30 YRS) =	5916.52	(MILLION DOLLARS)						

CALCULATION FOR RETURN WATER

CAPITAL COSTS		ANNUAL COSTS			UNIT COSTS			
		ANNUAL FIXED CHARGE ON DEBT	OPERATING COSTS					
PREPARATION	104.2	AVERAGE RATE BASE	549.9	OPERATING LABOR	4.0	\$/TON	7.70	
PIPING	941.8	RAIL BASE	68.2	ADMINISTRATION	2.0	/TON-MILE	1.32	
SEPARATION PLANT	53.8	FEDERAL TAX	19.1	MATERIAL	5.3	/MMBTU	37.40	
		STATE TAX	22.0	POWER-	35.3	/MMBTU-MILE	0.064	
		DEPRECIATION	36.7	WATER	0.0			
TOTAL CAPITAL COST	1099.8	TOTAL DEBT RETIREMENT	145.9	TOTAL OPERATING COST	46.6			
		TOTAL ANNUAL COST		192.6				
TOTAL COST (30 YRS) =	8784.58	(MILLION DOLLARS)						

COSTS AND RESOURCES FOR SLURRY PIPELINE

MILLION DOLLARS - 25 MMTY - 3.5 MPH

ROUTE - GENERALIZED PIPELINE - 585.0 MILES

COST OF WATER 2.68 DOLLARS/1000 GAL

CAPITAL COSTS		ANNUAL COSTS			UNIT COSTS		
		ANNUAL FIXED CHARGE ON DEBT	OPERATING COSTS				
PREPARATION	104.2	AVERAGE RATE BASE	386.9	OPERATING LABOR	4.0	\$/TON	6.10
PIPING	603.7	RATE BASE	47.2	ADMINISTRATION	2.0	/TON-MILE	1.04
SEPARATION PLANT	53.8	FEDERAL TAX	13.2	MATERIAL	5.3	/MMBTU	29.63
		STATE TAX	15.2	POWER-	22.9	/MMBTU-MILE	0.051
		DEPRECIATION	25.4	WATER	17.2		
TOTAL CAPITAL COST	761.8	TOTAL DEBT RETIREMENT	101.1	TOTAL OPERATING COST	51.5		
		TOTAL ANNUAL COST		152.6			
TOTAL COST (30 YRS) =	7896.40 (MILLION DOLLARS)						

COSTS AND RESOURCES FOR SLURRY PIPELINE

MILLION DOLLARS - 25 MMTY - 3.5 MPH

ROUTE - GENERALIZED PIPELINE - 780.0 MILES

COST OF WATER 1.07 DOLLARS/1000 GAL

CAPITAL COSTS		ANNUAL COSTS			UNIT COSTS		
		ANNUAL FIXED CHARGE ON DEBT	OPERATING COSTS				
PREPARATION	104.2	AVERAGE RATE BASE	481.5	OPERATING LABOR	4.5	\$/TON	6.95
PIPING	805.0	RATE BASE	59.7	ADMINISTRATION	2.2	/TON-MILE	0.89
SEPARATION PLANT	53.8	FEDERAL TAX	16.7	MATERIAL	5.3	/MMBTU	33.73
		STATE TAX	19.3	POWER-	27.0	/MMBTU-MILE	0.043
		DEPRECIATION	32.1	WATER	6.9		
TOTAL CAPITAL COST	963.0	TOTAL DEBT RETIREMENT	127.8	TOTAL OPERATING COST	45.9		
		TOTAL ANNUAL COST		173.7			

TOTAL COST(30 YRS)= 8171.44 (MILLION DOLLARS)

CALCULATION FOR RETURN WATER

CAPITAL COSTS		ANNUAL COSTS			UNIT COSTS		
		ANNUAL FIXED CHARGE ON DEBT	OPERATING COSTS				
PREPARATION	104.2	AVERAGE RATE BASE	706.9	OPERATING LABOR	4.5	\$/TON	9.73
PIPING	1255.7	RATE BASE	87.7	ADMINISTRATION	2.2	/TON-MILE	1.25
SEPARATION PLANT	53.8	FEDERAL TAX	24.5	MATERIAL	5.3	/MMBTU	47.22
		STATE TAX	28.3	POWER-	43.5	/MMBTU-MILE	0.061
		DEPRECIATION	47.1	WATER	0.0		
TOTAL CAPITAL COST	1413.8	TOTAL DEBT RETIREMENT	187.6	TOTAL OPERATING COST	55.6		
		TOTAL ANNUAL COST		243.2			

TOTAL COST(30 YRS)= 10876.15 (MILLION DOLLARS)

COSTS AND RESOURCES FOR SLUFFY PIPELINE

MILLION DOLLARS - 25 MMTY - 3.5 MPH

ROUTE - GENERALIZED PIPELINE - 780.0 MILES

COST OF WATER 2.68 DOLLARS/1000 GAL

CAPITAL COSTS		ANNUAL COSTS			UNIT COSTS			
		ANNUAL FIXED CHARGE ON DEBT	OPERATING COSTS					
PREPARATION	104.2	AVERAGE RATE BASE	421.5	OPERATING LABOR	4.5	\$/TON	7.36	
PIPING	205.0	RATE BASE	59.7	ADMINISTRATION	2.2	/TON-MILE	6.94	
SEPARATION PLANT	53.8	FEDERAL TAX	16.7	MATERIAL	5.3	/MMBTU	35.74	
		STATE TAX	19.3	POWER	27.0	/MMBTU-MILE	0.046	
		DEPRECIATION	32.1	WATER	17.2			
TOTAL CAPITAL COST	962.0	TOTAL DEBT RETIREMENT	127.8	TOTAL OPERATING COST	56.3			
		TOTAL ANNUAL COST			134.1			
TOTAL COST (30 YRS) =	9149.32	(MILLION DOLLARS)						

COSTS AND RESOURCES FOR SLURRY PIPELINE

MILLION DOLLARS - 25 MMTY - 3.5 MPH

ROUTE - GENERALIZED PIPELINE - 975.0 MILES

COST OF WATER 1.07 DOLLARS/1000 GAL

CAPITAL COSTS		ANNUAL COSTS			UNIT COSTS		
		ANNUAL FIXED CHARGE ON DEBT	OPERATING COSTS				
PREPARATION	104.2	AVERAGE RATE BASE	582.1	OPERATING LABOR	4.9	\$/TON	8.21
PIPING	1076.2	RATE BASE	72.2	ADMINISTRATION	2.4	/TON-MILE	0.84
SEPARATION PLANT	53.8	FEDERAL TAX	20.2	MATERIAL	5.3	/MMBTU	39.84
		STATE TAX	23.3	POWER-	31.1	/MMBTU-MILE	0.041
		DEPRECIATION	38.8	WATER	6.9		
TOTAL CAPITAL COST	1164.2	TOTAL DEBT RETIREMENT	154.5	TOTAL OPERATING COST	50.7		
		TOTAL ANNUAL COST		205.2			
TOTAL COST (30 YRS) =	9424.36 (MILLION DOLLARS)						

CALCULATION FOR RETURN WATER

CAPITAL COSTS		ANNUAL COSTS			UNIT COSTS		
		ANNUAL FIXED CHARGE ON DEBT	OPERATING COSTS				
PREPARATION	104.2	AVERAGE RATE BASE	873.9	OPERATING LABOR	4.9	\$/TON	11.75
PIPING	1569.7	RATE BASE	107.1	ADMINISTRATION	2.4	/TON-MILE	1.21
SEPARATION PLANT	53.8	FEDERAL TAX	30.0	MATERIAL	5.3	/MMBTU	57.03
		STATE TAX	34.6	POWER-	51.8	/MMBTU-MILE	0.058
		DEPRECIATION	57.6	WATER	0.0		
TOTAL CAPITAL COST	1727.7	TOTAL DEBT RETIREMENT	229.3	TOTAL OPERATING COST	64.5		
		TOTAL ANNUAL COST		293.7			
TOTAL COST (30 YRS) =	12967.72 (MILLION DOLLARS)						

COSTS AND RESOURCES FOR SLURRY PIPELINE

MILLION DOLLARS - 25 MMTY - 3.5 MPH

ROUTE - GENERALIZED PIPELINE - 975.0 MILES

COST OF WATER 2.68 DOLLARS/1000 GAL

CAPITAL COSTS		ANNUAL COSTS		UNIT COSTS			
		ANNUAL FIXED CHARGE ON DEBT	OPERATING COSTS				
PREPARATION	104.2	AVERAGE RATE BASE	582.1	OPERATING LABOR	4.9	\$/TON	8.62
PIPELINE	1006.2	RATE BASE	72.2	ADMINISTRATION	2.4	/TON-MILE	0.88
SEPARATION PLANT	53.8	FEDERAL TAX	29.2	MATERIAL	5.3	/MMBTU	41.85
		STATE TAX	23.3	POWER-	31.1	/MMBTU-MILE	0.043
		DEPRECIATION	38.8	WATER	17.2		
TOTAL CAPITAL COST	1164.2	TOTAL DEBT RETIREMENT	154.5	TOTAL OPERATING COST	61.1		
		TOTAL ANNUAL COST		215.5			
TOTAL COST (30 YRS) =	10492.24 (MILLION DOLLARS)						

COSTS AND RESOURCES FOR SLURRY PIPELINE

MILLION DOLLARS - 25 MMTU - 3.5 MPH

ROUTE - GENERALIZED PIPELINE - 1170.0 MILES

COST OF WATER 1.07 DOLLARS/1000 GAL

CAPITAL COSTS		ANNUAL COSTS			UNIT COSTS		
		ANNUAL FIXED CHARGE ON DEBT	OPERATING COSTS				
PREPARATION	104.2	AVERAGE RATE BASE	882.7	OPERATING LABOR	5.3	\$/TON	9.87
PIPING	1207.4	RATE BASE	84.7	ADMINISTRATION	2.7	/TON-MILE	0.81
SEPARATION PLANT	53.8	FEDERAL TAX	23.7	MATERIAL	5.3	/MMBTU	45.96
		STATE TAX	27.3	POWER-	35.3	/MMBTU-MILE	0.039
		DEPRECIATION	45.5	WATER	6.9		
TOTAL CAPITAL COST	1365.5	TOTAL DEBT RETIREMENT	181.2	TOTAL OPERATING COST	55.5		
		TOTAL ANNUAL COST		236.7			
TOTAL COST (30 YRS) =	10677.29 (MILLION DOLLARS)						

CALCULATION FOR RETURN WATER

CAPITAL COSTS		ANNUAL COSTS			UNIT COSTS		
		ANNUAL FIXED CHARGE ON DEBT	OPERATING COSTS				
PREPARATION	104.2	AVERAGE RATE BASE	1020.8	OPERATING LABOR	5.3	\$/TON	13.77
PIPING	1883.6	RATE BASE	126.6	ADMINISTRATION	2.7	/TON-MILE	1.18
SEPARATION PLANT	53.8	FEDERAL TAX	35.4	MATERIAL	5.3	/MMBTU	66.85
		STATE TAX	40.8	POWER-	60.0	/MMBTU-MILE	0.057
		DEPRECIATION	68.1	WATER	0.0		
TOTAL CAPITAL COST	2041.5	TOTAL DEBT RETIREMENT	270.9	TOTAL OPERATING COST	73.4		
		TOTAL ANNUAL COST		344.3			
TOTAL COST (30 YRS) =	15059.29 (MILLION DOLLARS)						

COSTS AND RESOURCES FOR SLURRY PIPELINE

MILLION DOLLARS - 25 MMTY - 3.5 MPH

ROUTE - GENERALIZED PIPELINE - 1170.0 MILES

COST OF WATER 2.68 DOLLARS/1000 GAL

CAPITAL COSTS		ANNUAL COSTS			UNIT COSTS		
		ANNUAL FIXED CHARGE ON DEBT	OPERATING COSTS				
PREPARATION	104.2	AVERAGE RATE BASE	682.7	OPERATING LABOR	5.3	\$/TON	9.88
PIPING	1207.4	RATE BASE	84.7	ADMINISTRATION	2.7	/TON-MILE	0.84
SEPARATION PLANT	53.8	FEDERAL TAX	23.7	MATERIAL	5.3	/MMBTU	47.97
		STATE TAX	27.2	POWER-	35.3	/MMBTU-MILE	0.041
		DEPRECIATION	45.5	WATER	17.2		
TOTAL CAPITAL COST	1365.5	TOTAL DEBT RETIREMENT	181.2	TOTAL OPERATING COST	65.8		
		TOTAL ANNUAL COST		247.0			
TOTAL COST (30 YRS) =	11655.16 (MILLION DOLLARS)						