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COAL/OIL MIXTURE PIPELINE:
A VIABLE ALTERNATIVE COAL TRANSPORTATION SYSTEM?

by

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ABSTRACT

Slurry pipeline systems have been promoted as minimizing the environmental and socio-economic impacts of rail transportation and as increasing competition in interstate coal transportation. However, the scarce water resources of the coal rich western states may limit the number and/or capacity of these systems. Furthermore, these systems are not without their own operating and environmental problems.

In this paper, a coal transportation system which utilizes coal/oil mixture technology will be compared to the coal/water system and to another alternative, coal/methanol system. The primary considerations addressed here are the system design considerations and trade-offs, the resource requirements (including capital) and the cost of delivered energy. Considerations such as the system environmental impacts, the status of the technologies, oil quality and supply, and the potential system flexiibilities will be discussed qualitatively.

INTRODUCTION

Future use of coal is not only limited by the cost impact of Federal and State environmental regulations but, also, by the demand for coal. In the present market situation, this demand comes from the utility industry which buys over 70% of this nation's coal output. Coal's future use is also tied to the projected growth in power consumption which is projected to be 1-2%/year.

This combination of factors dictates a very competitive coal industry in that any sales of coal will be highly dependent on price. A major ingredient of this delivered price is the transportation cost. It can vary from 20% of the delivered cost of Eastern coal to as much as 80% for Western coal delivered to the Midwest. Thus, Midwestern utilities are very interested in alternative transportation systems which would lower transportation costs and, thereby, increase competition among their potential suppliers.

Recently, because of the large, thick deposits of western coal, there have been pressures to increase coal production to supply markets in the Midwest and even as far away as Florida. The only large scale method available today for the transportation of these coals to the inland waterways is by unit train. In this case, the cost of transportation is essentially a non-negotiable item. Accordingly, transportation alternatives to unit trains are desirable. Slurry pipelines using water are the most often discussed alternatives, although they have been blocked by concerns over competition for limited water resources. Methanol slurry pipelines are another possible solution. However, they still use appreciable amounts of water and, also, pose additional environmental problems in coal mining states.

A third pipeline concept is to use a coal/oil slurry. This type of pipeline would minimize demands on water while also minimizing air pollution impacts for the utility customer because of the potentially lower sulfur fuel and higher BTU delivered. Such a concept envisions feeding the delivered coal/oil slurry directly to electrical generation units utilizing COM combustion technology.

OBJECTIVES

The purpose of this presentation is to compare four alternative pipeline schemes on a semi-quantitative basis. These include:

1) coal-water
2) coal-methanol
3) coal-oil (externally supplied)
4) coal-oil (internally generated)

This comparison is done on resource requirement, energy delivered, and cost bases. Differences are noted and the alternatives ranked. More subjective considerations such as environmental impacts, technological status, oil supply, and coal/oil system alternatives are discussed.

ASSUMPTIONS

Because the objective is to highlight differences between these alternatives, certain variables are assumed to be fixed. These are:

1) Pipeline - 1000 miles long
2) Route = Wyoming to the Midwest
3) Solids = 10 million tons per year of coal having an energy content of 0.25 quad
4) Pipeline Diameter - 24 inches
5) Pipeline Pressure Drop = 19 psi/mile
6) No heating of the pipeline is required
7) Wt % Coal = 50%; WT % Liquid - 50%
8) The flow of these slurries is newtonian

These assumptions are made to focus on the best case results for each of the four scenarios. If these are found favorable, then more analyses are justified. For example, the design (diameter, psi/mile, etc.) of a pipeline requires a detailed optimization between coal particle size, fluid characteristics, actual terrain to be traveled, etc. In this case, the focus is on what happens at the start and finish of the pipeline to highlight the opportunities for the development of a more economic transportation system. Accordingly, the pipe diameter and pressure drop are fixed which fixes the number of pumping stations. However, each case will require different grinding and deslurrying steps. Table I illustrates this.

The interesting thing to note here is that even though the oil is more viscous and, therefore, has the highest pressure drop of the three transport media, the combination of coal and oil as a lower pressure drop than either the water or methanol slurries, for the same fineness of grind. The combination of solids and liquid in this case lead to a more uniform mixture in which the solids are suspended and, therefore, do not contribute as much to frictional loss as in the other cases. For example, in the coal-methanol slurry, the solids of this grind are poorly dispersed which leads to high pressure drop. This can be overcome by grinding to a finer size, as illustrated in Table I. However, this requires about 75% more grinding energy than for the coal/oil slurry. Furthermore, the finer size coal will lead to more difficult and costly deslurrying steps.

Accordingly, for this comparison, a constant pressure drop of 19 psi/mile was chosen because it corresponds to the levels reported for the Black Mesa Slurry Pipeline.(2)

Based on these assumptions, the following cases were reviewed.

CASE DESCRIPTIONS

Case 1: Coal/Water Slurries

Figure 1 presents the flowsheet for a coal water slurry pipeline based on the Black Mesa pipeline as a model.(2,3) In this system, run of mine (ROM) coal is received by conveyor from the stockpile, distributed into raw coal bins, dry pulverized in cage pactors, and wet milled in rod mills. In order to meet the 18-19 psi pressure drop criteria, this coal must be ground to 100%-60 mesh which will require 25% more grinding energy than the coal/oil case. The fine coal is then distributed into agitated slurry tanks to make a 50% water coal slurry by weight. For this example, the coal is pumped through a 24 inch pipeline for 1000 miles. Fifteen (15) pumping stations are required assuming the 18-19 psi/mile pressure drop. Each pumping station utilizes Wilson Snyder slurry pumps with a maximum psig equal to 1500.

At the discharge end, the slurry is either sent directly to storage or to a primary dewatering step using solid bowl centrifuges. Final dewatering is accomplished using hot air swept pulverized mills whose output is delivered to pulverized fuel boilers. The recovered water would provide make-up in the power generation cycle.

Case II: Coal/Methanol Slurries

Figure 2 presents the flowsheet for a coal methanol slurry system. It has essentially the same steps except that methanol is made from coal to supply the transport liquid. In this case, 10 million tons per year of methanol is required. This is equal to approximately 110,000 barrels per day of oil equivalent (0.2 quads on a yearly basis). Assuming a Koppers-Totzek oxygen gasifier with a methanol synthesis step with an overall system efficiency of 45%, 17 million tons of coal, 13 million tons of oxygen and 12 million tons of water will be consumed(1) each year to produce the required 10 million tons per year of methanol.

In addition, as discussed in the assumptions, the coal feed to this slurry pipeline will need to be ground to approximately 100% - 100 mesh to meet the pipeline pressure drop criteria of 18-19 psi/mi. This finer grinding of the coal will require about 75%(1) more grinding energy than in the coal/oil case. The finer grind of coal will also require considerably more energy and capital equipment at the deslurrying station to separate the coal/methanol slurry and to provide for storing the recovered methanol.

Case III: Coal/Oil Slurry - External Oil Supply

Figure 3 presents the flowsheet for a coal oil slurry system. In this system, an external source of oil is mixed with ground coal (100% - 14 mesh) and pumped in the same system as before. At the discharge end, the slurry is put into agitated storage tanks. When needed the coal/oil mixture would be withdrawn from storage to boilers adapted and fed for burning coal/oil mixtures.

This system requires that 10 million tons of an oil comparable to #4 oil be available. This represents 0.45 quads per year or about 225,000 barrels per day which exceeds the current fuel oil refining capacity of the region.[7] Thus, some oil would have to be imported into the region or the production and refining capacity of the region would have to increase. Both might occur, since the region is one of the few areas in the conterminous U.S. where crude oil production is increasing and several proposals have suggested routing pipelines for Alaskan crude oil through the region.

Case IV: Coal/Oil Slurry - Internal Oil Supply

Figure 4 presents the schematic for a coal oil slurry system in which coal is used to supply the oil. In this system, oil generated from coal on site is slurried with ground coal, pumped through the same pipeline as before, discharged into agitated storage tanks, withdrawn from storage and fired to boilers adapted for use of coal/oil mixtures.

An oil, similar to #4 oil, would be produced from coal in an advanced coal liquefaction process such as the Exxon Donor Solvent process or the COGAS process. At a process efficiency of 65%, approximately 25 million tons per year of coal, 4-6 million tons per year of water, and 5 million tons per year of oxygen are required. This product oil would contain about 0.32 quad on a yearly basis slightly less than the amount assumed in Case III, but the capacity would still be 10 million tons per year (225,000 barrels per day).

COMPARISONS OF SYSTEMS

These slurry pipeline systems are compared in Table II through VII. The purpose of these comparisons is to highlight the technical and economic opportunities for this mode of coal transportation in the future. They assume that run of mine coal is delivered to the site for slurry preparation or processing.

A. Overall Resource Requirements

Table II summarizes the gross resource requirements of these systems. It shows that more coal is required to be mined with its attendent environmental concerns for the coal/methanol and coal/oil (internal) cases. However, given an external source of oil, the coal/oil slurry pipeline requires the least resources, particularly its demand for water. A coal/oil slurry pipeline based on internally generated oil would use less water than either the methanol or the water slurry pipeline systems.

Based solely on their water resource requirements, the systems can be ranked as follows:

1.	coal/oil (external) - COME	0 MMTPY
2.	coal/oil (internal) - COMI	4-6 MMTPY
3.	coal/water - C/W	10 MMTPY
4.	coal/methanol - C/MeOH	12 MMTPY

However, the internal oil supply requires a significantly greater amount of coal to be mined than in the coal/water case and also requires more capital, as described below. Whether or not this offsets the water resource advantages of the coal/oil (internal) system depends largely on one's point of view and, surely, will be a point of considerable debate. One Western perspective is that, for the same demand on its water resources, the coal/oil (internal) system would process and export four to six times as much coal energy as the coal/water system. Then the trade-offs become much more subjective than numerical differences between water and coal requirements. For example, what are the socio-economic impacts of the increased industrialization required for the coal/oil (internal) system relative to the coal/water system? Likewise, are the environmental impacts for the coal/oil (internal) systems acceptable.

B. Energy Delivered Comparison

Table III provides a comparison of the systems on an energy delivered basis. It shows that the coal/oil mixture delivers more energy than the other two systems. C/MeOH supplies more energy than the C/W system, but at a much higher energy input. However, the C/MeOH system is clearly in last place whether the basis for comparison is the net energy delivered or the overall system efficiency. In the coal/oil (external) case, the purchased oil does not make any more energy available to the utility. This is just a bookkeeping gain. Within the limited scope of this assessment, the delivery of the 0.25 quad of coal, the net energy delivered is the figure used for system comparisons. On the other hand, both the coal/methanol and coal/oil (internal) systems do provide a real increase in delivered energy above that contained in the solid coal.

C. Cost Comparisons

Table IV summarizes the capital cost comparisons for the four systems. The production of the quantities of oil and methanol require capital investments in the billions of dollars. Thus, in the coal/methanol case, the cost contributions due to grinding the coal finer to minimize pipeline pressure drop due to deslurrying are minor components in the overall costs.

Table V summarizes the operating cost comparisons for the four systems. The grinding and deslurrying costs are high for C/W and C/MeOH. The high operating costs for MeOH and oil production cases reflect a production cost in the vicinity of $35/BBL of oil equivalent.

Based on a cost basis, the systems can be ranked as follows:

1. COME
2. C/W
3. C/MeOH
4. COMI

The final basis of comparison then is the net cost/energy ratios presented in Table VI.

These comparisons show quite clearly that the ranking based on the cost of the net energy delivered is:

1. COME
2. C/W
3. COMI
4. C/MeOH

D. Environmental Comparison

Table VII lists some of the major qualitative comments for the four cases. In essence, the coal/water and coal/oil (external) pipeline are the most favorable with coal/oil (external) systems eliminating the need for any Western water and, thereby, the need for reusing the water at the discharge of the pipeline. The production of the carrier fluids in the coal/methanol and coal/oil (internal) cases involve the highest impacts at the Western terminal of these pipelines. However, the impacts at the Midwestern terminal would be substantially less for the coal/oil (internal) system than the coal/methanol system.

E. Other Considerations

The technology for slurry pipelining is quite well established with the most experience in water based systems. Using either oil or methanol as a carrier should not present any serious problems. However, the production of methanol or oil from coal entails the greatest technical uncertainties of any of these systems.

Storage of the slurries at the utility site would probably be a lesser problem for the coal/oil slurry than for the coal/water slurry. The coal/methanol slurry would probably be the least stable mixture of the three.

The methanol system suffers the further disadvantage of balancing the peaking power needs of a utility system against its coal-fired, base-load capacity. If the methanol supply exceeds the demand of the utility, the utility would be forced to develop markets for the excess methanol.

The coal/oil systems have two other potential advantages which have not been studied in any detail here. The first is the possibility of integrating a fine coal cleaning system into the slurry preparation step by utilizing bulk oil flotation technology currently under development. The second advantage is that a single coal/oil pipeline system could feed several, widely dispersed power plants without significant loses of economies of scale.

CONCLUSIONS

This qualitative comparison shows that the coal/oil slurry pipeline is an attractive economic, environmental, and technical alternative for shipping coal provided that oil is available in the region.

Coal/water pipelines are a second choice based on economics and, furthermore, they are limited by their demands on western water resources.

The third choice is coal/oil slurry pipelines using oil generated onsite. The main attraction is the saving of about 1/2 the water requirements. However, the capital costs will be high.

Coal/methanol slurry pipelines do not appear to have any economic or environmental advantages.

Should oil become available in the West (either via exploration or from Alaska), then, further, secondary considerations must be addressed before a technically and economically viable coal/oil slurry pipeline could be implemented. These considerations include:

1) Stability of coal/oil mixtures over long distances;
2) stable rheology over long distance;
3) increasing the coal content in the coal/oil slurry;
4) the effect of heavier oil (and, therefore, cheaper oils); and
5) specific environmental questions.

REFERENCES

1. American Petroleum Institute, Basic Petroleum Data Book, June 1977, including supplements through 1979.
2. Aude, T.C., N.T. Cowper, T.L. Thompson, and E.J. Wasp, "Slurry Piping Systems: Trends, Design Methods, Guidelines," Chemical Engineering, June 28, 1971, pg. 75-90.
3. Badger Plants, Inc., Conceptual Design of a Coal to Methanol Commercial Plant, FE-2416-24, February, 1978.
4. Cowper, N.T., T.L. Thompson, T.C. Aude, and E.J. Wasp, "Processing Steps: Keys to Successful Slurry - Pipeline Systems," Chemical Engineering, February 7, 1972, pg. 58-68.
5. Office of Technology Assessment, A Technology Assessment of Coal Slurry Pipelines, March, 1978.
6. Resource Engineering Cost & Process Files
7. Wasp, E.J., J.P. Kenny, R.L. Gardhi, Solid-Liquid Flow: Slurry Pipeline Transportation, Trans Tech Publications, Clausthal, Germany, 1977.

SLURRY	GRIND	CALCULATED PSI/MILE*	NO. OF PUMPING STATIONS**	ASSUMED PSI/MILE***	GRIND REQUIRED TO ACHIEVE ASSUMED PSI/MILE	RELATIVE GRINDING POWER REQUIRED
COAL/OIL	100% -14 mesh	19	13	19	100% -14 mesh	1.00
COAL/METHANOL	100% -14 mesh	259	173	19	100% 100 mesh	1.75
COAL/WATER	100% -14 mesh	75	50	19	100% 60 mesh	1.25
OIL ONLY	X	14	10	X	X	X
WATER ONLY	X	11	8	X	X	X
METHANOL ONLY	X	10	7	X	X	X

*References No. 2,3,4

**Using pumps with 1500 psig allowable between pumping stations

***Based on Black Mesa Pipeline Data. References No. 1,2,3,4

TABLE 1 ILLUSTRATIVE PRESSURE DROP CALCULATIONS

TRANSPORTATION SYSTEM

RESOURCE	COAL/WATER C/W	COAL/METHANOL C/MeOH	COAL/OIL (external) COME	COAL/OIL (internal) COMI
COAL (MM TPY)	10	27*	10	35*
WATER (MM TPY) (M ACRE-FT/YR)	10 (7.45)	12 (8.81)	X	4-6 (2.9-4.4)
OXYGEN (MM TPY)	X	13	X	5
OIL (MM TPY)	X	X	10	X

*Includes 10 MM TPY of coal to be transported.

TABLE II TRANSPORTATION SYSTEM OVERALL RESOURCE REQUIREMENTS[1]

Transportation System	Coal Energy Mined (Quads)	Purchased Oil (Quads)	Energy Delivered (Quads)		
			Coal	Medium	Net
C/W	0.25	--	0.25	0	0.25
C/MeOH	0.70	--	0.25	0.2	0.45
COME	0.25	0.45	0.25	0.45	0.25
COMI	0.74	--	0.25	0.32	0.57

TABLE III ENERGY DELIVERED

	CAPITAL, MM$ (1980 dollars)			
	C/W	C/MeOH	COME	COMI
<u>SLURRY MEDIUM</u>				
• Water	24	--	--	--
• MeOH Product	--	3,000-3,500*	--	--
• Oil Production	--	--	--	3,500-4,000*
<u>SLURRY TRANSPORT**</u>				
• Slurry Preparation	31	40	28	28
• Pipeline (24" line)	390	390	390	390
• Pumping (15 stations)	118	118	118	118
• Deslurry	50	88	--	--
• Storage	--	15	20	20
TOTALS	613	3,651-4,051	556	4,056-4,556

*Estimates prepared from REI files [1,6]
**Estimates prepared from reference material[2,5,6]

TABLE IV TRANSPORTATION SYSTEM CAPITAL COST COMPARISONS

OPERATING COST (MM$/YEAR)

	C/W	C/MeOH	COME	COMI
COAL	250	250	250	250
SLURRY MEDIUM				
· Water	9	--	--	--
· MeOH	--	1,200*	--	--
· Oil	--	--	--	1,600*
SLURRY TRANSPORT**				
· Preparation	19	26	17	17
· Pumping	192	192	192	192
· Deslurrying	30	50	--	--
· Storage	--	7	7	7
TOTAL	500	1,725	466	2,066

*Estimates prepared from files.[1,6]
**Estimates prepared from reference material.[2,5,6]

TABLE V TRANSPORTATION SYSTEM OPERATING COST COMPARISONS
(Including Annual Capital Costs)

	C/W	C/MeOH	COME	COMI
Capital Costs ($MM/MM Btu/hr)	2.45	8.10 - 9.00	2.20	7.10 - 8.00
Delivery Cost $/MM Btu	2.00	3.85 - 4.20	1.85	3.60 - 3.90

TABLE VI COMPARISON OF THE COST OF DELIVERED COAL ENERGY

ENVIRONMENTAL IMPACTS	C/W	C/MeOH	COME	COMI
• Coal Preparation and Processing	Little	High	Similar to C/W	High
• Western Water Usage	Medium	High	Essentially Zero	Low
• Operating Problems – Gas	Essentially Zero	Process Plant Effluents	Essentially Zero	Process Plant Effluents
– Solid	Essentially Zero	Major – Trace Elements and other solids. Dust emissions.	Essentially Zero	Major – Trace Elements and other solids. Dust emissions.
– Liquid	Low except for slurry water reuse at end of pipeline; steam blow-down.	Methanol must be used for peaking power generation which can lead to emissions during storage. Process Plant effluents.	Essentially Zero	Minor – Depends on plant design

TABLE VII QUALITATIVE ENVIRONMENTAL CONSIDERATIONS

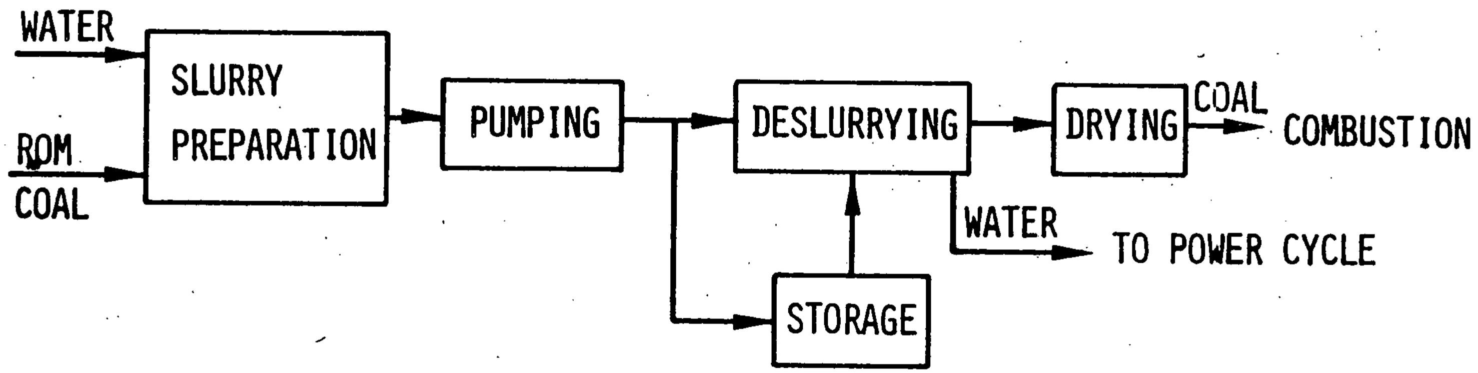

FIGURE 1: COAL/WATER SLURRY PIPELINE FLOWSHEET

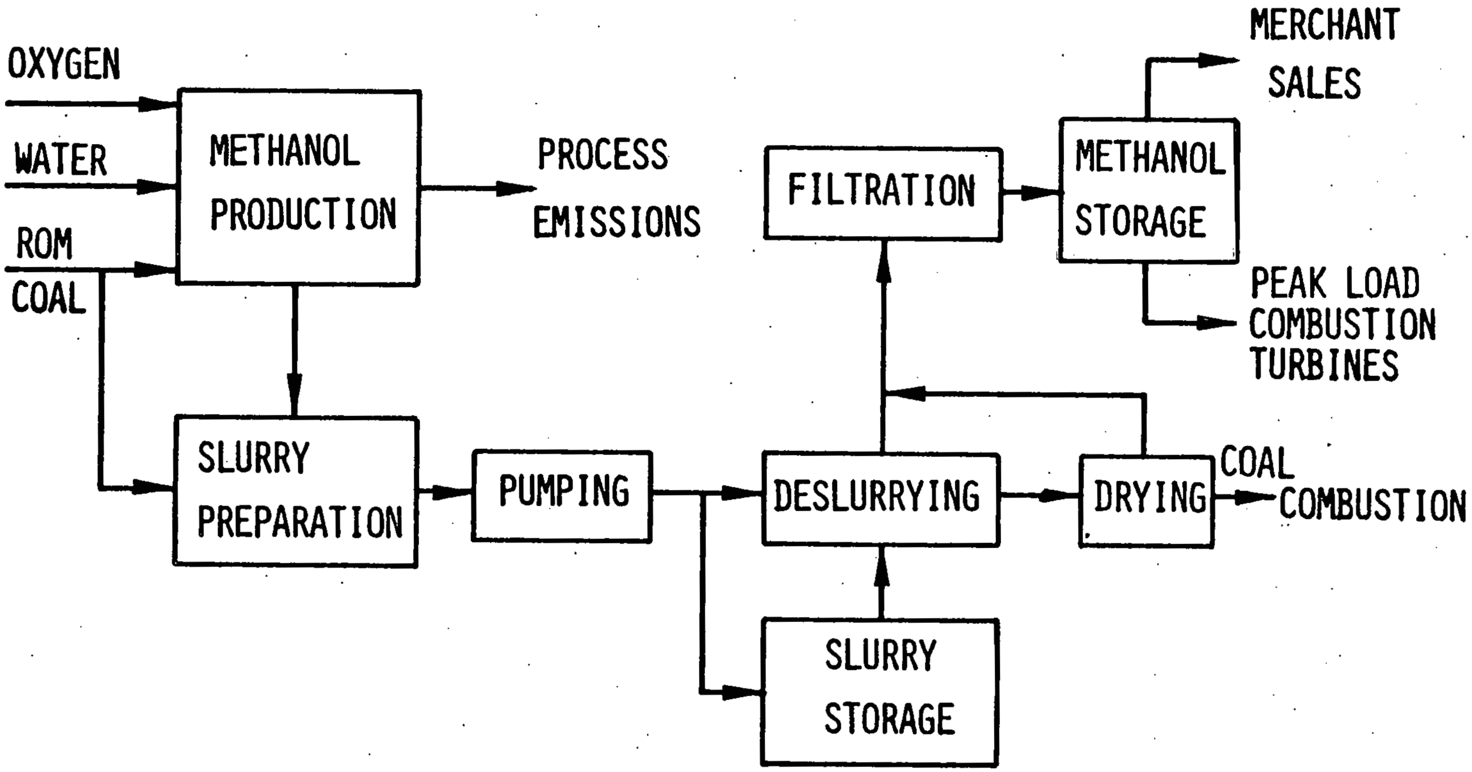

FIGURE 2: COAL/METHANOL SLURRY PIPELINE FLOWSHEET

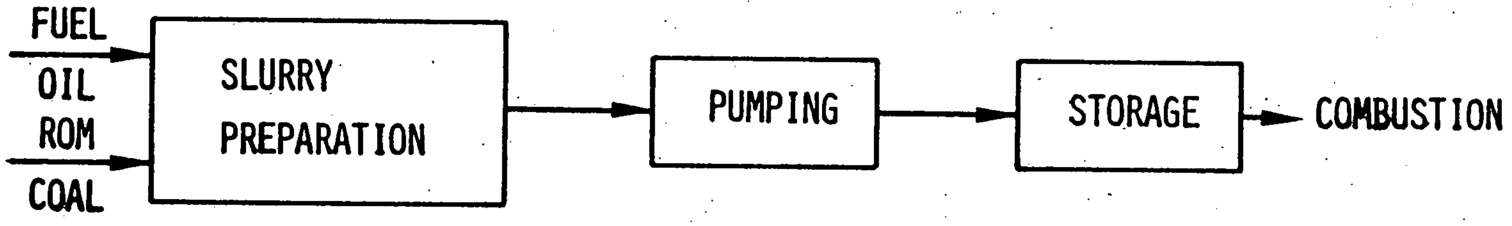

FIGURE 3: COAL/OIL SLURRY PIPELINE FLOWSHEET
(EXTERNAL OIL SUPPLY)

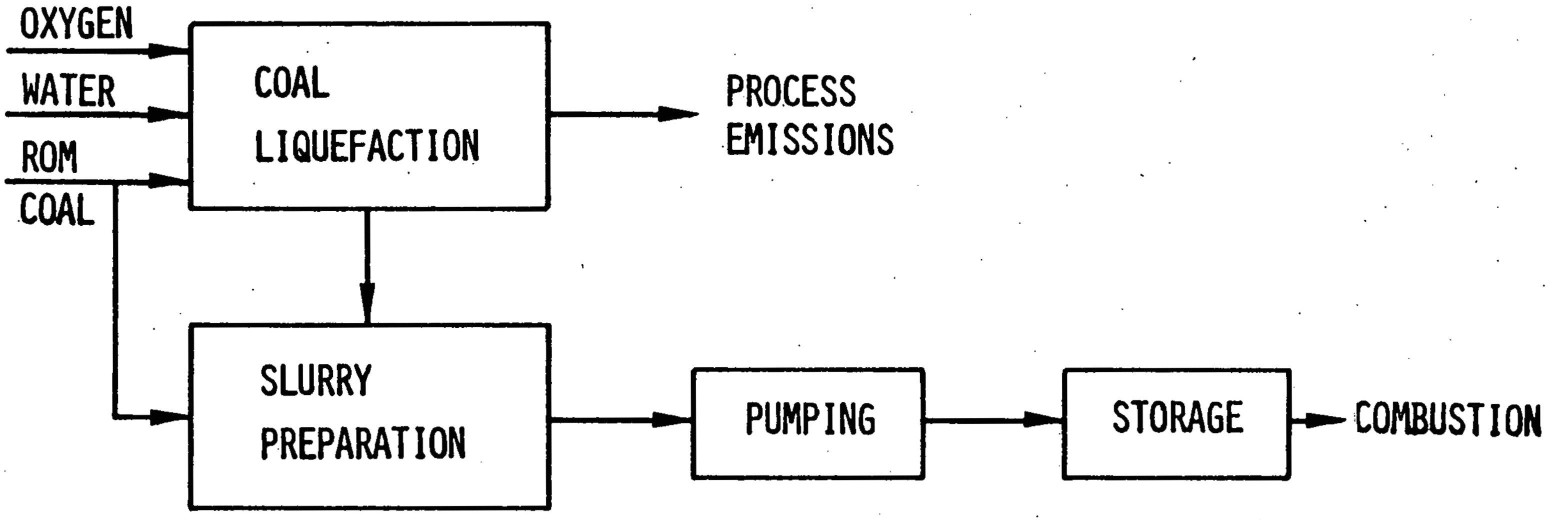

FIGURE 4: COAL/OIL SLURRY PIPELINE FLOWSHEET
(INTERNAL OIL SUPPLY)