HCP/I3461-01

MASTER

SURVEY OF COST OF RAIL VERSUS NEW TECHNOLOGY FOR LONG DISTANCE COAL TRANSPORTATION

FINAL REPORT

PREPARED FOR THE

FEDERAL ENERGY ADMINISTRATION

PREPARDED BY

J. J. DAVIS ASSOCIATES, INC.

J. J. DAVIS
ASSOCIATES, INC.
MANAGEMENT ENGINEERS

Suite 915 · 7900 Westpark Drive · McLean, Virginia 22101 · Telephone 703-790-5500

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

SUMMARY

1. Coal slurry pipelines were determined to be:

   - potentially more economical and environmentally acceptable
   - more suitable than rail in rugged terrain
   - relatively inflation resistant (capital intensive)
   - large consumer of water
   - low in environmental pollution (electric power, underground system)
   - proven technology (Black Mesa Pipeline) although not fully developed

2. Pneumatic pipelines were determined to be:

   - not technically proven for long distance
   - effective for short distance coal haulage (about 10 miles)
   - potentially effective for transporting coal to central locations for shipment by other means
   - a potential alternative to slurry pipelines if development of the present technology continues

3. Rail coal transport was determined to be:

   - most economical in areas where system exists
   - dependent on petroleum now
   - able to convert to electric power
   - susceptible to inflation (labor intensive)
   - polluting (diesel exhaust, noise, dust)
   - more hazardous to the general public (rail-roadway crossings)
   - able to increase efficiency through available technology (lightweight coal cars, more efficient locomotives, advanced design roadbed)

4. Both rail and slurry pipelines will require large capital investments to increase capacity equal to future coal production.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

5. Relative merit of each system changes in relation to terrain and existing systems.

6. To fully meet projected coal transportation needs, both systems will be needed.

7. By 1985 coal slurry pipelines could carry 10% of western coal.

8. Introduction of pipeline coal transport will not pose a threat to the survival of the western railroads.

9. Eastern railroad tariffs are unlikely to be significantly affected by the existence of western slurry pipelines.

Table of Contents

List of Figures

List of Tables

1.0 INTRODUCTION

The objectives of this study were:

1. To review the available literature on rail versus slurry and pneumatic pipelines for long-distance transportation of coal (over 100 miles).

2. To prepare a detailed comparison of the assumptions, methodologies and results of each comparative study.

3. To prepare a review report covering the
   - Status of the technology
   - Likelihood of the technology being a major contributor to coal transportation by 1985;
   - Relative life-cycle and costs, including inflation rates and other parameters;
   - The likely amount of new capital investment by railroads and its effect on average cost;
   - Rights of way and water availability questions, while crucial to the problem, are not intended to be studied in depth in this project;
   - Rail rate setting procedures and likely trends, for Eastern and Western railroads;
   - Prepare recommendations based on the above review process.

2.0 STATUS OF TECHNOLOGY

2.1 Rail Transportation Technology

2.1.1 Diesel Traction

The use of unit trains with diesel traction is proven technology, readily available. Its application is limited by the quality of track and road bed maintenance on existing rail lines, which is generally only fair, and by the need for new track to reach some of the new mining areas in the West.

Unit trains are flood loaded and at the unloading point the train is normally kept intact and each car dumped individually or in small groups. The train returns empty to the mine site. A 1550 mile round-trip coal haul requires only four days. Freight car utilization can reach 80% or more.

About two-thirds of the total coal produced in the U. S. is now carried at least in part by railroads. Current estimates predicting increases of coal production from the present 650 million tons per year (TPY) to approximately 1.2 billion TPY in 1985 imply an increase in rail tonnage from the present 450 million TPY (in 1975) to nearly 800 million TPY by 1985. Some estimates range even higher, predicting rail coal traffic alone to exceed 1 billion TPY by 1985 (Ref. 1). Jerome W. Komes (Ref. 8) Vice Chairman of Bechtel, stated that their study "assumed that by 1985 coal slurry pipelines would have an annual volume of 53 million tons of coal while rail tonnage still would soar to 510 million tons from 300 million tons last year (1974)." (According to the Association of American Railroads data, the nations rail lines in 1974 carried 391 million tons of coal).

2.1.2 Electrified Rail Transportation

The use of electric locomotives for traction has several advantages over diesel electric traction, including:

1. High traction and short time overload capability, which is important for steep gradients.

2. Lower maintenance required, which enhances the use of highly automated processes for the entire coal haul system.

3. Less air pollution and noise pollution.

4. Lower energy consumption by 10 to 20%.

5. Uses electrical energy which can be generated from coal, thereby reducing requirements for petroleum imports.

At this time the number of electrified unit trains is very limited and they are of short range (13 to 78 miles).

		Length
1.	Muskingum Electric Rail, Ohio	15 miles
2.	Black Mesa and Lake Powell Railroad - Arizona	78 miles
3.	Texas Utilities Generating Company - Texas	one 13 miles one 19 miles (Plans for 50 miles, additional)

The provision of an overhead contact wire system and power supply facilities requires costs ranging from $80,000 to over $100,000 per track mile. This is about 30% to 38% of the estimated cost of $267,000 per mile for new rails and ties (excluding right of ways costs) and only 4 to 5% of the estimated cost of $1,875,000 per mile if the right-of-way cost is included (Ref 2).

2.1.3 Rail Car Designs

Use of lightweight, high strength alloy materials in the construction of rail cars could significantly increase the tonnage of coal transported without an increase in locomotive power. This savings would be directly proportional to the weight saving on each specialized car as compared to standard cars.

Couplers of high strength alloys would also increase the permissable train size. Trains of more than 100 cars would be possible with less risk of train separation, thus increasing the efficiency of each train by uitlizing more of the locomotive power potential.

2.1.4 Roadbed

Use of advanced design and materials in the roadbed would permit higher speeds, and heavy loads without increased roadbed maintenance. Existing roadbeds in most areas will not carry the proposed increase in traffic without considerable maintenance and/or modification. Use of specialized materials such as concrete for ties have not been proven. Although sucessfully used in Asia and Europe, concrete ties have not worked well on one U. S. coal line.

The Black Mesa and Lake Powell Railroad has experienced difficulties in operation requiring replacement of concrete ties by wooden ties on about 1/3 of the line and limiting load on each car to 90 instead of 122 tons to reduce roadway and equipment maintenance (Ref. 3). Although this experience has not been positive, future railroad development will benefit from these experiences. Advanced concepts for railroad equipment and facilities should prove practical in the near future.

2.2 Slurry Pipeline Technology

Experience with water and coal slurry pipelines has been obtained with two pipelines in the U. S. The 108 mile, 10-inch diameter line from Cadiz to Cleveland, Ohio operated from 1957 to 1963 (at 1.3 million TPY). The 273 mile, 18-inch diameter Black Mesa pipeline has operated since 1970. Its capacity is 4.8 million TPY. This pipeline traverses a 273 mile route, whereas rail movement would have been over 408 miles, and would have required 150 miles of new track.

In addition, a 72 mile, 6-inch diameter Gilsonite and water slurry pipeline operated from 1957 to 1974 at 380,000 TPY.

For distances greater than about 50 miles, coal must be ground to less than 8 mesh, and contain sufficient fine coal to suspend the larger sizes. The coal concentration is typically 45 to 55% by weight. Pumping is accomplished by electrically driven reciprocating pump stations at intervals of 50 to 100 miles. Maximum line pressures are generally below 2000 pounds per square inch and flow velocity is about 5 to 6 feet per second. Carbon steel pipe is used with welded joints and depth of burial is 3 feet. In case of line shutdown, the pipe is flushed with water, although after temporary flow stopping, the line can be restarted.

Coal is dewatered by centrifuges to permit final grinding and feeding directly to boilers. By further dewatering, it would be possible to handle the coal by conventional means including rail transport. The water is used as part of the power plant cooling water.

For short distances, coarse coal with lump sizes up to 4 inches can be transported hydraulically suspended in a slurry of fine coal. Two short pipelines (6 and 7 miles long) exist in the USSR and a 26 mile long pipeline is planned in the Ukraine.

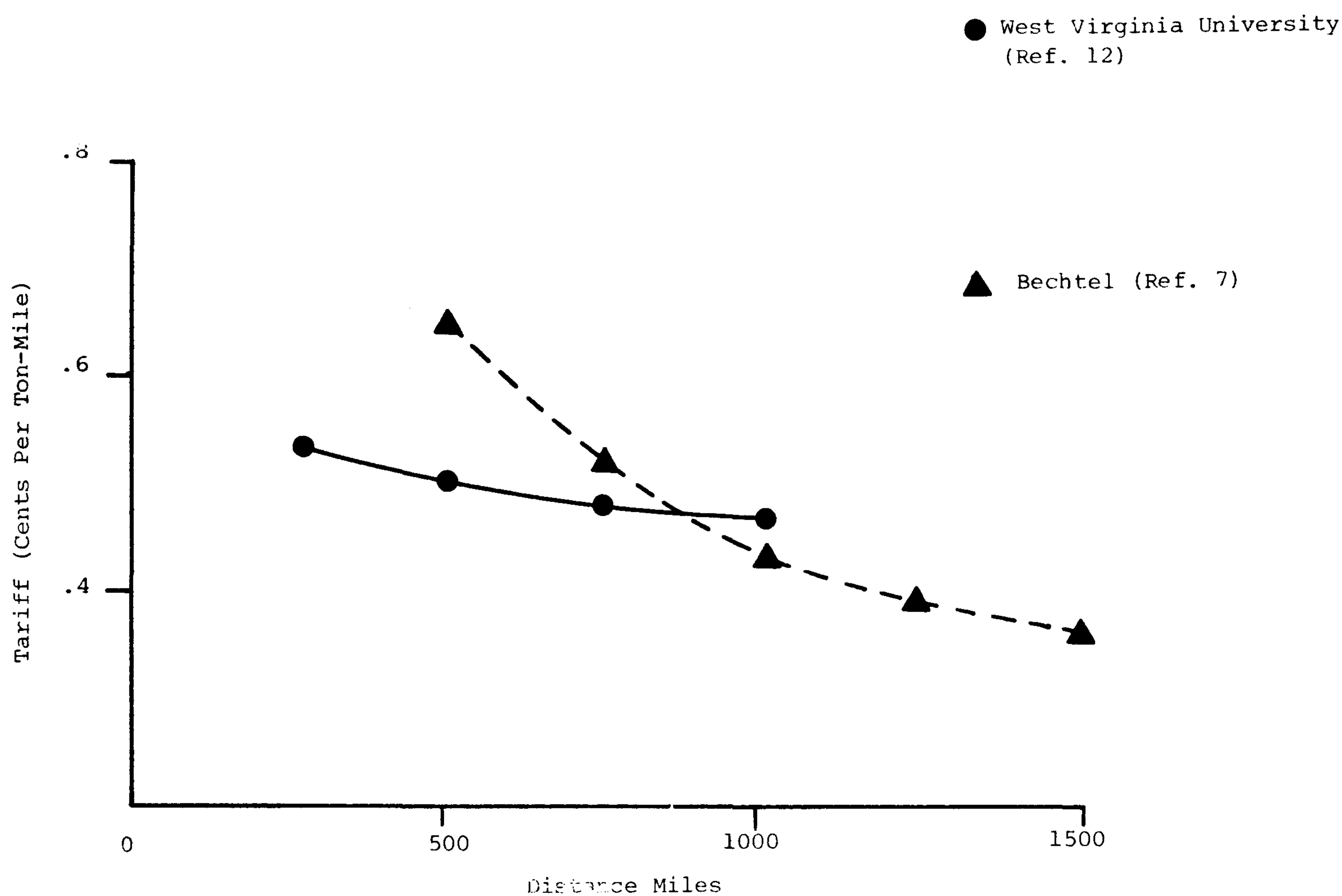
In these cases, water is recycled to be used in underground hydraulic coal mines. In the planned 26 mile system, fly ash will be carried in the return water line to be used for underground hydraulic stowing in a coal mine.

2.3 Pneumatic Pipelines

The use of compressed air or natural gas to transport coal by pneumatic pipeline is in an early stage of development. The economical transport distance at present is very limited for gaseous slurries. Velocities are high and pipe wear is a problem which is not yet solved. Long distance transport may require the coal to be contained in capsules which are returnable, possibly carrying other materials on the return trip.

No data were found indicating that pneumatic pipelines using air will be a reliable alternative for transporting coal for distances of 100 miles or more by the year 1985. They may be applicable sooner for short distance transportation of a few miles.

Figure 1
Estimated Tariff for Coal
Slurry Pipelines Carrying 15 Million TPY



3.0 LIFE-CYCLE AND COST COMPARISONS

3.1 Life-Cycle Data

Insufficient data exists to establish the economic life of a slurry pipeline. However, it has been stated that pipeline erosion-corrosion is expected to permit a life of up to 75 years (Ref. 4), which exceeds the typical life of a power generating plant (25 years). The wear of pipes and pumps is very dependent on the content of abrasive impurities in the coal. Extensive research on on hydrotransport of coal has been conducted in the USSR (Ref. 15 + 16).

According to current estimates, new rails can be expected to last 60 years and tie replacemnt every 35 years. In 1968 the average tie replacement life was 48 years and the rate of rail replacement was 121 years.

Substantial increases in track maintenance will be needed to meet future rail transport requirements. The western railroads which have profitable operations will be best prepared to upgrade track quality without subsidy.

3.2 Cost Comparisons

Although cost comparisons are often made on the basis of cost per ton-mile, it must be noted that the length of a rail system generally exceeds the length of pipeline required between two points. For example, the alternative rail route for Black Mesa was 408 miles, which is 50% longer than the 273 mile length of the actual pipeline.

Typical high volume long distance unit trains have transprotation costs of approximately 0.6 cents per ton-mile (Ref. 4, 5, and 6). Tariff may increase to 1.2 cents/ ton-mile at 500 mile range (Ref. 7) from 0.9 cents at a 1500 mile range. However, the cost and tariff depends on the amortization costs of the railroad as well as the fraction of maintenance costs assigned to unit train coal operations.

Estimated tariffs per ton-mile for slurry pipelines vary with distance and capacity from 0.95 cents at 500 miles to 0.67 cents at 1500 miles for a capacity of 10 million TPY (Ref. 7). The cost decreases with an increase in capacity.

Assuming that the 25 million TPY ETSI line could move coal for 0.5 cents per ton-mile versus rail cost of 0.8 cents per ton-mile, utilities could save $14 billion over 30 years (Ref. 9). However, the University of Illinois study claims that Burlington Northern moves coal on one line for 0.68 cents per ton-mile (Ref. 11), which would reduce the estimated savings to 8.4 billion.

Figure 1 shows a comparison of tariffs estimated by Bechtel and by West Virginia University for 15 million tons per year and distances of 300 to 1500 miles. It is seen that the two methods of cost analysis are quite different, although a tariff of 0.63 to 0.67 cents/ton-mile is obtained at a distance of 1000 miles. This is very close to the rail cost of 0.68 reported for Burlinton Northern (again note that the pipeline could be shorter than the rail route).

3.3 Pipeline Feasibility

Life cycle cost comparison between rail and slurry pipeline transport of coal must include considerations for the basic operating nature of each system, and the long term effects of inflation. Pipeline slurry systems will require large capital investments to establish the system initially, but relatively low labor and repair inputs to operate one established. An example of this is the Black Mesa Pipeline, where one operator can control the entire 273 mile system, and repair downtime has been minimal. Extensive automation of pipeline systems should make this small labor requirement common on all future slurry pipelines.

Railroads also require large capital investments. Unlike pipelines, however, railroads require large numbers of persons for operation and maintenance. Each train needs a complete crew, and a large number of support personnel. Roadbeds require periodic maintenance, and continuous maintenance is needed for all rolling stock. This maintenance accounts for approximately 71 percent of all railroad expenses (Ref. 26). This percentage should not decrease in the near future, and may increase with inflation and increased haulage rates.

Over the expected lifetime of a pipeline, the effects of higher labor costs due to inflation should add only marginally to the cost of coal transport. With the capital nature of these systems, inflation should have a significant effect only on equipment repair/replacement costs and the cost of energy to power the system. This should allow the increase in pipeline transportation costs to grow at a rate slower than the general inflation rate. The reliance of pipelines on electrical energy should also retard the energy increases, as coal could be used to supply the generating stations providing the required electricity.

Railroads will be significantly more vulnerable to the effects of inflation. Because of their labor intensive nature, they will be directly affected by price increases in any section of the economy. Increased energy costs will potentially be passed to the railroads twice. First as direct increases in energy cost and secondly in increased labor rates through "cost of living" increases. With labor being a significant contribution to the cost of rail transportation, rates will necessarily follow the inflationary trends.

3.4

All available studies indicate that coal slurry pipelines provide a feasible method of coal transport for long distances which can compete economically with unit train rail transport under the following conditions:

1. No existing rail route is available.
2. Capacity will exceed 5 to 6 million TPY.
3. Transport distance is at least 100 miles.
4. Water is available for export at reasonable cost.
5. Right to cross railroad right-of-way is available.

These conditions are sufficient to warrant serious consideration of slurry pipelines as an economic alternative. However, all these conditions are not necessary for slurry pipelines to be competitive. In particular, even when existing rail lines exist for part or all of the route, the slurry pipeline may prove more economical or socially preferable if:

1. The length of the rail line is appreciably greater than the pipeline distance.
2. New track would have to be laid for a substantial part of the route.
3. The quality of existing track needs great improvement to permit unit train operation.
4. The capacity of the existing track would become saturated within the projected life of a pipeline system (up to 75 years).

5. The environmental or socio-economic impact of increased rail transport would be an excessive burden on existing or required population centers (e.g., operation of the ETSI line was estimated 2570 rail workers to move the same amount of coal (Ref. 110).

4.0 PROJECTED CAPITAL INVESTMENT AND REVENUES

Louis W. Menk, chief executive of the Burlington Northern Railroad has said (Ref. 8) that a doubling of coal production in 10 years "could mean $1.7 billion in new annual rail freight revenues by 1985. It is interesting to consider the possibilities of what an additional $1.7 billion yearly would mean to an industry whose entire capital improvements budget last year (1974) was $100 million less than that." Menk claims that the ETSI pipeline would cost Burlington Northern $120 million per year in revenues and would jeopardize their $450 million program to increase coal hauling volume five fold by 1980 (Ref. 9).

Jervis Langdon, Jr., President of Penn Central (Ref. 8) said that "the nation must face up to the fact that it cannot permit the most profitable segments of railroad traffic to be siphoned off and still have a viable railroad system."

In the first half of 1975, Burlington Northern had coal freight revenues of $94 million. By 1980, BN's coal revenues are expected to hit at least $700 million, against only $64 million in 1971. The first of the projected pipelines (ETSI) threatens to drain away about $150 million of that (Ref. 10).

An estimate of the capital investment per ton-mile per year of coal delivered by pipelines is given in Table 1. Data on Figure 2, which plots the expected growth in coal freight revenues of the Burlington Northern railroad, with and without competition from the ETSI (Wyoming to Arkansas) slurry pipeline.

If one assumes that the BN investment of $450 million to increase coal hauling volume five fold by 1980 will permit an increase in coal revenues to $700 million from about $200

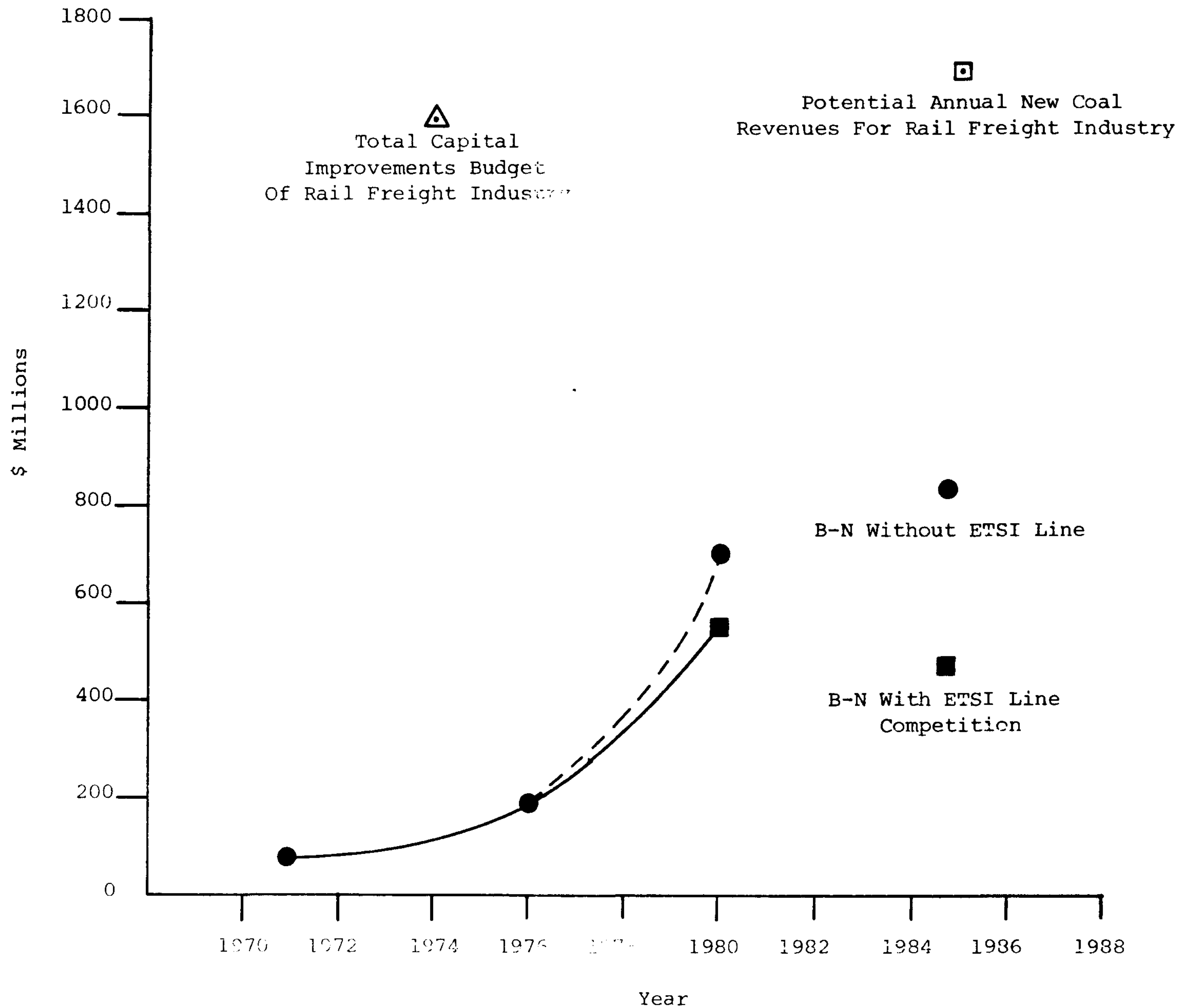
Table 1

Capital Investment for Pipelines

Pipeline	Capacity Million TPY	Length Miles	Capital Investment $Millions	Capital Investment $per ton mile per year
ETSI	25	1000	750	$ 0.03
Wyoming Oregon	10	775	500	$ 0.065

Figure 2

Actual and Projected Coal
Freight Revenues of Burlington Northern
Railroad Compared to Total Rail Freight Industry



million (twice $94 million) in 1975 (Ref. 10), then the ratio of new investment to increased annual revenue is about 450/500 = 1. If this ratio is applied to the $1.7 billion in new coal revenues estimated for 1985 for the entire rail freight industry (Ref. 8), then the new investment required by the industry would be less than $1.7 billion. This estimate is much lower than the University of Illinois estimate (Ref. 11) that an estimated capital outlay of approximately $20 billion by 1985 will be required to triple the volume of coal shipped. The discrepancy may be attributed to the fact that the Burlington Northern tracks are presently underutilitzed and therefore require much less investment per unit increase in revenue than the national average. However, the projection that BN coal revenues could increase to $700 million in 1980 in the absence of pipeline competition, would undoubtedly be accompanied by an increase of their profit margin to levels which would not be possible to maintain in the face of pipeline conpetition. It seems clear that the amount of capital investment to be committed by western railroads and their subsequent tariff rates and profit margins will be substantially affected by plans for slurry pipelines, if and when their construction is implemented. It seems probable that each percent of coal volume "siphoned off" by slurry pipelines will result in more than one percent decreased revenue for effectively competing railroads because of the presence of competition, tending to lower railroad tariffs. However, the revenues and profits of the slurry pipeline industry are expected to remain a small proportion of total coal transportation revenues and profits throught 1985 (volume handled by pipeline will not exceed 20% to 33% of the western coal).

5.0 CONCLUSIONS

1. Coal slurry pipelines are potentially a more economical and environmentally acceptable transportation system than unit trains for certain large capacity long distance routes, generally located in the western U. S., where new railroad lines would be required.

2. Coal slurry pipelines should be considered as an adjunct to, and not a replacement for, existing rail systems, since the capacity of western rail systems must in any case be greatly expanded by 1985. Slurry pipelines could carry 20% to 33% of western coal by 1985.

3. The selection of an optimum transport system from a given coal mining area to one or more potential power generation plants is a very complex problem involving economics, environmental impacts, and socio-economic impacts. There is no one best solution which is generally applicable.

4. Coal slurry pipelines are more inflation proof than rail transport systems.

5. Slurry pipelines require less manpower for operation than rail systems. Therefore, they entail less socio-economic impact along western coal transportation routes (e.g., roads, schools, and private services). The external costs which fall on local and state governments can be reduced by using pipelines wherever economically feasible. The hazard of railroad grade-crossing accidents can be elimated.

6. Slurry pipelines can use electrical power for pumping, whereas present diesel rail systems require petroleum fuel. Unless rail systems are electrified, the pipeline offers a better opportunity to reduce dependence on petroleum imports.

7. The authorization of coal slurry pipelines in the West will tend to limit somewhat the capital investments, revenues, tariffs and profit margins of effectively competing western railroads, but would pose no threat to survival of these railroads, which will generally experience rapid growth of coal freight revenues, assuming the availability of capital for expansion of capacity. The highest estimate of the fraction of western coal to be moved by pipeline in 1985 is the National Academy of Engineering study, which estimated 100 million tons by pipeline out of a total of 300 million in the West (one-third). The Bechtel estimate is 53 million tons out of a national total of 510 million tons (about 10% of the national total or 20% of the western coal).

8. Tariff setting procedures for eastern railroads are unlikely to be significantly affected by the existence of western slurry pipelines. Some increase in eastern coal freight revenues can be expected when and if western low sulfur pipelined coal is available at points near the Mississippi River (e.g. Arkansas).

6.0 RECOMMENDATIONS

1. More detailed studies should be made to identify the relative environmental impact, hazards and socio-economic impact of expansion of coal transport in the West by unit trains (diesel or electric) as compared to slurry pipelines.

2. Regional Planning studies should be conducted to identify an optimum combination of railroad expansion and slurry pipeline systems for transport of western coal which will have the lowest cost/benefit ratio within fixed constraints on the hazards, environmental impacts and socio-economic impacts during the next 10 to 25 years. Attention should be given to the relative benefits and taxation of the operators of railroads and slurry pipelines. Consideration should be given to fair taxation of coal mined on or transported over land originally acquired by federal grant.

3. A study should be made of the economic feasibility of electrifying some of the major western coal freight rail lines as a means for reducing dependence on imported petroleum for diesel fuel. New rail lines may be desirable to be dedicated to coal transport or to provide general transportation to new mining areas.

4. A study should be made of the technical and economic feasibility of establishing one or more regional power systems in which underground hydraulic coal mining of steam coal is integrated with a slurry pipeline and with direct combustion of minimally dewatered slurry at the power generating station. The environmental impact of the system, including effects on air pollution, should be investigated. Potential mining sites in the Uinta coal basin of Colorado or Utah should be considered (see Ref. 13 + 14).

5. A comparison should be established for one sample coal producer-consumer system. This comparison would aid in the identification of factors not yet considered, and would possibly indicate weighting scales for economic, environmental and social consideration in the choice of the best coal transportation method.

7.0 REFERENCES

1. Weiss, W. D. and Dunn, R. H., "Modern Railroad Concepts for Transporting Western Coal", Mining Congress Journal, Vol. 62, No. 10, October 1976 (pp. 39-44)

2. Soo, S. L. and Ballard, L., "Cost of Transportation of Coal: Rail Versus Slurry Pipeline", Appendix F to "The Coal Future: by Rieber, Soo and Stukel, University of Illinois

3. Business Week, "A Railroaders Bad Day at Black Mesa", August 4, 1975

4. Houston Natural Gas Corporation and Rio Grande Industries, Inc., "Slurry Pipelines - Innovation in Energy Transportation", August, 1976

5. Rieber, M., "The Coal Future - Economic and Technological Analysis of Initiatives to Secure Fuel Supply Independence", appendix entitled "Unit Train Transportation of Coal", University of Illinois, 1975

6. Bechtel, Inc. - "Coal Slurry Pipeline, An Enviornmental Answer"

7. Aude, T. C., Thompson, T. L. and Wasp, E. J., "Economics of Slurry Pipeline Systems", May, 1975

8. Washington Post, Business and Finance, "Railroads See Coal Pipelines as Big Threat", December 7, 1975

9. Business Week, "Trying to Scuttle a Coal Pipeline", December 15, 1975, p. 24

10. Wall Street Journal, "The Battle Over Coal Slurry", December 8, 1975

11. Rieber, M., Soo, S. L. and Stukel, J., "The Coal Future - Economic and Technological Analysis of Initiatives and Innovations to Secure Fuel Supply Independence", University of Illinois

12. Chvang, K. D. and Nichols, D. G., "A Cost Model for Coal Slurry Transport", West Virginia University

13. Cooley, W. C., "Survey of Underground Hydraulic Coal Mining Technology", 4 Volumes, Terraspace Inc., report for the U. S. Bureau of Mines (NTIS-PB251492), 1975

14. Nunenkamp, D. C. and Cooley, W. C., "Survey of Coal Preparation Technology for Hydraulic Coal Mines:, Terraspace, Inc., report for U. S. Bureau of Mines (to be published) 1976

15. Coolex, W. C. and Faddick, R. R., "Review of Russian Data on Hydrotransport of Coal", Terraspace Inc., report for U. S. Bureau of Mines (to be published) 1976

16. Traynix, V. V., "Parameters and Modes of Hydrotransport of Coal", Translated from Russian by Terraspace Inc., 1976

17. Montfort, J.G. and Wasp, E.J., "Coal Transportation Economics", May 1974

18. Hudson Institute Report 2409PR, "Research Analysis of Factors Affecting Transportation of Coal by Rail and Slurry Pipeline", April, 1976

19. Bechtel Corporation, "Clean Coal Energy: Source-to-Use Economics, Phase I Report"

20. Parker, N.A., "Federal Energy Administration Memo of January 28, 1976 -- Slurry Pipelines" to Pendley, Robert and Gaffen, Mike

21. Halloran, J.J., Combustion Engineering, Inc. "Coal Slurry Dewatering Equipment Maintenance Developments: Techniques and Costs". Presented at STA Annual Meeting, Houston, Texas, August 24-25, 1976

22. Hale, Don W., Brown & Root, Inc. "Slurry Pipelines in North America Past, Present and Future". Presented at Hydrotransport 4 Conference, Banff, Alberta, Canada, May 20, 1976

23. Snock, P.E., Aude, T.C., and Thompson, T.L., Bechtel, Inc. "Utilization of Pipeline Delivered Coal", Paper at, Hydrotransport 4, Banff, Alberta, Canada, May 1976

24. Cooley, W.C., "Notes of Hydraulic Transport of Coarse Coal in the USSR", May 19, 1976

25. Delyagin, G.N., "Means of Effective Combustion of Wet Fuels in the Form of Slurry Fuel Systems and Prospects for the Creaton of a Fuel and Power Complex (Hydraulic Mine--Dydrotransport Pipeline--and Regional Power Plant)", Novokuznetsk, 1968

26. Ferguson, J.A., "Unit Train Transportation of Coal", University of Illinois, at Urbana - Champaign, May 1975

APPENDIX A

Title: Modern Railroad Concepts for Transporting Western Coal, Mining Congress Journal, October 1976, pp.39-44

Authors: W.D. Weiss and R.H. Dunn

Introduction:

Assumes an increase in rail tonnage of coal from 420 million TPY at present to 800 million TPY in 1985. Some estimates range even higher, predicting rail coal traffic alone to exceed 1 billion TPY by 1985.

The paper summarizes technology of unit trains and stresses electrified unit train systems because of operational and environmental advantages as well as avoiding the uncertainty of future diesel fuel prices.

Conclusions:

Electrification of track requires a high investment in the overhead contact wire system and power supply facilities, the costs ranging from $80,000 to $100,000 per track-mile. However, there are operational savings in locomotive maintenance, replacement and fuel costs. The break-even point (electrical vs. diesel) has variously been estimated at from 10 to 30 million net TPY on typical mainline operation.

Title: "Cost of Transportation of Coal: Rail vs. Slurry Pipeline" (Appendix F to "The Coal Future: Economic and Technological Analysis of Initiatives and Innovations to Secure Fuel Supply Independence", by Michael Reiber, Shao Lee Soo and James Stukel)

Authors: S. L. Soo and L. Ballard, Department of Mechanical and Industrial Engineering, Univeristy of Illinois

Methodologies: Unit Train
Slurry Pipeline
Pneumatic Pipeline

Technology Status:

UNIT TRAIN: Operational, but increased utilization may warrant track upgrading, through new rails and ties, or new tracks and right-of-way.

SLURRY PIPELINE: Two have been constructed; the one from the Consolidated Coal Mine in Cadiz, Ohio, to Cleveland Electric Illuminating Company (108 miles) was built in 1957 and the other that connects Black Mesa Mine in Northeast Arizona to the Mohave Power Plant in Southern Nevada (273 miles). Four others have been proposed.

PNEUMATIC PIPELINE: This would be used in conjunction with rail transportation of coal. While high pressure, long distance pneumatic systems remain to be developed, current technology would allow for short distance pipelines of up to 20 miles. The latter type has been experimentally evaluated.

Costs:

Captial costs based on 25 x 10^6 tons/year:

UNIT TRAINS:

Roadbed: $38.8 k/mi. for minimal track upgrading
$267 k/mi. for new rails and ties
$1,875 k/mi. for new tracks and right-of-way

Equipment: $75 k/mi.

SLURRY PIPELINE:

Total Capital Cost - $944 k/mi.

Conclusions:

Slurry pipeline may have a cost advantage as great as two to one over rail if new railroad must be built.

Water requirements and results of a possible break or loss of power in the case of slurry are unresolved environmental impact problems. Where roadbed is already available, rail cost is only half of slurry, even with elaborate upgrading of railroad.

Railroad could be potentially used for hauling other material on the return trip.

Use of pneumatic pipeline for gathering and distribution in conjunction with rail would make rail transportation more attractive.

Where a railroad is non-existent, and for long distances, a pneumatic pipeline will become competitive with a slurry pipeline.

The slurry pipeline is capital intensive, rail is skilled labor intensive.

Abandoning existing railroad in favor of slurry is not attractive.

Disposal of water containing residue in the slurry process can be a problem.

Title: "A Railroader's Bad Day at Black Mesa"
Business Week, August 4, 1975

Summary:

This article summarizes difficulties encountered in operating the 78 mile Black Mesa and Lake Powell railroad in Arizona.

Conclusions:

1. The 750 pound prestressed concrete ties will be replaced by wooden ties on about a third of the track.
2. The 122 ton capacity coal cars are too heavy and were put up for sale. In the meantime, each is limited to 90 tons.
3. A study recommended adding a second train, sidings for passing and smaller cars, as well as wooden ties.

Title: "Slurry Pipelines - Innovation in Energy Transportation" August 1976

Source: Houston Natural Gas Corporation and Rio Grande Industries, Inc.

Introduction:

This is a survey type paper including comments, questions, and answers. It includes a cost comparison of coal slurry pipelines and unit trains showing lower costs for 1000 mile distance for the pipeline with capacity greater than 6 million TPY.

Energy Transporation Alternatives

There are three basic ways in which coal energy for utility use can be transferred from the sparsely populated western states to the major urban centers where it is needed. They are:

1. Generate electricity at the mine, then send the electrical energy to the consumer via Extra High Voltage (EHV) transmission lines.

2. Transport the coal itself via rail.

3. Transport the coal itself via slurry pipeline.

Among these alternatives, slurry pipelines offer the greatest cost and environmental advantages.

Title: "The Coal Future; Economic and Technological Analysis of Initiatives to Secure Fuel Supply Independence"

Author: Michael Rieber - Center for Advanced Computation, University of Illinois at Urbana, Champaign

Appendix is entitled "Unit Train Transportation of Coal" 1975.

The document is divided into the following nine major sections:

1. Introduction
2. Loading and Unloading Facilities
e. Unit Train Operation
4. Railroad Suitability
5. Illinois Unit Train Model
6. Computer Model for Pricing
7. Unit Train Coordination with Other Transportation Systems
8. Discussion
9. Summary

Assumptions:

The trend in coal usage has been toward large consumers with smaller energy consumers using other more easily transported fuels. By far the largest users of U. S. coal are the electric utilities companies which in 1970 accounted for nearly 60% of the total demand. Obviously, the transportation cost can be lowered significantly by obtaining economies of scale by dealing in large shipments and currently the most common method of moving coal is by rail, accounting for approximately 67% or 376 million tons of the coal mined in 1969. Other less significant modes include truck, barge and slurry pipelines. The unit train is defined as a single purpose train for hauling one commodity, coal, in this example. It is composed of special purpose cars which haul continuously from mine to consumers. The unit train dates back to 1957 when the Reserve Mining Company transported iron ore over a 50 mile private sector of track in Minnesota. Unit coal trains have become significantly refined in the late 1960's and have been improved further. From the beginning the unit train always depended on close cooperation between the Mining Company, the Railroad and the Electric Utility. Typically, long-term contracts were made so that large capital investments can be justified including the unit train itself, in coal handling at both ends of the haul. Unit train operation involves much more than the locomotives and freight cars. Successful operation depends upon usage of equipment so that the train spends as much time on the road as possible. Naturally, high speed loading and unloading facilities and good storage capacity must be installed to supplement this train. A factor which sometimes is ignored in fixing unit train rates is the cost of building and maintaining the railroad. The typical large mine consists of capacity of 2.5 million tons per year and based on a 250 day working year, mine production amounts to 10,000 tons per working day. This is a typical tonnage for a single unit train; thus, at least one day's mine capacity must be stored to load a unit train. Actually, some mines carry as much as 50,000 tons of live storage to meet their varied demands. Unloading times for a unit train is considerably less than the on-loading time. For example, an extremely high speed unloading system fed by the Black Mesa and Lake Power Railroad in Arizona is capable of unloading a 10,000 ton capacity train in twenty minutes. The 83 car train moves through a 360-foot long unloading shed where six, four-door bottom dump cars are unloading simultaneously. Typically, the unit train uses cargo capacity based on 100-ton capacity cars. The train size in terms of length has increased putting further demands on the locomotive power. The one situation which is in need of the most improvement is the condition of railroad tracks and roadbeds. At present, the state of track maintenance is generally only fair. The railroads are failing to uphold present track conditions in most areas. In addition, the railroads are seeking to abandon many delapidated and little used lines to reduce their outlay for track maintenance.

In 1968 the average tie replacement life was 48 years while the rate of rail replacement was 131 years. According to current estimates new rails can be expected to last 60 years and tie replacement every 35 years. It became apparent that even at this rate of tie and rail renewal, the railroads will be badly crippled by the end of the 20th century.

Methodology:

A model of an Illinois unit train is formulted in order to evaluate the economics of railroad lines supplying electric utilities or gasification facilities in the Chicago vicinity. In addition, it is used to formulate and demonstrate a computer model for a general unit train system. The basic assumptions are as follows: six-hundred miles of double track is required; 350 miles of mainline and 250 miles of branch line, a round-trip distance of 500 miles is assumed. The unit trains are assumed to be continuous operation as are the loading and unloading facilities. Train crews remain with the train during loading and unloading as well as during maintenance operations.

Conclusions:

One of the major factors for comparing the cost on a particular mode of transportation for coal is the ton per mile cost. The typical high volume long distance unit trains have transportation costs of approximately 0.6 cents per ton-mile. Large volume coal movements on inland rivers typically cost .25 cents per ton-mile, the average being about 0.3 cents per ton-mile when they are combined. The coal train system, although possibly adequate for today's coal needs, will have to improve significantly in order to meet the upcoming demand for coal as an energy source for alternatives to oil derived energy. Unit trains may probably remain the prime mover of coal, especially over high volume supply lines. In order to be economical in the future energy market, coal must be capable of moving swiftly and in large volume. The biggest difficulty for this desirable outcome is the present condition of the rail line itself.

Title: "Coal Slurry Pipeline - An Environmental Answer"

Author: Bechtel Incorporated, Slurry Pipeline Systems, Fifty Beale Street, San Francisco, California 94105

Assumptions:

The United States has 40% of the world's coal reserves, half of it in western states. This coal will be mined and shipped to processing plants located at great distances from mines.

Methodology:

Coal slurry pipeline

Technology Status:

Black Mesa pipeline operational (273 miles from Northeast Arizona to Southern Nevada)

Costs:

Less vulneralbe to inflation than rail (85% of operating costs are capital-related fixed charges)

Miles per KWH as a function of plant capacity (1000 mile transport distances)

	Electrical Transmission	Slurry Pipeline	Rail @.6¢/ to Mile
2 Million KW	3.5	3.0	3.0
4 Million KW	3.2	2.0	3.0
6 Million KW	3.1	1.5	3.0

Water Availability:

Slurry pipeline use less water than other methods of developing coal fields.

Conclusions:

Low environmental impact (underground)

Non-polluting

Less vulnerable to inflation than rail

Safe - Zero combusibility because coal is mixed with water

Title: "Economics of Slurry Pipeline Systems"

Authors: T. C. Aude, T. L. Thompson, E. J. Wasp, Pipeline Services Division, Bechtel Incorporated, May, 1975

Methodology: Slurry pipeline systems for coal, iron concentrate, copper concentrates and limestone--contains comparisons with rail.

Technology Status:

Technology of long distance pipeline transportation is now advancing from art to science. Sixteen systems are in operation, under construction or being planned; four for coal, five for iron concentrate, three for copper concentrate and four for limestone.

The two major types of equipment for slurry systems are:

1. Carbon steel line pipe with welded joints;

2. Positive displacement pumps--higher pressure capabilities and higher operating efficiency than centrifugal pumps. Current pumps are up to 1750 hp, pumps up to 4000 hp are being considered.

Availability has been 99% for Black Mesa coal slurry system over three years; outages have been due solely to power failure.

Small environmental impact--pipe is three feet underground--no noise.

Pumping stations use electric motors--no effluent gas pollution.

Water used for transportation is clarified and returned to the environment or used as a part of the terminal process or power plant intake.

Slight risk of spills. Spilled material would not endanger the environment.

Energy losses along pipeline are small; for annual throughput of 10 million tons, energy consumed = 2.8% of that transported. For rail - 3.9%, for EHV - 10%, for barge - 3.2%.

Cost:

Tariff (¢/ton-mile) at various values of annual throughput (million tons):

	500 Miles 5 x 10^6 tons	10 x 10^6	15 x 10^6	20 x 10^6
Pipeline	1.3¢/ton-mile	0.95	0.85	0.75
Rail	1.2¢/ton-mile	1.20	1.20	1.20
	1000 Miles 5 x 10^6 tons	**10 x 10^6**	**15 x 10^6**	**20 x 10^6**
Pipeline	1.05¢/ton-mile	0.75	0.63	0.57
Rail	0.97¢/ton-mile	0.97	0.97	0.97
	1500 Miles 5 x 10^6 tons	**10 x 10^6**	**15 x 10^6**	**20 x 10^6**
Pipeline	0.95¢/ton-mile	0.67	0.55	0.48
Rail	0.90¢/ton-mile	0.90	0.90	0.90

Escalation:

Pipeline is more capital intensive, resulting in lower escalation.

Operating Cost Element	Index	Relation to GNP Deflator
Pipeline - Power & Fuel	WPI - Industrial Power	0.7
- Labor	BLS - Transport & Public Utilities	1.5 (Escalation 1.4%/year)*
- Supplies	WPI - Metals & Metal Products	0.9
Rail - Tariff Payments	American Association of Railroads Material Prices & Wage Rates	1.9 (Escalation 7.6%/year)*

* 5% inflation

Conclusion:

Slurry pipeline is economically feasible.

Title: "The Coal Future--Economic and Technological Analysis of Initiatives and Innovations to Secure Fuel Supply Independence"

Authors: Michael Rieber, Shao Lee Soo, James Studel - Center for Advanced Computation, Univeristy of Illinois at Champaign-Urbana

Introduction:

This is a very inclusive document that includes a great many subjects under the general title. The second section, for example, is on Nuclear Power-Fuel Cycle Costs. The third section is on Coal Reserves, Resources and Production, the fourth section is on Coal Transportation, which is the item of interest to this specific task.

Assumptions:

The use of coal has been declining relative to other fuels in almost every area of fuel consumption. Partly, the problem is transportation, air pollution and, in addition, coal in its natural form is the least flexible of all fossil fuels. It is more difficult to extract, transport and handle in consumption than either oil or gas. Further, after combustion, the ash and sulfur residue that remains creates a disposal problem. As a result, coal is used in its natural form only when it is significantly cheaper than other fuels. Moreover, in its natural form, the economies of scale in coal handling are such that only large users find that they can cheaply overcome the cost disadvantages. This explains the concentration of coal use among large consumers of fuel. The principal obstacle to the use of coal involves transportation costs and the sulfur content. Transport costs are high with respect to the price of coal at the pit head. Reduction in transport costs arising from changes in the mode of transport result in a lower cost power supply for coal at the consumption point. Section 4 of this report is concerned with coal transportation. The emphasis in this section is on the cost of distribution rather than the price charged for coal. The analysis includes unit trains, coal slurry pipelines and high pressure pneumatic pipelines. High pressure pneumatic pipelines are included even though they have not yet reached the same commercial stage as the first two because given the enormous increase of coal volume requirements in the near future, reasonable alternatives even in the development stage are important. Unit trains are used as the standard for comparison. An analysis and validation of their costs are presented in Appendix E by John A. Ferguson, entitled: "Unit Train--Transportation of Coal". Comparisons and analyses of unit trains, slurry pipelines and high pressure pneumatic pipelines are contained in Appendix F.

Conclusions:

Findings confirm those made elsewhere that when a new railroad is to be built, even if only 40% of the total distance, a slurry pipeline may have a cost advantage of as much as two to one. However, water requirements and the results of a possible line break or power loss are still unsolved environmental problems. Where a road bed is already available even if the most elaborate upgrading is required to sustain a minimum loaded train speed of 50 miles an hour, the result in transportation cost is roughly one half that of a new slurry pipeline. This result together with the availability of rail for other types of shipment and a further decrease in total coal transport cost if the rail is served by pneumatic pipeline system for gathering and distribution rules out replacing existing railroads by slurry pipelines. Where railroad is non-existent for long distances, a pneumatic pipeline will become competitive with a slurry pipeline. The cost distribution shows that the slurry pipeline is capital intensive while the railroad upgraded to 50 miles per hour loaded remains a skilled labor intensive distribution. For example, if railroad equipment utilizes one half of the steel tonnage of a slurry pipeline further the building of elements of a rail system is labor intensive and therefore contributes to employment in the years to come. Abandoning railroads in favor of a slurry pipeline such as the one proposed for shipment from Wyoming to Arkansas would be a wasteful policy error. The recommendations include indemnification of coal shipping railroads for upgrading and federal expenditures to study the alternative indirect and economic and social impacts. Among the options for coal transportation, existing technology offers the choice of rail (unit trains) and slurry pipelines. Pneumatic pipelines offer another option; however, this technology for the shipment of comparable tonnage is presently incomplete and is more suitable for programs in the long-range future. Among the presently available options are new slurry pipelines and new rails, or upgrading existing rails in various degrees for unit train shipment. The ability to double or triple the amounts of coal shipped must be found. An estimated capital outlay of approximately 20 billion dollars by 1985 will be required. The tripling of the coal shipped is not expected to be uniform. For example, coal gasification might take 30 to 40 percent and regional concentration is expected. Alternatively, the estimated 50/50 distribution of surface and underground mine production might be altered. The unit train computer model was tested against the real world for one particular unit train contract. An average of 0.68 cents per ton-mile is in line with the cost of 0.52 cents per ton-mile based on our computer modeling.

Title: "A Cost Model for Coal Slurry Transport"

Author: K. C. Chvang & D. G. Nichols, Department of Chemical Engineering, West Virginia University

Assumptions:

Water Cost	=	$	.75/1000 gal.
Electricity Cost	=		.0182/KW-HR
Maintenance & Repairs	=		.0142 Capital Investment
Overhead	=		.003 Capital Investment
Operating Labor	=		.009 Capital Investment
Other Utilities	=		.015 Captial Investment
Insurance & Taxes	=		.0158 Capital Investment

The costs as a function of capital investment are assumed to follow the same relationships for coal slurry as for other slurry systems.

Methodology:

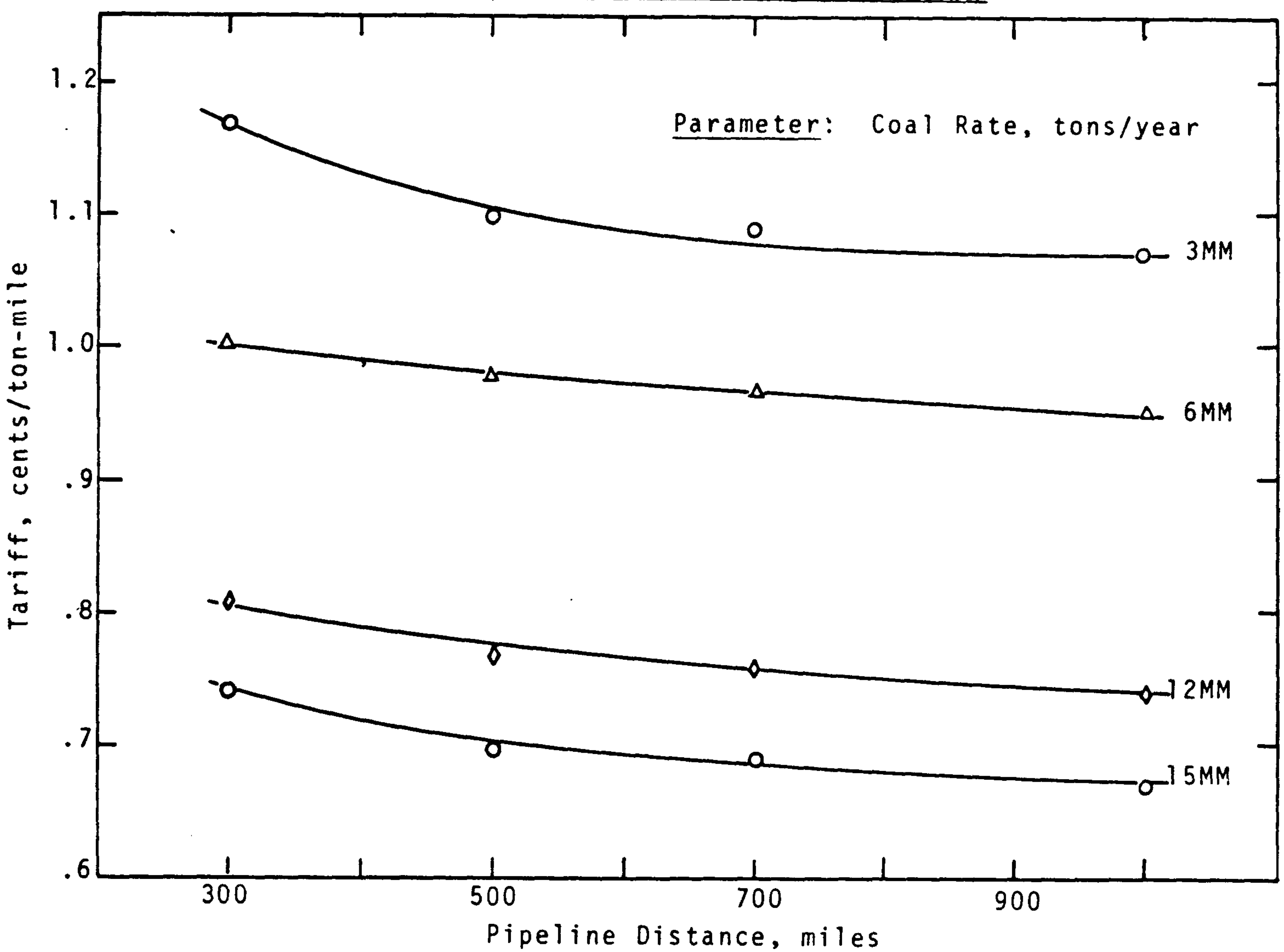
Regression analyses are used on the following data:

Pipeline	Large project pipeline costs as a function of pipe diameter.
Pumping Stations	Manufacturers quotes and data from existing coal slurry installations. Capital costs are amortized over 25 years on the basis of straight line depreciation and zero salvage value. Tariff was set to yield 15% return on investment.

Conclusions:

It is feasible to provide reliable cost estimates of coal slurry systems during the design stage of the project. The attached figure showing a reduction in tariff (cents/ton-mile) with increasing coal rate.

TRANSPORTATION COST FOR COAL-SLURRY



Highly automated - minimum labor force required

High line efficiency - only small amount of coal's energy is absorbed in the transportation process.

Title: "Parameters and Modes of Hydraulic Transport of Coal by Pipelines"
Published in Russian by NAVKA Press, Moscow, 1970;
Translated by Terraspace Inc.
304 N. Stonestreet Avenue
Rockville, Maryland March 1976

Author: V.V. Traynis

Introduction:

This 191 page book has 6 chapters which summarize extensive Soviet experimental research on coal slurry transport.

Conclusions:

If it is necessary, in addition to the coal suspension, to produce still coarser coal for a consumer, the size of the lump coal immersed in the suspension can be increased to 6-25 mm. In this mode, at the end of the pipeline this coal is separated from the suspension on ordinary vibration type dewatering screens and the lump coal is delivered to its consumer. As was noted earlier, technical and economic calculations have shown that the transportation of coal suspensions through pipelines yields a savings when pipeline complexes including hydraulic mining, preparation of the suspension or slurry, transportation through the pipeline and, finally, combustion at the electric power plant, are constructed. The use of such complexes allows the cost of 1 kw.hr produced by the electric power plant to be reduced by up to 20-30%.

The analysis of various versions of transportation of coal suspensions from the richest deposits of power coal in eastern Siberia and northern Kazakhstan to electric power plants in the Urals and Central Russia would also be a worthy project. For example, to cover the shortage of fuel at operating electric power plants in the Urals, resulting from the exhaustion of local coal deposits in the next few years, an annual volume of rail transportation of tens of millions of tons of coal from the great open pit mines of northern Kazakhstan over a distance of many hundreds of kilometers is planned. Under these conditions, the use of hydraulic transportation of the coal would yield a significant savings.

Until recently, the area of application of hydraulic transport of coal was limited only to transport within a mine during working of coal deposits by hydromechanization.

At present, hydraulic transport is beginning to be used for external transportation between fuel producing and fuel consuming enterprises. This is facilitated by the enlargement of the enterprises and the resulting flow of coal in constant directions, by the difficulties related to the use of massive transportation of coal by the railroads of the country, by the development of technological processes involved in the conversion and utilization of wet coal (beneficiation, combustion of wet coal or even water-coal suspensions).

Plan development and the experience of operation of the first long main line coal pipelines have shown that this type of continuous transportation can compete successfully with railroad transport -- the traditional form of transportation of massive cargo.

The problem of economical transportation of coal over long distances if one of particular interest for our country, since the primary promising regions of deposition of coal are separated from regions of its consumption by many hundreds of kilometers.

However, the transportation of coal through main pipelines has not yet been fully developed due to the insufficient study given the process of hydraulic transportation of coal.

This work has attempted to further the development of the scientific principles of this type of transportation to allow development of recommendations for the calculation and selection of parameters and modes of hydraulic transportation of coal through pipes.

The basic problems arising in the calculation of the hydrotransport of lump and run-of-mine coal through pipes in a turbulent stream of water and resulting from the interaction of the coal transported with the walls of the pipe (determination of hydraulic drag, grinding of coal and hydroabrasive wear of the pipe) have been studied.

The basic method of study of the hydraulic transportation of solids continues to be the experimental method, a result of the complexity of the processes occurring. The performance of experimental investigations, in addition to the use of the usual experimental installations with horizontal pipes, has included the use of the wheel stand. Imitating the process of movement of lump materials through pipes, this stand simplifies the conduct of experimental investigations of hydrotransport. This has allowed the production of extensive experimental material on the influence of various parameters on the hydraulic drag, grinding of coal and hydroabrasive wear of the pipe being studied and has allowed a detailed study of the changes in these parameters over the length of a large pipeline.

Summarization of the experimental material on hydraulic drag and critcal speeds during the transport of lump and run-of-mine coal have allowed calculation formulas (I.18) and (I.23) to be produced, which correspond rather well with the experimental data.

In the development of calculation recommendations for the determination of the expected crushing of coal during hydro-transport through pipes of significant length, the task arises of determining the yield of all size fractions of the coal, not only the change in the weighted mean diameter of the particles transported, as had earlier been done. With this method, attention was given to the study of the formation of the finer fractions in the pipe, beneficiation and dewatering of which represent significant difficulties.

The investigation of the influence of hydraulic and technological parameters on hydroabrasive wear of a pipe has shown, as would be expected, qualitatively the same regularities as in the study of the influence of these parameters on crushing of the coal. The change in hydroabrasive wear over the length of the pipe was also studied, allowing selection of the thickness of the walls of a main pipeline so that it will be equally strong over its entire length.

Studies are performed on the parameters and modes of transportation of finely dispersed, highly concentrated water-coal suspensions and the transportation of lump coal in them.

The development of the problem of direct combustion of these suspensions makes their transportation through main pipelines from the point of mining of the coal to thermal electric power plants promising. Coal suspensions can be used as carrier media for hydraulic transportation of lump coal. The movement of this coal in the suspended state in the structured core of a stream of viscous-plastic suspension allows the interaction of the lump coal being moved with the walls of the pipe to be reduced, thus decreasing the hydraulic drag, crushing of coal and wear of the walls of the pipe in comparison to the transportation of this same coal in a turbulent stream of water.

The studies have shown that finely dispersed, highly concentrated coal suspensions have the combined rheological properties of both fluids and solids. At high shear speeds, characteristic for the operating modes of transportation of coal suspensions through pipelines, these suspensions have the viscous-plastic properties of non-Newtonian systems; at lower shear speeds, coal suspensions take on more complex rheological properties, characteristic for non-Newtonian systems with unstable properties. Having plastic properties, coal suspensions can hold in the suspended state heavier lumps of coal, even when at rest. This fact completely eliminates the danger of plugging of coal pipelines in case of an emergency shutdown and makes it possible to store such slurries in containers without the danger of separation of the slurry into solid and liquid layers.

Analysis of the experiments performed in pipes of many diameters has allowed recommendations to be given for the calculation and selection of parameters and modes of transportation of coal suspensions and the transport of lump coal in them.

The investigations performed, naturally, do not exhaust the possibilities of further study of the problems in question, but rather demonstrate that further study of these problems should most expediently be undertaken in the following directions:

The study of the peculiarities of motion of slurries of run-of-mine coal with high concentrations (30-50%) through pipelines in transtion modes, falling in the intermediate area between trubulent and structured modes;

The study of the process of the interaction of run-of-mine coal being transported both with the walls of the pipe, leading to crushing of the coal and hydroabrasive wear of these walls, and the interaction of lump fractions of coal with finer fractions, leading to more intensive wear of the finer fracttions;

The study of viscous-plastic flow modes and th rheological properties of finely dispersed coal suspensions and the transportation of lump coal in them in order to clarify the calculation recommendations for determination of the transportation parameters;

The search for inexpensive, effective stabilizer reagents, as well as other means of acting on the structure of highly concentrated coal suspensions (ultrasound, magnetic fields), allowing the strength of the structure to be reduced, thus decreasing the power consumption of transportation;

And the selection of optimal parameters for transportation, assuring the minimum adjusted cost for the entire installation, including the preparation of the slurry and transportation through the pipeline, as well as subsequent utilization of the coal.

Title: "Research Analysis of Factors Affecting Transportation of Coal by Rail and Slurry Pipeline"

Author: Hudson Institute Report 2409PR, dated April, 1976

Introduction:

Hudson Institute, located in the state of New York, is a non-profit corporation serving the public interest. The Institute is independent and its function is to meet the growing needs for reserach and analysis. The Hudson Institute received a grant to study the factors affecting transportation of coal from the Burlington Northern, Inc. The authors have assembled a definitive work on transportation of coal both by rail and slurry pipeline. The report is quite complete and it is indeed a definitive work on the subject at hand. In Section I, the research is introduced. Section II describes the various systems and transport cost estimates. Section II is socio-economic considerations and Section IV is summary and conclusions. Under Summary and Conclusions, there is an indication that there is a divergence of thought regarding the viability of slurry pipelines as an alternative to railroads for the movement of coal.

Assumptions:

The issue of which transportation system moves commodities or indeed survives in severe competition is normally a question of price and product. Proper economic theories suggest that when a new industry comes into being which is more competitive than an existing institution, constructive desctruction should be allowed to take place. All people are, or should be, sensitive to the possibility of lower produced power costs to users. It means more affordable services to the residential customer and a more competitive position for the industrial user.

Socio-economic considerations enter the cost-benefit analysis when determining the true cost and valid preference for one system over another. Discussions of socio-economic factors have a tendency to be tedious and to some people they seem to make the problem unduly complex. However, it is through these that the welfare of the average citizen can be related to the effects of a policy decision. Recent history on a multitude of transportation, energy, resource and environmental issues points up the necessity of such discussions, the need for careful evaluation of all factors before making possible irreversible decisions.

Conclusions:

DIRECT COSTS: In the judgment of the authors, the arguments are not compelling that pipelines can consistently deliver steam coal more cheaply than a unit train operation, particularly if possible technological improvements, increased capacity and increased labor efficiency of unit trains are considered. The authors are skeptical of the projected pipeline tariffs advanced by some slurry proponents, and are also skeptical of those suggested by some largely theoretical engineering studies. The authors endorse the statement, "No single comprehensive theory is available now to deal with the relative cost differences associated with the capacity of slurry lines". Uncertainties associated with pipeline proposals are such that it cannot be stated which system is superior on a straight performance basis. The authors are also more comfortable with the economics associated with railroad operations, which are much better known.

The pipeline case is constrained by lack of complete financial data for most of the suggested major lines and, since pipelines are capital intensive systems, the financial ground rules assumed for each case can contribute heavily to the suggested tariff rates. This may be the cause of differences of opinion with regard to ton-mile charges.

The externals of gathering, distribution and allocation would appear to add substantially to the slurry transportation costs. Operational problems may be exacerbated when one relatively unflexible pipeline serves many plants which have varying loads. It may be that slurry pipelines systems have their best economy when handling 5 to 10 million tons per year to one or two major power plant sites. Anything larger may have the tendency to turn the curve associated with increased economy of scale upward, reflecting the externatlities mentioned above.

The conclusion of the studies is as follows: Examination of existing data indicating the direct effects of slurry pipelines on future coal tariff rates shows no compelling reason for their construction in the presence of an existing rail system. On a case by case basis, there could be exceptions. There appear to be so many potential problems raised on the broad socio-economic area which do not resolve in favor of the proposed new duplicate system. We feel the argument against proceeding with construction of the slurry lines at this time is strengthened. Further studies should be undertaken to help clarify where the public good lies. Such studies may prove that this new duplicate specialized carry will produce direct or indirect good for the communities it services. This is despite its competition with the existing common carrier.

Comments on the Document:

This is a most impressive document.

Title: "Clean Coal Energy: Source-to-Use Economics, Phase I Report"

Author: Bechtel Corporation, Fifty Beale Street, San Francisco, California

Methodology:

Conventional rail, unit train, barge, ship and slurry pipeline are addressed for coal transportation. Electrical high voltage transmission data are provided to allow comparison with this alternative mode of energy transfer.

Technology Status:

All modes shown above are operational.

In 1971, the distribution of modes of transportation of bituminous coal was as follows:

Rail (all types)	52.8%
River	19.6%
Great Lakes Carriers	8.6%
Tidewater	1.6%
Truck	12.6%
Tramway, conveyor and private railroad	4.8%

Costs:

In 1971 cost of rail shipment for coal was \$3.70/ton; production cost was \$7.07; total cost of coal delivered by rail was \$10.77/ton. Therefore, rail transportation accounted for 34% of the total cost.

Conventional Rail:

$$C = 142.04D^{-0.418}$$

where,

C = Conventional rail transport rate in 1972 dollars (mills/ton - mile)

D = Short-line rail distance (miles)

Rail Rates for Conventional Shipments
Western Trunk Line Territory
1972

One Way Distance Interval (miles)	One Way Average Mileage (miles)	Average Rate (mills per ton-mile)	No. of Waybill Data Samples
0-100	75.07	27.18	43
100-200	123.33	13.15	319
200-300	242.92	16.33	65
300-400	331.59	11.04	189
400-500	448.56	14.43	34
500-600	551.46	11.06	146
600-700	634.51	10.90	35
700-800	756.86	9.99	7
800-900	888.00	6.52	9
900-1000	920.00	11.20	1
1000-1100	-	-	-
1100-1200	1165.00	6.55	28

Source: 1972 Carload Waybill Statistics, F.R.A.

UNIT TRAINS:

$C = 122.45D^{-0.391}$ where

C = Unit train rate in 1974 dollars (mills/ton-mile)

D = Short-line rail distance (miles)

Rail Rates for Unit Trains
Western Railroads - 1974

One-Way Distance (miles)	Rate (mills/ton-mile)
100	20
200	16
300	13
400	12
500	11
600	10

One-Way Distance (miles)	Rate (mills/ton-mile)
800	9
1000	8
1500	7

BARGE TRANSPORTATION:

$C = 20.93\ D^{-0.285}$ where

C = Barge transportation rate in 1970 dollars (mills/ton-mile)

D = One-way barge distance (miles)

In addition, a charge of 40 cents per ton was included for all barge/rail or rail/barge transfers.

Barge Transportation Rates - 1970
(Mills/Ton-Mile)

One-Way Distance (miles)	Rate (mills/ton-mile)
50	7.0
100	5.2
200	4.2
300	3.8
400	3.6
500	3.5

Great Lakes Carriers:

Great Lakes Coal Transport Rates
June 1974

Origin to Destination Shipment	Rate ($/ton)
Erie to Superior	1.82
Erie to Milwaukee	2.20
Erie to Michigan (north of Milwaukee)	2.06

SLURRY PIPELINES:

$$Cf = 0.73\ (GNP) - 10.48/T + 1.69 + (GNP)/T - 16.84$$

$$Cv = 0.015\ (GNP) - 0.627/T + 0.0259\ (GNP)/T - 0.0415$$

where

Cf = Fixed unit transport cost (capital charge plus operating cost) in cents per ton

Cv = Variable unit transport cost (capital charge plus operating costs) in cents per ton-mile

GNP = Gross National Product implicity price deflator index:

July 1971	141.6
July 1972	146.1
July 1973	153.9
July 1974	(181.4 - projected)

T = Capacity in million tons delivered coal/year

ELECTRIC TRANSMISSION:

$$C = 5.55 - 0.731 \ln (V)$$ where

C = Transmission cost-circa 1970 (mills/KWHr/200 miles)

V = Line Voltage (kV)

Electric Transmission Costs for Various Line Voltages and Line Loadings

Line Voltage (kV)	Line Loading (10^3 MW)	Cost (mills/KWHr/ 200 miles)*
230	0.1 - 0.4	1.65
345	0.3 - 1.0	1.20
500	0.8 - 1.8	0.95
765	0.8 - 4.0	0.76

* Cost data are only representative of lowest cost line load.

Source: The 1970 National Power Survey, Part I, EPC

Title: "Federal Energy Administration Memo of January 28, 1976--Slurry Pipelines" to Robert Pendley and Mike Gaffen

Author: N. A. Parker

Methodology: Slurry pipelines--comparison with rail, truck, conveyor. Water requirements compared with mine-mouth power plant and coal conversion.

Technology Status:

108 mile system from Cadiz, Ohio to Cleveland (10 in. diameter line). Began in 1957, operated six years with 98% availability, handling 1.2 million tons/year. No longer in operation.

273 mile Black Mesa line from Northeast Arizona (Black Mesa Coal Mine) to generating station near Bullhead City, Nevada. Availability to date = 99%. Still in operation.

Planned 1030 mile line carrying 25 million tons per year from Gillette, Wyoming to White Bluff, Arkansas.

Transportation Costs:

Cost comparison for solid volumes of 2 million to 6 million tons per year.

Carrier	Cost in Cents per Ton-Mile	Conditions
Slurry Pipeline	0.3 - 0.7	Over 50 miles
Rail	0.4 - 0.9	Unit train, over 400 miles
Truck	5.0 - 8.0	One-way haul, empty return
Conveyor Belt	2.0 - 2.6	Less and 0.5 miles

Transport costs (1 trillion Btu per day movement over a distance of 1000 miles).

Fuel	Cents/mm Btu/Day (100 miles)
Oil	0.8
Gas	2.0
Coal Slurry	2.4

Fuel Fuel	Cents/mm Btu/Day (100 miles)
Rail (0.6 cents per ton-mile plus 10% greater distance	4.0

Source: Oil and Gas Journal, December 24, 1973, p. 44-50

Estimate by Slurry Transport Association (April 1975)--25 million tons of coal per year over 1036 miles plus an extension carrying 12.5 million tons of coal per year over 140 miles.

Average delivered cost over 30 years:

Pipeline	$7.90/ton
Rail	$28.50/ton

Estimated savings in transport = $14 billion

From Hearing before Subcommittee on Minerals, Materials and Fuels of the Committee on Interior and Insular Affairs, United States Senate, June 11, 1974:

Cost per hundred miles is 2.5¢/million Btu for unit train carrying 3 million tons/year of coal.

3.8¢/million Btu for slurry pipeline carrying 5 million tons/year

Latter should be reduced to 1.3¢/million Btu when volume reaches 25 million tons/year

Conclusions:

Slurry pipelines should be recommended as an adjunct to existing rail transportation rather than replace it. The pipelines are more cost-effective than building new railroad lines.

Title: "Coal Slurry Dewatering Equipment Maintenance Developments: Techniques and Costs" Presented at STA Annual Meeting, Houston, Texas, August 24-25, 1976

Author: J.J. Halloran, Combustion Engineering, Inc.

Summary:

Discusses maintenance of Dynacone centrifuges at the Mojave Generating Station, Southpoint, Nevada for dewatering coal from the Black Mesa pipeline. Direct shop costs for maintenance are 10.7 cents per tons of coal cake, assuming unit operation at 25 tons per hour of cake discharge. The overall cost including installation and removal amounts to 11.1 cents per ton of cake. These figures will be approximately 10% lower for centrifuges used in storage-type systems where operation is at atmospheric pressure.

Title: "Slurry Pipelines in North America Past, Present and Future"

Author: Don W. Hale, Brown & Root, Inc.)Presented at Hydrotransport 4 Conference) Banff, Alberta, Canada, May 20, 1976

Introduction:

This paper summarizes coal slurry pipeline history and proposed slurry lines in the U.S. including:

1. Nevada power line - from southern Utah to Las Vegas
2. Northwest pipeline - Wyoming to Oregon
3. ETSI line - Wyoming to White Bluff, Arkansas
4. WYTEX line - Montana and Wyoming to Houston
5. Houston Natural Gas Co. line - New Mexico and Colorado to Texas near Houston
6. Salt River System - Star Lake, New Mexico to St. Johns, Arizona

A list is presented of the factors which have convinced sponsors and customers of the economic attractiveness of the projects. A projection of western coal supply and demand is presented through 1985, as well as natural gas consumption in Texas which is to be phased out by 1985 for boilers consuming in excess of 100,000 standard CFD.

Beyond these operating considerations, however, are the basic issues of community development in the western states. Mining and pipeline operations are capital intensive and thus involve relatively small operating crews. But some of the other methods proposed for using western coal - mine-mouth power plants and coal conversion plants - would involve large work forces. Even a relatively small increase in the work force in the sparsely populated western states could have a serious impact on local communities and their style of life.

Title: "Utilization of Pipeline Delivered Coal"
Paper El, Hydrotransport 4, Banff, Alberta
Canada, May 1976

Authors: P. E. Snock, T. C. Aude and T. L. Thompson, Bechtel, Inc.

Introduction:

The main relevant impact of this paper is to stress the need to provide dry storage for pipelined coal to permit decoupling of the pipeline from the power plant. Control of moisture of the dewatered coal permits rail coal handling procedures to be applied and would allow use of pipelined coal in existing power plants.

Conclusions:

(A) Utilization of pipeline delivered coal today can be considered comparable to the coal preparation and transportation phases; that is, an operation based on proven technology. Substantial operating experience exists, both at the commercial and pilot plant level.

(B) For the near future, pipeline delivered coal will be utilized primarily in pulverized coal firing systems. Air pollution NO_x regulations limit the application of direct slurry injection in cyclone furnaces.

(C) Pulverized coal firing requires removal of the surface moisture before the fuel is injected into the furnace. Continued emphasis will be placed on improving dewatering techniques. The use of heat in conjunction with screen bowl centrifuges and horizontal belt filters appears particularly promising. In some situations it may be possible to eliminate the need for thermal drying. This would lead to a significant reduction in the total cost of utilization.

(D) Utilization systems should be designed to operate independently from the power generation step. This allows the equipment to be sized for an economic continuous rate rather than peak demand.

(E) Careful control of the dewatered pipeline product moisture allows conventional rail coal handling procedures to be applied. This opens the door to utilization of pipeline delivered coal in existing power plants.

Title: "Notes of Hydraulic Transport of Coarse Coal in the USSR"

Author: W. C. Cooley (May 19, 1976)

On May 18, 1976, a group of Canadians and American met with Mr. G. V. Zhdanovich, President of the all-union association "Soyuztransprogress"; Mr. A. Y. Kodentzov, Deputy Director of the "Ukrniigidrougol" (the Ukranian Hydraulic Coal Mining Institute at Voroshilovobrad in the Donetsk Coal Basin) and with an interpreter, Mrs. Tanya Aydeeva.

Mr. Zhdanovich is responsible for projects on pneumatic, hydraulic and capsule transport for long distances.

Mr. Kodentzov reported that there are two hydraulic coarse coal pipelines in the Kuznetz Coal Basin which have been operating since 1966. One is 10 km long and supplies steam coal from a hydromine to a power station at Belovo. Its capacity is 1.5 million metric tons per year. The second system (at Novokuznetsk) supplies metallurgial coal from a hydromine a distance of 11 km through a 350 mm pipe at 4 million TPY to a preparation plant. Coal size is 0 to 100 mm with one pumping station and a flow rate of 2000 m^3/hour. The coal to water ratio is 1 to 3 (25% concentration by weight). The velocity of the slurry is 2.5 to 3 m/second. The pipelines are on the surface and there are two coal pipelines (one operating and one standby) with a third pipe to return water to the mine.

On May 19, 1976, in response to my question, Mr. Kodentzov stated that plans are now being made for a coarse coal pipeline of 42 km length with two pump stations which will transport steam coal from the Orzhonikidzeugol No. 4 hydromine to a power plant. The return line will carry fly ash from the power plant to be used for hydraulic stowing underground in the mine. The entire mine, pipeline and power plant will not begin operation before 1980. It is located in the Donetsk Coal Basin near Voroshilovograd.

The addresses of the two Russians are:

A. Y. Kodentzov
Deputy Director
UKRNIIGIDROUGOL
Vorochilovograd
Ul. Oboronnoy, 34
USSR

Mr. Zhdanovich, President
Ministry of Oil and Gas Construction
Soyuztransprogress
Kirova Street, 13
Moscow USSR

Title: "Means of Effective Combustion of Wet Fuels in the Form of Slurry Fuel Systems and Prospects for the Creation of a Fuel and Power Complex (Hydraulic Mine--Hydrotransport Pipeline--and Regional Power Plant)"

Published in Russian, Novokuznetsk, 1968; Translated by Terraspace, Inc., 304 North Stonestreet Avenue, Rockville, Maryland; January 1976

Authors: G. N. Delyagin, et al

Introduction:

This Russian report of 1968 deals with direct combustion of coal slurry from pipelines in boilers. It discusses the advantages of using wet coal in lowering ignition temperature and increasing combustion rate in a boiler. Although lowering the heating value, it can increase the combustion efficiency.

The paper summarizes the results of a planning and cost study on four variants for supplying steam coal from a mine near Lugansk, a distance of about 400 kilometers (250 miles) to a 16 MW power platn near Nikopol in the Ukraine. Two variants used rail transport and two used slurry pipelines.

Conclusions:

The most economical system used underground hydraulic mining, a slurry pipeline and direct combustion of slurry at the power plant. The savings are at the mine and the power plant. The costs of the pipeline are somewhat higher than the additional cost for rail transport, but it allows a decrease in utilization of the railroad and avoids losses of fine coal during rail transport in open cars at high speeds.

The preferred variant allows a 34% reduction in manpower requirements and a reduction in capital investment for housing. The two variants using rail transport would require capital investments of 2.2% or 12.02% greater than for the preferred variant, taking in to account production, housing and social construction projects. It is concluded that the preferred variant can reduce the cost per Kilowatt-hour for the 1600 MW system by almost 10% in comparison to powder-phase combustion of coal mined by conventional mechanical methods and using rail transport. The annual savings are estimated to be 12.33 million rubles (about $9.5 million).

It should be noted that these comparisons are based on Russian economic comparisons and 1968 costs. However, they point out the need to consider overall costs of mining, transportation, electrical power generation and social construction costs in comparing slurry pipeline and rail transport systems.

In this report, there is no mention of air pollution NO_x limitations on direct slurry injection into cyclone furnaces (as referred to by Snoek, Aude and Thompson, Hydrotransport 4, Paper E1).

Title: "Coal Transportation Economics"

Author: J. G. Montfort and E. J. Wasp, May 1974

Assumptions:

Water and right-of-way are readily available for slurry pipelines. Rail transport is susceptible to inflation (i. e. labor intensive). Slurry transport relatively immune to inflation. Unit rail system now exists.

Conclusions:

Slurry transport has been proven technically and economically feasible. At volumes above 20 MM tons/year pipeline is cheaper.