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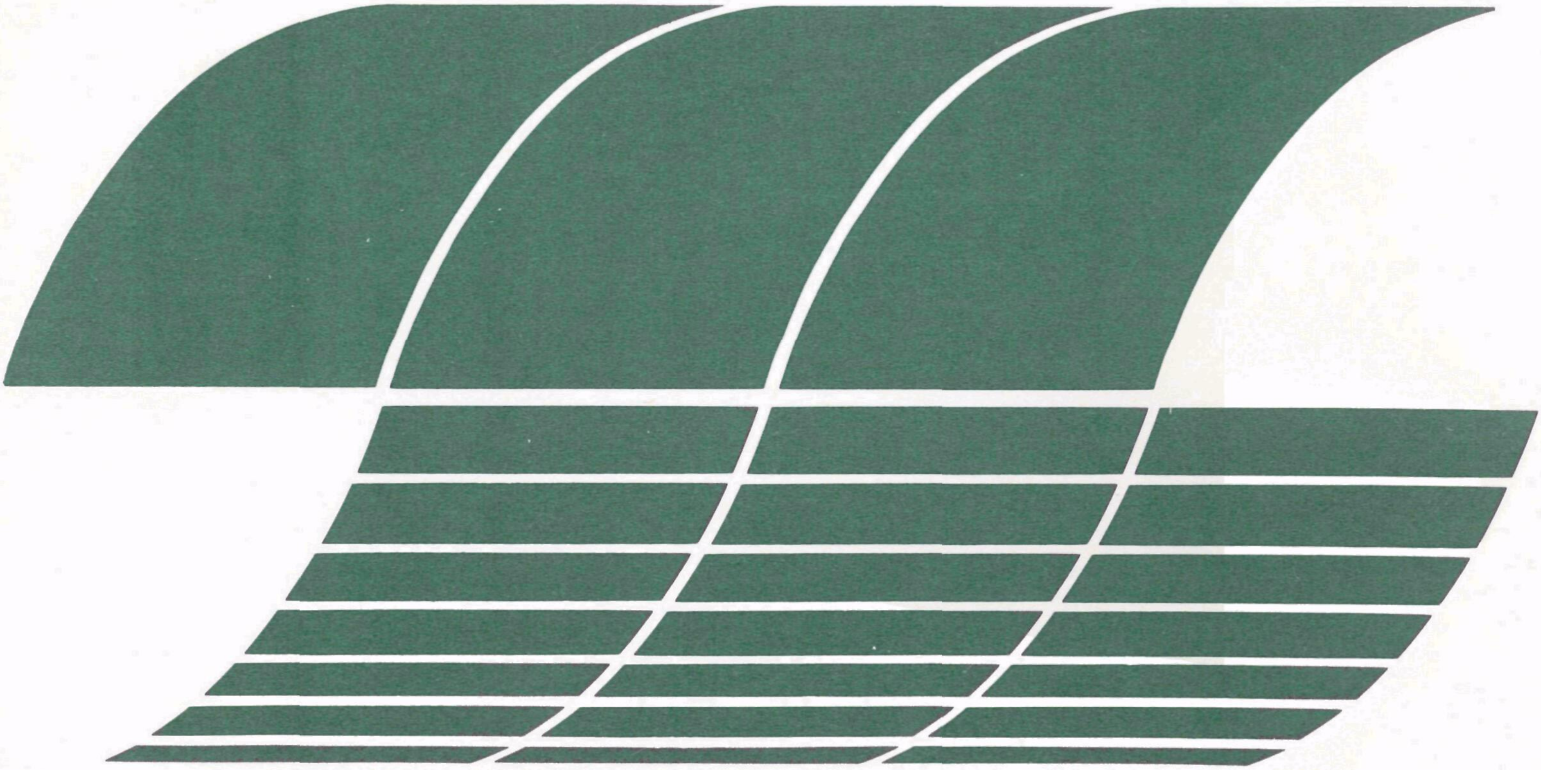
Research and Development

Environmental Assessment of Coal Transportation

Interagency Energy/Environment R&D Program Report



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May 1978

ENVIRONMENTAL ASSESSMENT OF
COAL TRANSPORTATION

by

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Contract No. 68-02-1321

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-CI) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report deals with primary and secondary environmental impacts resulting from transportation of coal by slurry pipeline, railroad, barge, truck, and conveyor. The information developed herein characterizes the pollution problems and thus becomes important as a planning and design tool for transportation systems. Agencies involved in energy systems planning, and individuals conducting research in the areas of coal mining and coal movement and utilization should find this publication to be of value. For further information contact the Resource Extraction and Handling Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
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ABSTRACT

As a result of an increase in U.S. coal production to help achieve energy independence, much attention is being focused on regional-scale transportion of coal in volumes projected to reach 1.32 billion metric tons (1.2 billion tons) in 1985. Most transportation studies to date have centered on economics. Equally important, however, are the possible environmental impacts due to both normal operation and catastrophic events associated with preparation and transportation of coal.

Work described herein deals with (1) primary and secondary environmental impacts resulting from transportation of coal by slurry pipeline, railroad, barge, truck, and conveyor; (2) coal preparation and associated activities, such as loading and unloading, and (3) energy efficiencies of the transport modes. Many of the environmental impacts can be lessened by improvements in control technology; most of these impacts are not critical in terms of health and welfare; some, however, such as toxic properties of effluents from coal preparation plants, storage piles, and slurry lines, need further characterization. Dewatering and treatment of coal fines from slurry lines are troublesome aspects of slurry line operation. Emergency procedures in the event of breakage of slurry lines must be better defined. Other factors critical to the future of slurry lines are availability of water in the semi-arid western states and eminent domain legislation. Uses of energy associated with the transport modes should receive consideration in planning of coal transportation systems.

This report is submitted in fulfillment of Task 40 under Contract 68-02-1321 by PEDCo Environmental, Inc., under the sponsorship of the U.S. Environmental Protection Agency. The report covers a period from February 1976 through December 1976, and work was completed as of November 1977.

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ACKNOWLEDGMENT

This report was prepared for the Industrial Environmental Research Laboratory (IERL), U.S. Environmental Protection Agency, by PEDCo Environmental, Inc., Cincinnati, Ohio. The project director was Mr. Timothy W. Devitt; the project manager and author was Mr. Michael F. Szabo. Principal investigators were Messrs. Jim Burke, Charles Hewitt, Thomas Janszen, Michael Szabo, and Edward Zawadski.

The author appreciates the assistance and cooperation provided by Mr. Martin, Mr. J.G. Montfort, President, Black Mesa Pipeline Company, Flagstaff, Arizona, and Mr. M.L. Dina, Plant Engineer, Mojave Generating Station, Southern California Edison Company.

SECTION 1

INTRODUCTION

The purpose of this project is to identify the potential environmental impacts associated with coal transportation and the methods available or potentially feasible for controlling or reducing the impacts. Where the available methods are inadequate for control, PEDCo recommends research and development programs aimed at developing effective control systems.

Coal is extracted by surface or underground mining. It then undergoes some type of preparation, such as crushing and/or cleaning, before delivery to the consumer. The extent of preparation is determined by the quality of the coal as mined, the quality desired by the consumer, and the mode of transport. If the coal is to be transported by slurry pipeline, for example, preparation may be much more extensive than if it is to be shipped by train. Section 2 discusses specifications of U.S. coals, mining technology, coal preparation, and end use of coal.

The mode of coal transportation is often dictated by physical conditions such as terrain, climate, water resources, navigabilty of waterways, road conditions, and distance of transport. Railroads carry most of the coal that is transported over long distances (>160 km (>100 miles)); barges carry the second largest quantities over long distances. Although coal slurry pipelines are capable of long-distance transport, only one pipeline is now operating. Trucks, conveyor belts, and pneumatic pipelines are functional over relatively short distances. Trucks are the major haulers over short distances because of their versatility and the widespread availability of public roads. Use of conveyor belts is increasing greatly because of recently developed technology, such as eddy-current clutches that control motor speed and torque to maintain proper belt tension over long distances. Use of pneumatic pipelines may increase as the technology advances.

Cost is another major factor determining transport mode. If, for example, a railroad right-of-way now runs from near the mine mouth to the consumer area, transport by rail probably will be less expensive than construction and operation of a slurry pipeline. Without an existing railroad right-of-way, however, operation of the pipeline may be cheaper. Lastly, energy use affects the choice of transport mode. Comparisons of energy use should be based on energy demands of the total system that moves the coal, not on the demands of the transport portion alone. Section 3 describes the several modes of coal transport, changes in use of these modes over the past 25 years, and their costs and energy requirements.

Each method of mining, preparation, and transportation of coal causes impacts upon the environment that vary in intensity and duration. These impacts occur during construction, operation, and abandonment of the systems. Often these impacts can be minimized or even eliminated by proper precautions. Section 4 discusses the environmental impacts of coal preparation and transport and the available control technology.

Most of the environmental impacts of coal transport can be mitigated. Some of them, however, are as yet undefined, such as the toxic properties of coal slurries and of runoff from coal storage piles. Section 5 concerns the impacts of each transport mode for which the current control methods are inadequate, the major areas of needed information, and priorities for research and development.

There is currently much controversy regarding the compatibility of slurry pipelines and railroad transport. There is controversy also, especially in the central western states, as to whether water resources are sufficient to support pipeline requirements without depriving other present and projected demands for water. Appendix A deals with water availability in the central-western states and the implications for coal slurry pipelines.

Appendix B presents a detailed discussion of recent cost studies on coal transport.

SECTION 2

BACKGROUND INFORMATION ON U.S. COALS AND METHODS OF MINING PREPARATION (1)

DEFINITIONS, GRADES, SPECIFICATIONS (2,3)

Coal, like wood and peat, contains carbon, hydrogen, oxygen, nitrogen, sulfur, and other constituents in small quantities. The proportions of these major constituents differ greatly in different grades of coal. For practical purposes, however, coal is categorized by "proximate" analyses, which are empirical tests, or by ultimate analysis, which is a more complete determination of coal composition.

A proximate analysis of coal involves determination of four constituents: 1) moisture; 2) ash, the residue from complete combustion; 3) volatile matter, consisting of gases or vapors driven off when coal is heated at 960°C for 7 minutes; and 4) fixed carbon, the solid residue that remains after the volatile matter is driven off, less its ash content.

An ultimate analysis of coal indicates the contents of ash, carbon, hydrogen, sulfur, nitrogen, and oxygen, calculated by difference. Moisture, sulfur, and ash are undesirable constituents. Volatile matter and fixed carbon produce most of the energy when coal is burned.

The heating value of coal is generally expressed in British thermal units (Btu) per pound or kilocalories per kilogram. One Btu is the amount of heat needed to raise the temperature of 1 pound of water from 60°F to 61°F. One kilocalorie equals 3.9685 Btu.

In ascending order of rank, coals are classified as lignitic, subbituminous, bituminous, and anthracitic. Rank increases as the amount of fixed carbon increases and as the amounts of inherent moisture and volatile matter decrease. The great variation in composition of coals is apparent in the following analyses, on an ash-free basis, of a typical lignite and an anthracite, in percent:

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[1] Information in this section is largely abstracted from Bureau of Mines Publications.

	Lignite	Anthracite
Fixed carbon	33	92
Volatile matter	26	5
Moisture	41	3
Total	100	100

When exposed to air, lignite loses moisture and crumbles, so that precautions must be taken in storage. Because its heating value is lower than that of bituminous coal, primarily owing to its high moisture content, the shipment of unprocessed lignite over long distances is uneconomical. It is generally used in areas near the mines.

Bituminous coal is the most abundant and widespread coal in the United States. It is used most commonly for industrial purposes, power generation, and space heating. Coal is categorized also in terms of its coking properties, which determines whether it will produce a hard cellular carbon residue (coke) when heated to a minimum of 1500°F in the absence of air. Nearly all eastern bituminous coals have coking potential but those that contain excessive ash or sulfur are not suitable for metallurgical purposes. Western bituminous coals generally are noncoking and free burning.

Both coking and noncoking coals soften when they are heated, and volatile gas and vapors are released. When coking coals are heated to 1500°F or higher in a sealed oven, coke is formed after most of the volatile constituents have been driven off. Coke is a dull-gray, porous, carbonaceous mass, consisting largely of fixed carbon and ash. Under similar heating conditions, noncoking coals generally produce weak chars or powdery residues. Noncoking and coking bituminous coals may be used interchangeably as a fuel in some power plants, depending on the design characteristics of the combustion unit.

RESERVES-RESOURCES (4,5,6)

The U.S. Geological Survey (USGS) has identified resources containing over 1542 billion metric tons (1700 billion tons) at depths of less than 915 meters (3000 feet). On the basis of geological knowledge and theory, USGS personnel estimate additional U.S. coal resources of over 1995 billion metric tons (2200 billion tons). To indicate the great magnitude of these resources, they cite the U.S. production in 1975 of 0.58 billion metric tons (0.64 billion tons).

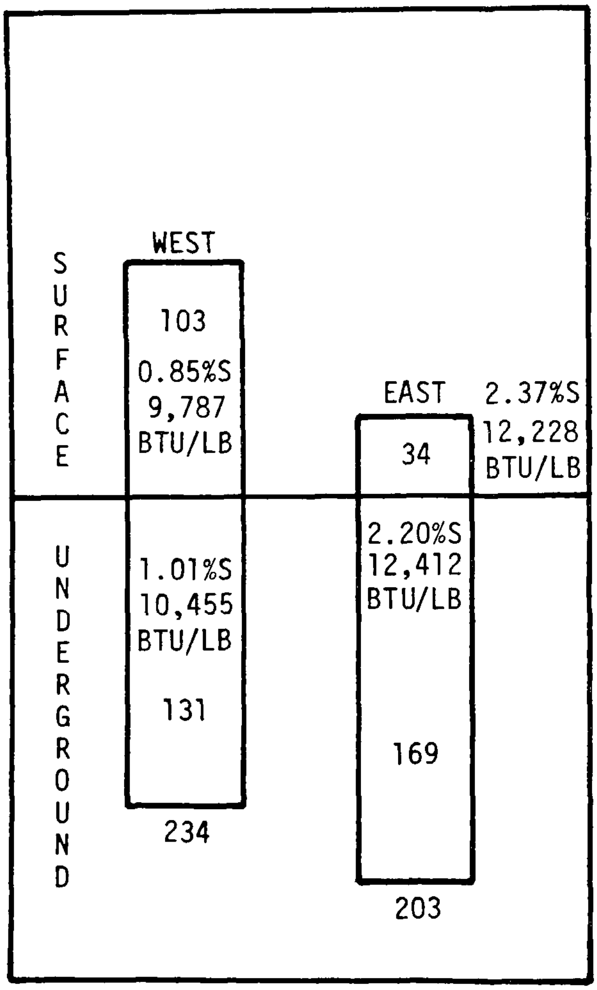
The Bureau of Mines estimates that of the 1542 billion metric tons available at depths less than 915 meters, approximately 396 billion are in deposits of the type and depth considered amenable to current mining and economic conditions. Table 2-1 summarizes these deposits, which the Bureau considers as the demonstrated coal reserve base of the United States. Approximately two-thirds is in deposits normally minable by underground methods, and the remainder is in deposits minable only by surface methods. Figure 2-1 depicts the geographic location of these reserves and the applicable type of mining.

'Reserve' coal is that which is recoverable. Recoverability of a deposit ranges from 40 to 90 percent according to the characteristics of the coalbed, the mining method, and the legal restraints on mining. Mining experience in the United States indicates that nationwide at least half of the underground in-place coals can be recovered.

The sulfur content of U.S. coals also varies considerably. Although 46 percent of the total reserve base is identified as low-sulfur coal (generally containing less than 1 percent sulfur), 21 percent contains 1 to 3 percent and an additional 21 percent contains more than 3 percent sulfur. The sulfur content of 12 percent of the coal reserve base is unknown, largely because many coal beds have not yet been mined.

Sulfur content of coals significantly affects the future siting of mines and of plants that will utilize coal. Approximately 84 percent of the Nation's reserves of low-sulfur coal are in the western States(5,6).

In 1974, the World Energy Conference and U.S. Geological Survey estimated world resources of 'hard' coal at nearly 80 percent of all in-place resources. Hard coal includes all coals of higher rank than lignitic or 'brown' coal. Hard coals, including anthracite (amounts of which are not given separately), are estimated at 9009 billion metric tons (9933 billion short tons); brown coals and lignite are estimated at 2418 billion metric tons (2666



(FIGURES IN BILLIONS OF TONS)

BUREAU OF MINES
U.S. DEPARTMENT OF INTERIOR

Figure 2-1. U.S. coal reserves, classified according to geographic area and type of mining (1).

Table 2-1. SUMMARY OF DEMONSTRATED COAL RESERVE BASE OF THE UNITED STATES (1)

(Billion short tons)

Rank of Coal	Underground mining reserve base	Surface mining reserve base	Total	Estimated total heat value (quadrillion Btu)
Bituminous	192	41	233	6,100
Subbituminous	101	68	169	2,800
Lignite	0	28	28	400
Anthracite	7	a	7	200
Total	300	137	437	9,500

[a] Less than 1/2 unit.

Metric conversion: 1 ton = 0.90718 metric ton.

billion short tons). Total in-place resources of all ranks of coal are estimated at 11,427 billion metric tons (12,599 billion short tons). The United States is said to have approximately 31 percent of world coal resources. Note however, that because the several nations that report coal resources do not use the same criteria, the reported values are not directly comparable.

METHODS OF MINING AND PREPARATION

Current underground coal mining is characterized by a variety of specially designed mechanical cutting and loading devices, such as mobile loading machines, continuous mining machines, and longwall equipment. Continuous mining machines have replaced mobile loaders at many locations, and in 1974 these machines cut and loaded nearly two-thirds of the coal extracted underground.

The rapidity of coal extraction by continuous mining makes it imperative that haulage be well-coordinated with extraction and loading operations. Short, supplemental belt conveyor systems, which move coal from continuous mining machines to the main haulage system are now used extensively instead of shuttle cars. Considerable improvement of underground haulage methods is needed to keep pace with the high productivity of continuous mining machines, which often must halt operation while the coal is moved from the face of the seam.

Development of methods of controlling respirable dust continues. Several new collection and spray systems, foams, and wetting agents were introduced in 1974 and 1975. New bits and cutting systems also offer potential for dust control.

In strip mining, the trend is toward larger equipment, particularly for removing overburden and for loading and hauling the coal.

Haulage trucks are becoming larger, more powerful, and more versatile. One of the more promising trends in design of off-highway coal haulers is the integration of the power and drive trains and the payload body into a single-unit chassis, in contrast with the conventional tractor trailer design. The largest size haulage trucks currently in use are 100 ton units.

To negotiate slippery roads, difficult grades, and tight turns, all-wheel-drive haulage units are becoming increasingly popular. An articulated chassis is being incorporated on some all-wheel-drive units to reduce tire wear.

Conveyor belts also are being used more widely at surface-mining operations. As annual tonnages and haulage distances increase, the costs of installing and operating conveyor belts become more favorable. Some operators of surface mines are considering use of shiftable and portable conveyor systems in the pits, as is now done in some European operations.

Tractor-scrapers are proving versatile in both production and reclamation operations. They are widely used at western and Appalachian mines for removing and stockpiling topsoil and other suitable materials that are later replaced on graded mined lands. At some surface mines tractor-scraper units are the primary means of removing overburden. As the use of units of this type increases, more efficient power trains and other improved design features are being introduced.

Bucket wheel excavators are a valuable reclamation tool. In the relatively flat land of the Midwest, these excavators are used to remove topsoil and upper layers of overburden. Power shovels then remove the remaining drilled and blasted strata above the coal bed. In Illinois, these wheel-shovel units are used as often as draglines to remove primary overburden.

In Appalachia, new methods have been introduced to meet regulations relating to highwalls and slopes in surface mining. In West Virginia, in 1975, more than 20 surface mining companies used or were planning to use haulback techniques. Although the haulback concept is not new, it has been tried only recently on long, steep slopes. Blasting must be precise, and well-controlled, so that no material goes down the slope; the overburden is then hauled from the working site in trucks for use as backfill in nearby worked-out areas. This practice often reduces the amount of disturbed lands by up to two-thirds.

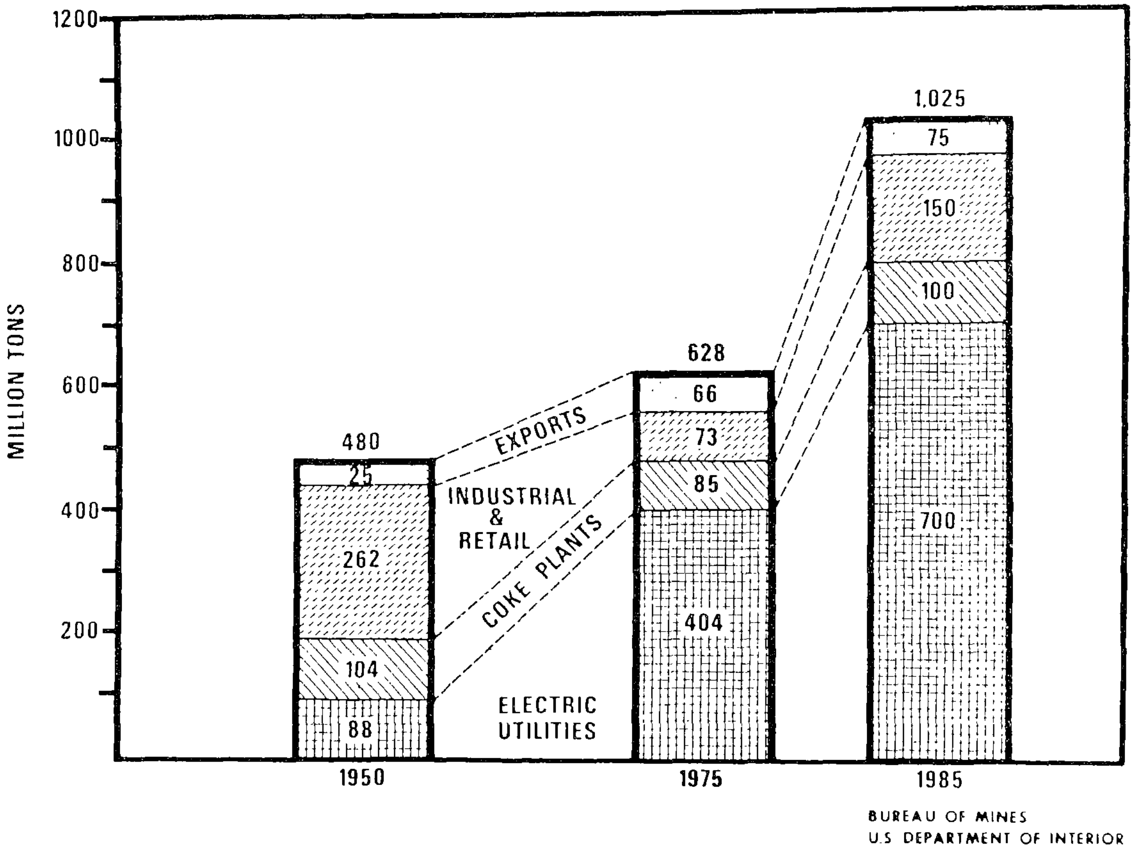
About 41 percent of the bituminous coal and lignite produced in 1975 was mechanically cleaned. Cleaning equipment consists of a variety of jigs, tables, launders, densemedium and flotation washers, and pneumatic devices. With all of these devices, separation depends on the difference in specific gravities of coal and impurities. Selection of a specific method depends on the size of coal to be cleaned, its composition, and the chemical quality specifications imposed by the consumer. In general, American coals are easy to clean except when the sulfur is structurally bound in the coal matrix as organic compounds, or is present as finely divided pyritic (inorganic) compounds. Some coal can be crushed to free the coarse pyritic sulfur, but as the particle size becomes smaller, separation becomes more difficult and costly. Coal preparation equipment is technically well advanced and is commercially available.

Design features of coal preparation units using gravity separation are fairly well established. Improvements in design and operating features will permit thorough separation, including greater reduction of pyritic sulfur. The demands of the metallurgical market will impose increasingly stringent requirements on grades of coal, especially in regard to sulfur content. Similarly, electric utilities, which constitute coal's major growth area, are being required to burn low-sulfur coals until they can meet air pollution control regulations either by reducing the sulfur content of coals or by removing sulfurous pollutants from flue gases. Some of the coal preparation processes being developed by private industry appear to be nearing technical feasibility.

COAL USE

Consumption of coal by electric utilities in 1975 far outranked all other uses, accounting for 73 percent of domestic coal consumption. Between 1968 and 1975, coal demand by electric utilities increased by 98 million metric tons (108 million tons), or 37 percent. In 1975, coal firing produced 43 percent of the total power generated and 55 percent of the total generated from fossil fuels.

Next in importance to electric power generation is the use of coal in the primary metal industry, principally in production of coke for the steel maker's blast furnaces. Production of coke from coal generates useful byproducts, including sulfur, ammonia, light oil distillates, and coal-tar derivatives. In other industrial markets, coal is used principally in industries producing food, paper, chemicals, stone, clay, glass, and cement. Coal consumption in house-hold and commercial markets has declined steadily since the early 1940's, when the average was 109 million metric tons (120 million tons) annually, to less than 5 million metric tons (6 million tons) in 1975. Figure 2-2 illustrates coal usage in 1950 and 1975, with projections to 1985.



one ton = .9071847 metric tons

Figure 2-2. U.S. coal uses, 1950-1985(1).

SECTION 3

REVIEW OF THE COAL TRANSPORTATION INDUSTRY

Coal transport methods are discussed in this section, followed by projections to 1985 of U.S. coal production and use of the several transport modes. Costs and energy requirements of the transport modes comprise the remainder of this section.

COAL TRANSPORTATION METHODS

Coal Slurry Pipelines

Although the earliest coal slurry pipelines covered short distances, their operation indicated deficiencies in design and materials. The knowledge gained from operation of these pipelines has led to new designs and has made pipeline operation competitive with other means of long-distance transport.

In 1957, the Consolidation Coal Company of Ohio pioneered in operation of long distance slurry pipelines. Their 25.4-cm (10-in.)-diameter pipeline ran 174 km (108 miles) from a mine in Cadiz, Ohio, to the East Lake Power Plant of the Electric Illuminating Company. The system operated successfully for 6 years, carrying approximately 1 million metric tons (1.1 million tons) of coal per year. Shutdown of the line resulted from a reduction of rail tariffs on all coal leaving District 8 in Ohio; this reduction made the system economically impractical.

The only other commercial system is the Black Mesa pipeline, which began operations in 1970 and is the longest slurry pipeline in use today. Peabody Coal Company operates the 46-cm (18-inch)-diameter pipe, which at full capacity transports approximately 4.5 million metric tons (5 million tons) of coal per year over a distance of 437 km (273 miles) from the Black Mesa coal field in Arizona to the Mohave generating station in Nevada. Black Mesa is the only coal pipeline currently operating in the United States.

The well-established eastern transportation routes can readily absorb future increases in coal demand. Mining of western coal, however, is in the early stages of development and demand is increasing rapidly. Transportation routes must be constructed and must be designed to minimize adverse environmental impacts. In this respect slurry pipelines constitute an attractive option.

Pipeline systems now in the planning stage will traverse the West over distances ranging from 290 to 2030 km (180 to 1260 miles). The most advanced system under development is the 1660-km (1030-mile) pipeline being undertaken jointly by Energy Transportation Systems, Inc. (ETSI, an affiliate of Bechtel), Lehman Brothers, and the Kansas-Nebraska Natural Gas Company. The proposed 96.5-cm (38-inch)-diameter pipeline is to run from Wyoming to Arkansas, moving 22.7 million metric tons (25 million tons) per year of coal at full capacity. The longest pipeline planned is a 107-cm (42-inch)-diameter line running 2030-km (1260-miles) from the Powder River basin in northeastern Montana to the Houston area of Texas. The Northwest Pipeline Corporation (Salt Lake City, Utah) has considered the possibility of a 76-cm (30-inch)-diameter pipeline hauling 14.5 million metric tons (16 million tons) per year over 1610 km (1000 miles) from Wyoming to Oregon. Others now in planning include a 1770-km (1100-mile) pipeline from Colorado to Texas, and a 290-km (180-mile) line to move coal in Utah to a power plant in Nevada. Figure 3-1 shows current and planned pipelines in the United States; Table 3-1 summarizes the pipeline data.

Coal Preparation for Slurry Transport --

For successful transportation in slurry form, the coal must be prepared to a specific size without excessive deviation from that size.

Coal preparation criteria for the line operated by Consolidation Coal Co. (Consol.), in Cadiz, Ohio, were based on pilot work conducted by the company. The specifications were ultimately patented and were established as follows: all coal must be ground smaller than No. 4 mesh, with 18 to 33 percent by weight less than 325 mesh, less than 60 percent larger than 28 mesh, and the remaining material smaller than 18 mesh.

A coal strip mine operated by the Peabody Coal Company in Kayenta, Arizona, supplies coal to the Black Mesa Pipeline

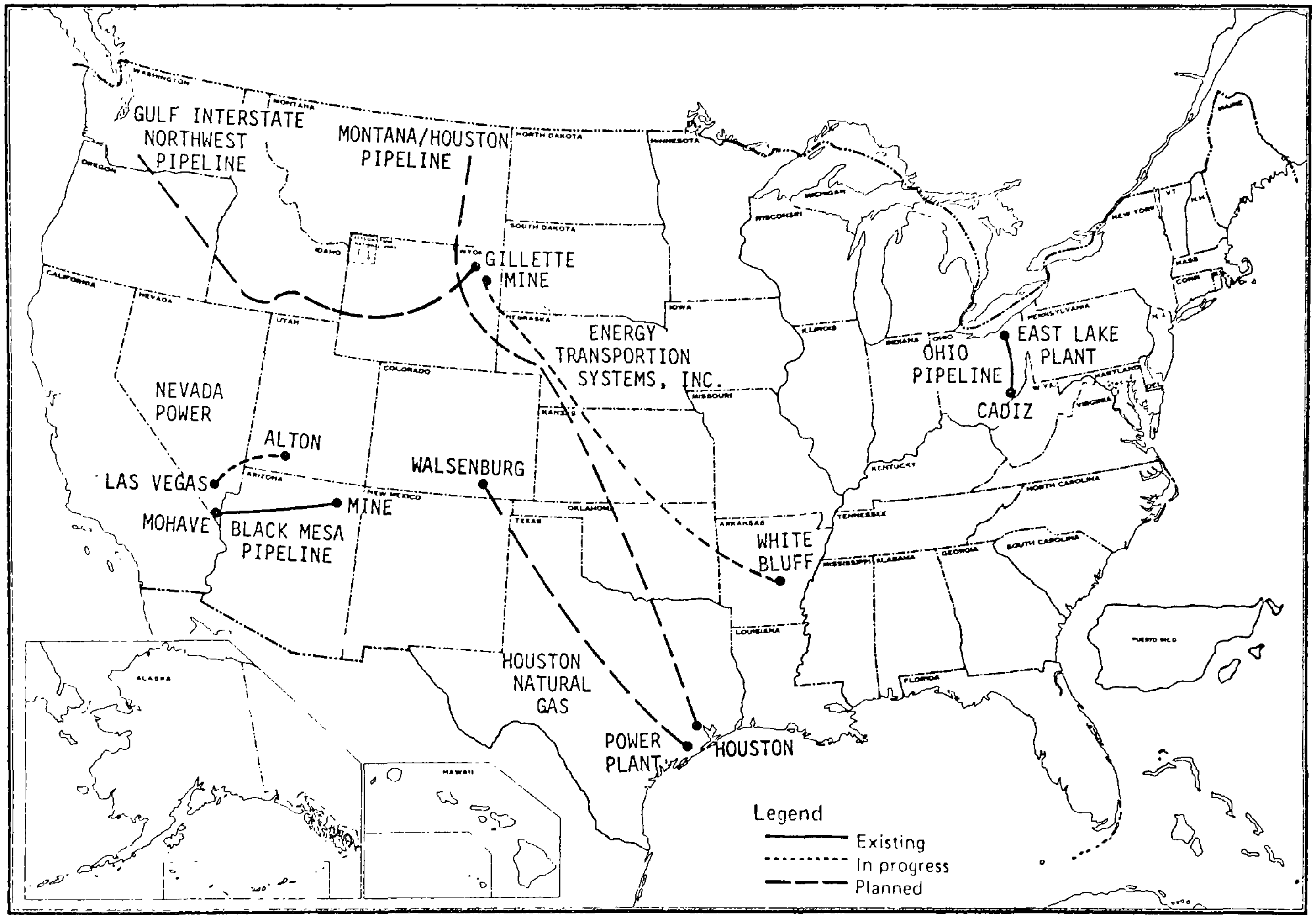


Figure 3-1. Status of coal slurry pipelines in the U.S.(7).

Table 3-1. CURRENT AND PROPOSED COAL SLURRY PIPELINES (7)

System	Length, km (mi)	Pipeline diameter, cm (in.)	Annual throughput, million metric tons (million tons)
Black Mesa	439 (273)	46 (18)	4.5 (5)
Nevada Power	290 (180)	61 (24)	9 (10)
Northwest	1770 (1,100)	51 (20-24)	9 (10)
Energy Transportation	1667 (1036)	96.5 (38)	22.7 (25)
Wytex	2510 (1560)	46-122 (18-48)	19-34.5 (21-38)
Houston Natural	1784 (1109)	20-71 (8-28)	13.6 (15)
Salt River	290 (180)	41 (16)	3.6 (4)

Company for slurry preparation and transportation to the Mohave Generating Station. Figure 3-2 depicts the pipeline system from the Black Mesa Mine site to the Mohave terminal. The coal supplied to the Black Mesa Pipeline Company is sized at 5.1 cm x 0 (2-inch x 0).

Heating value of the coal as received from the mine site ranges from 1.34 million g-cal/kg (11,700 Btu/lb) to 2.58 million g-cal/kg (12,600 Btu/lb), with an average of 2.55 million g-cal/kg (12,300 Btu/lb). Ash content ranges from a low of 6.5 percent to a high of 17 percent, with an average of 9.8 percent. Sulfur content ranges from 0.38 percent to 0.43 percent, with an average of 0.40 percent. The moisture content of the coal as delivered to the pipeline company is 10.74 percent (9).

Coal is prepared according to the flow diagram shown in Figure 3-3. From a transfer tower located at the mine site, the coal is conveyed to one of three 536-metric ton (590-ton) cylindrical bunkers. A variable-speed belt feeder conveys the 5 x 0 cm (2 x 0 inch) coal to a two-deck vibrating screen with capacity of 263 metric tph (290 tph). Coal sized at 0.6 cm (+1/4 inch) is retained on the screens, then is fed to an impactor and crushed to -0.6 cm (-1/4 inch). The coal that passes through the screens is combined with the impactor product, then supplied with water. Slurry density is controlled by a densimeter. The coal/water slurry is fed to a rod mill, then screened through 0.32-cm (1/8-inch) screens. The oversize material is recirculated through the mill. The -0.32-cm (-1/8-inch) material is stored in one of four 2.46-million-liter (650,000-gal.) tanks equipped with agitators. No coal fines are discharged in this system. The coal is not cleaned to reduce ash or sulfur contents.

The maximum and minimum pumping rates are 600 metric tph (660 tph) and 510 metric tph (560 tph) respectively. The maximum pumping rate is equivalent to pumping 265 liters/sec (4200 gpm) of coal slurry at a density of 48 percent solids by weight; the minimum pumping rate is equivalent to pumping 237 liters/sec (3750 gpm) of coal slurry at 46 percent solids.

The Black Mesa pipeline began operation with coal having the following approximate size distribution: 2 percent greater than 14 mesh, 82 percent 14 x 325 mesh, and 16 percent less than 325 mesh. The fines content was increased to 20 percent because plugging occurred during

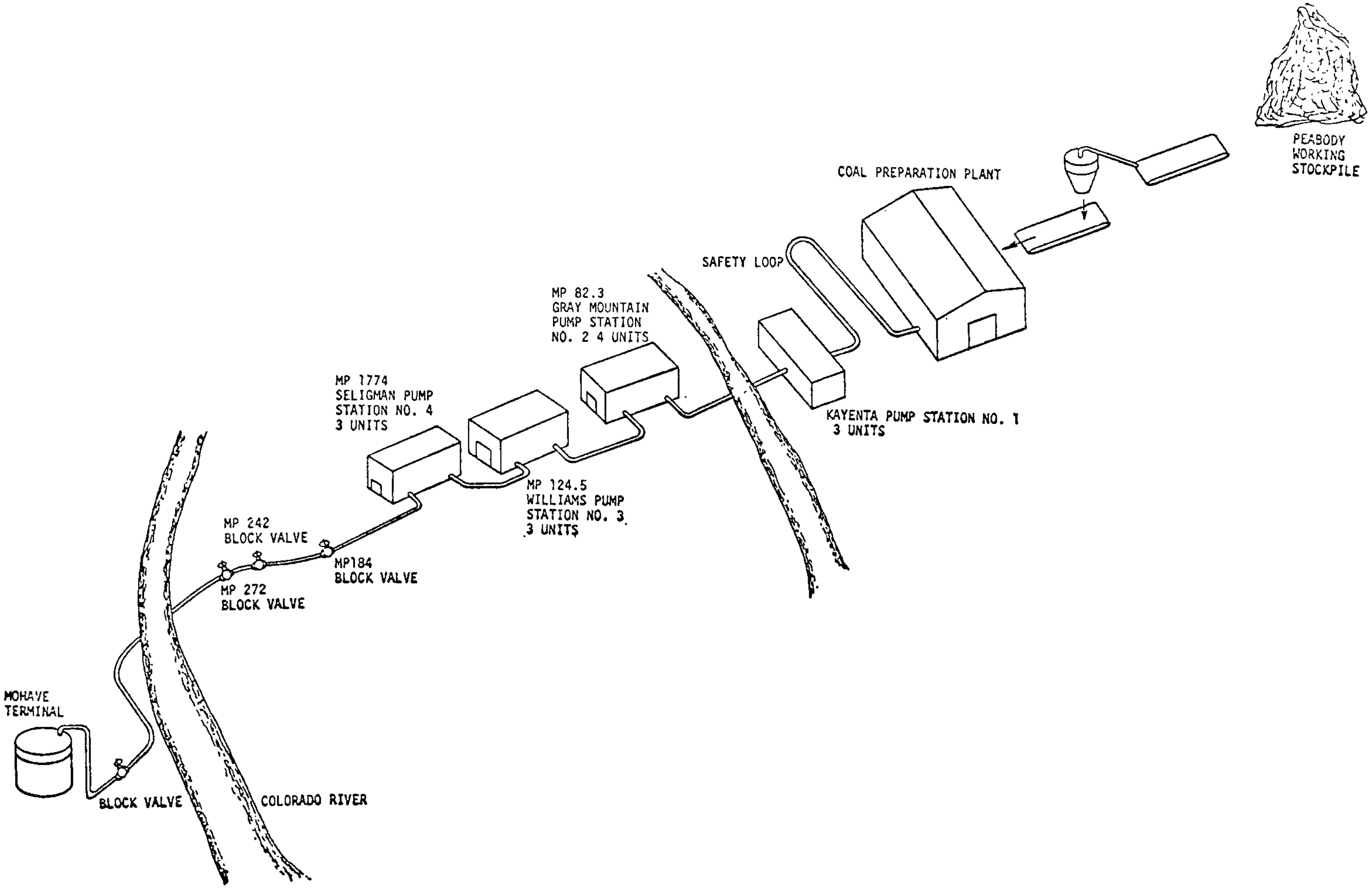


Figure 3-2. Black Mesa pipeline from mine site to Mohave Terminal (8).

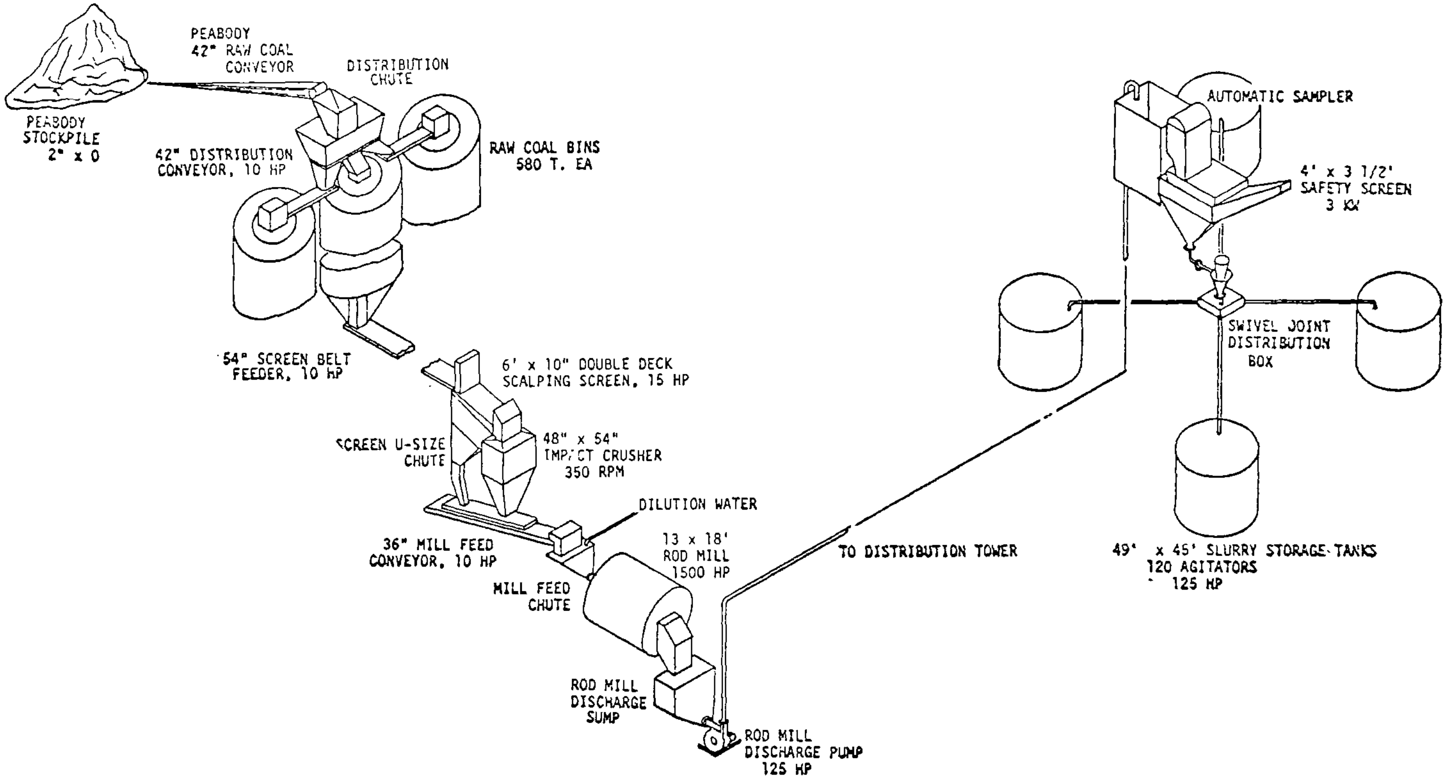


Figure 3-3. Coal preparation plant for the Black Mesa pipeline (10).

attempts to restart the line after shutdown. A typical size distribution of the current coal is illustrated in Figure 3-4.

Four pumping stations move 590 metric tph (650 tph) of coal at a rate of 6.4 km/hr (4 mph). The three-unit stations (Nos. 1, 3, and 4) operate at about 70 kg/cm^2 (1000 psi), and the four-unit station (No. 2) operates at about 105 kg/cm^2 (1500 psi). The driving power is 1300 or 1120 kW (1750 or 1500 hp) depending upon location. A dump pond and water supply are provided at each station in case an emergency should necessitate clearing the line. The dump pond would hold the upstream slurry and the water supply would be used to flush the downstream section.

Dewatering - Black Mesa Line --

Upon arrival at Mohave, the coal slurry is stored in four active storage tanks with a capacity equivalent to 4 days total station full-load operation, approximately 117.3 million liters (31 million gallons). A 373-kW (500-hp) mechanical agitator with a double paddle is operated in each slurry tank to maintain the solids in suspension. Slurry from the tank is pumped into Dynacone centrifuges (a total of 20 for each unit), where it is dewatered. The coal cake (at 20 percent moisture) is conveyed to the unit's 10 pulverizers, where it is dried and then transported to the furnaces pneumatically. Gas burners are used in the primary air ducts to increase the primary air temperatures from 343° to 400°C (650° to 750°F). The 400°C (750°F) air is hot enough to prevent plastering of the pulverizer and coal pipe and to maintain a nominal temperature of 80°C (175°F) at the pulverizer outlet.

Effluent from the centrifuges (centrate) containing a portion of the coal fines is pumped to the clariflocculators and is chemically treated to separate the coal fines from the water. The treated coal fines (underflow) are then pumped directly to the furnace at the top two burner elevations by means of underflow guns at each of the eight corners of each boiler. The moisture content of the underflow is 80 percent. The overflow water is pumped to the circulating water-cooling system. Excess clarified water is diverted to large evaporating ponds. No liquid discharge is permitted.

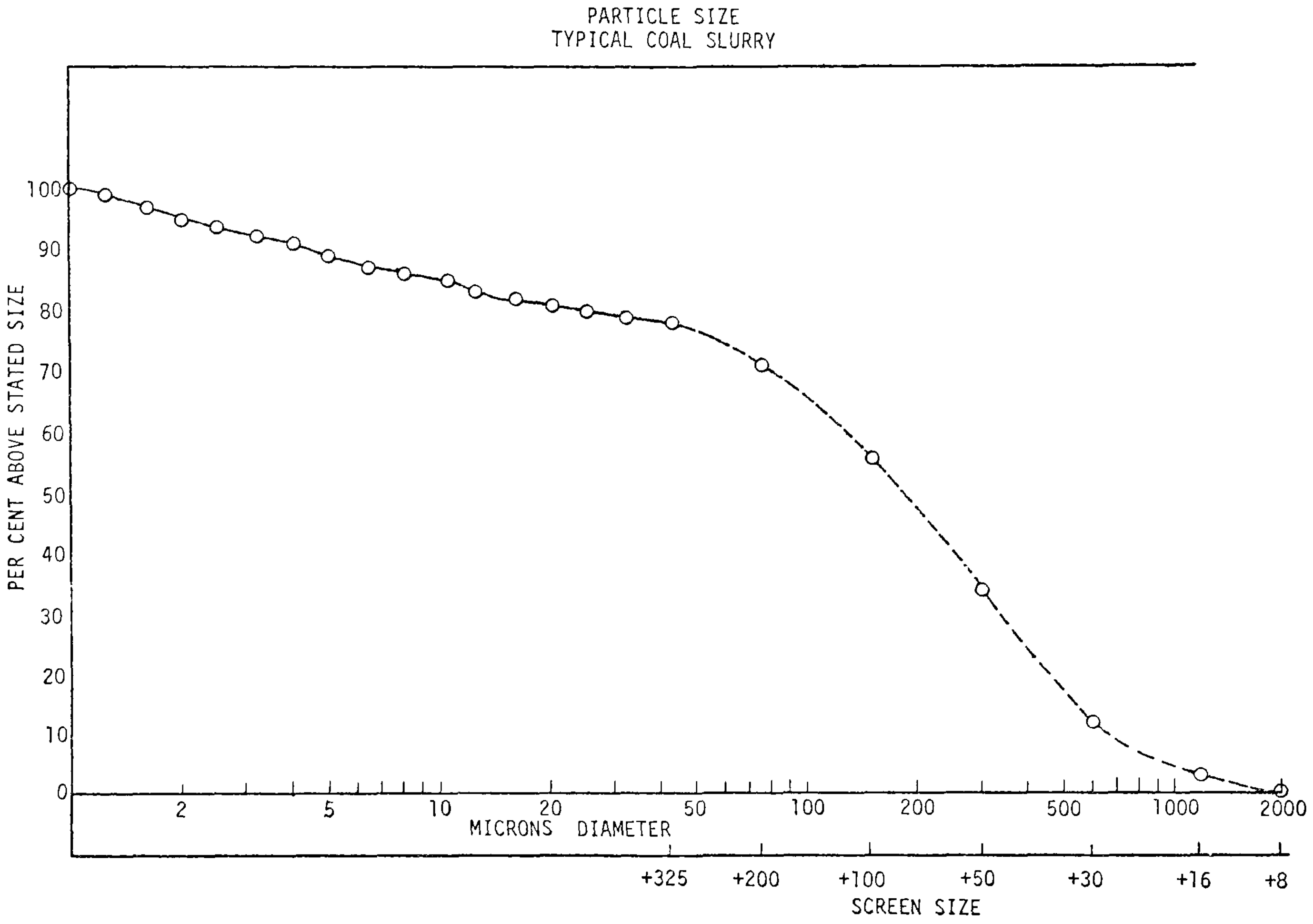


Figure 3-4. Typical size distribution of present coal used in the Black Mesa pipeline (9).

Water Supply --

The Black Mesa pipeline uses water supplied from seven deep wells and an emergency resevoir. The wells are located at depths between 1067 and 1128 m (3500 and 3700 ft) and are encased in concrete to a depth of 610 m (2000 ft) (11). The wells are drilled deep and the casings are used to protect the shallow-well ground-water supply for domestic consumption.

Other Aspects of Coal Slurry Pipelines --

1. Corrosion control - A primary maintenance item in coal slurry pipelines is pipe replacement. Corrosion inhibitors may be added to the slurry to minimize corrosion. The literature identifies a number of inhibitors. Consolidation Coal Co. patented a process that involves the addition of 12 ppm each of a chromate and a polyphosphate together with a pH above 6, to control corrosion (12). The patent claims that the chromate is removed from the water by fine coal present in the clarifiers. Others claim the use of 10 to 1000 ppm of chromate coupled with organic phenols, polyacrylamides, or alkylene oxides for corrosion control.

2. Viscosity control - The literature also cites the use of polyalkylbenzenes to adjust the viscosity of coal slurries. The effect is to increase coal tonnage by a significant percentage.

Coal Slurry Combustion --

1. Without dewatering - Consolidation coal has patented a process that utilizes coal slurry as a fuel without dewatering. The important features of the process are as follows (13):

   a. A suspension of particles of which 40 percent are larger than 0.85 mm can be transported in 34 percent water and subsequently burned.

   b. This slurry can be burned in a cyclone burner provided the particles are in the size range of 0 to 3 mm.

   c. Factors that affect the stability of combustion of this slurry include particle size distribution of the coal and the aerodynamic structure of the coal-water stream injected into the boiler; an undesirable combination of these factors causes large particles to fall out without satisfactory combustion.

Others have studied combustion of coal slurries (14, 15). The consensus is that combustion is good but that heat losses are large because of water evaporation and loss of sensible heat. Another difficulty in firing of fuel with high moisture content is the potential that the temperature of the mixture could drop below the acid dew point. This could cause significant corrosion.

This study does not consider the economics of direct coal-slurry firing as opposed to dewatering and pulverized-coal firing.

Railroads

Introduction --

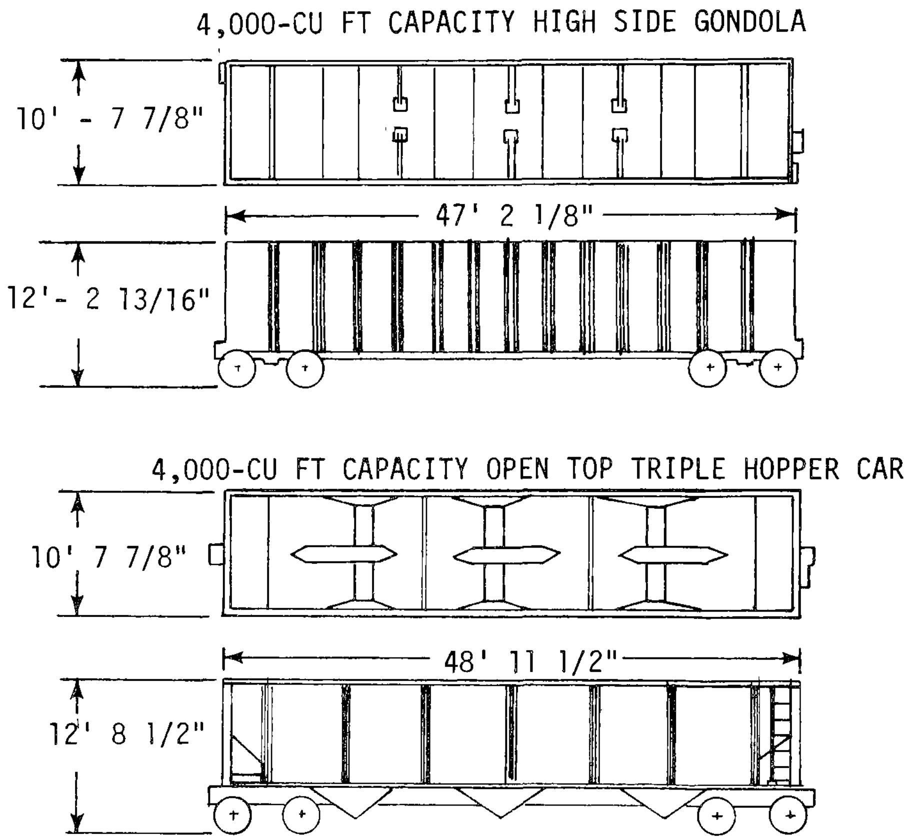
Railroads move approximately 70 percent of the coal produced in the United States. Although this movement entails significant environmental problems, rail transport offers several advantages.

Single-car loading is practiced at the smaller coal mines. Empty hopper cars are parked at the mine site and loaded as ordered. Crew efficiency and equipment utilization are low since the crew and locomotive units must make two trips for only a few cars.

Most coal shipped by rail is moved by multiple-car loading, which is practiced at medium to large mines. Although this system is somewhat more efficient than single-car loading, the cars still must be sorted at intermediate terminals.

The most efficient method of rail transportation is by unit trains, which can serve medium and large mining operations. The unit train consists of a series of large-capacity coal cars, typically hauling 9100 metric tons (10,000 tons) of coal; such a unit train would consist of one hundred 91-metric-ton (100-ton) cars. Examples of these large cars are shown in Figure 3-5. The concept has revolutionized coal handling by providing nonstop service for both producers and users (14).

Shipment by unit trains requires facilities for rapid loading and unloading, with associated stockpiling and dedicated railroad equipment. From 1969 through 1973, unit train tonnages increased in 14 of 21 coal producing states. Western States gained nearly 18 million metric tons (20



4,000-CU FT CAPACITY HIGH SIDE GONDOLA

4,000-CU FT CAPACITY OPEN TOP TRIPLE HOPPER CAR

Metric conversion: 1 ft. = 0.3048 m

Figure 3-5. Examples of coal cars used in unit trains (16).

million tons), which represents a 350 percent gain, while states east of the Mississippi River gained only 12 million metric tons (13 million tons) or an 11.5 percent gain. Table 3-2 shows a time series of unit train loadings by State from 1968 through 1973.

Loading --

Unit trains are loaded either at the plant-flow rate or by flood-loading. In loading at normal plant rate, booms and chutes are used to direct the output into the cars; coal is not accumulated in storage. This was the early approach to train loading, and even for unit-train shipment some operations still find the plant-flow rate acceptable. In most unit train operations, however, coal is accumulated in storage and then flood-loaded as shown in Figure 3-6.

Storage for unit train flood-loading is in open piles on the ground or in silos or bins (17). Ground storage is the most common method of accumulating the supply necessary for high-speed unit-train loading. Conveyors are generally used for piling and reclaiming, but truck transportation is used occasionally.

By far the most popular form of open-space storage is the single conical pile, as shown in Figure 3-7. The pile may be situated directly over a loading station as in Figure 3-7 to minimize handling of the coal. In this case a fabricated steel tunnel with earth piled around it forms the base for the pile. The loading chute is located in the center and is designed to accommodate different size cars and different loading rates.

Limitations include a small live storage capacity, possible spillage in the tunnel, and fugitive dust emissions from the large open pile. Also, the pile is open to public view and is exposed to the weather.

In a simple form of ground storage, a conveyor dumps the coal into a conical pile over a conveyor gallery equipped with one or more feeders to move the coal when loading starts. If dozing and dead (unused) coal are to be minimized or eliminated, fabricated walls or earth embankments sloped at 40 to 45 degrees may be used. Partial enclosure of the pile will also lessen its visual and environmental impacts. Figure 3-8 illustrates an enclosed-trench storage pile.

Table 3-2. UNIT TRAIN MOVEMENTS OF BITUMINOUS COAL AND LIGNITE

(THOUSANDS OF NET TONS) (18)

State	1968	1969	1970	1971	1972	1973
Eastern:						
Alabama		2,257	3,088	3,373	4,253	3,930
Arkansas		40		89		
Illinois	13,363	17,621	17,217	17,329	21,777	22,155
Kentucky East	8,537	7,420	9,361	11,164	9,522	12,197
Kentucky West	4,864	6,845	8,762	7,730	6,706	7,291
Total Kentucky	13,401	14,265	18,123	18,894	16,228	19,489
Maryland		150	232	210	60	122
Ohio	10,477	13,014	13,308	16,688	18,063	18,266
Pennsylvania	18,054	20,370	21,325	19,125	18,228	22,262
Tennessee			398	1,343	1,171	1,208
Virginia	5,372	5,067	5,861	2,525	3,301	4,477
West Virginia	42,289	40,733	30,110	26,793	33,446	34,203
Total eastern	102,956	113,517	109,662	106,369	116,527	126,111
Western:						
Colorado	731	1,336	2,427	1,692	1,210	2,391
Indiana	a	1,913	2,997	2,351	3,048	5,493
Iowa					378	
Kansas	a	96		762	214	190
Missouri		365				
Montana (Bitum.)	1	2	3,022	6,526	7,698	10,115
New Mexico		742	1,130	1,034	623	778
North Dakota (Lig.)		787	916	923	1,577	1,607
Oklahoma		934	974	910	462	489
Utah	a	2,031	2,055	1,825	1,905	2,094
Wyoming			107	441	2,889	5,826
Other	5,435					
Total western[b]	6,167	8,206	13,628	16,464	20,004	28,983
Grand total[b]	109,125	121,722	123,289	122,832	136,534	155,094

[a] Included in "other".

[b] Totals may not add because of independent rounding.

Metric conversion: 1 ton - 0.90718 metric ton.

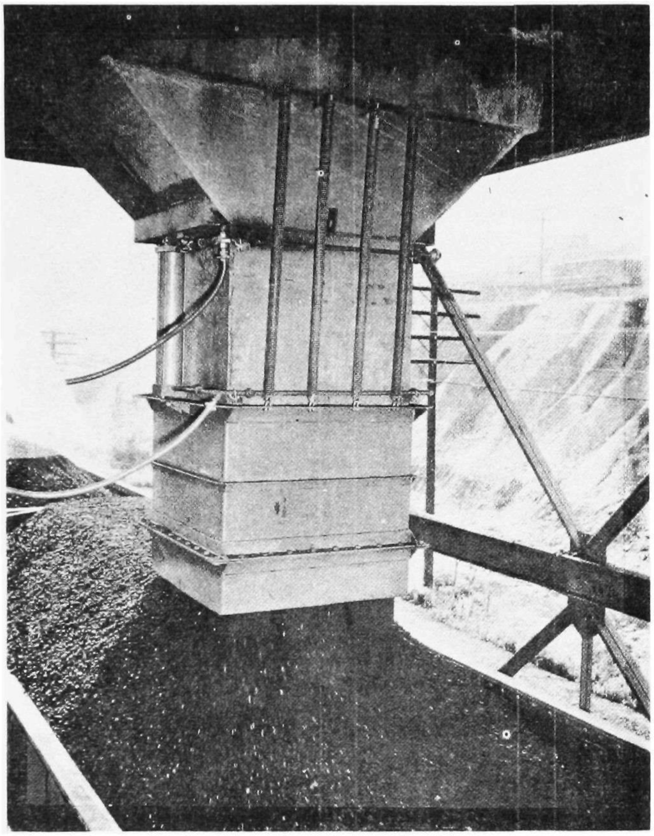


Figure 3-6. Flood loading in a conical pile ground-storage system (17).

Source: 1974 Keystone Coal Industry Manual

Figure 3-7. Typical open storage single conical pile (17).

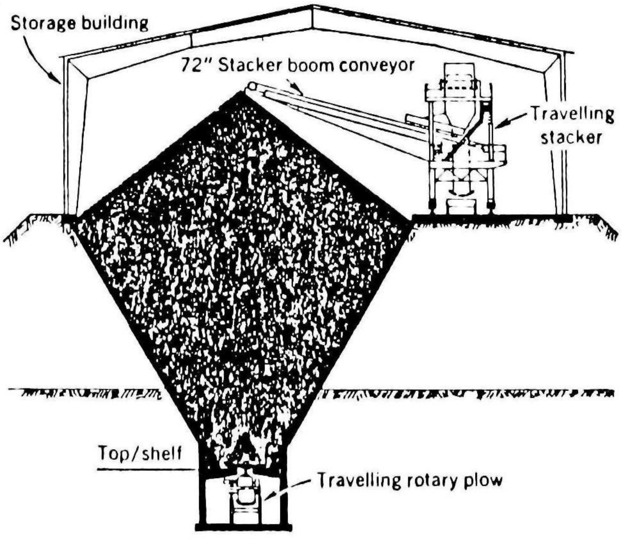


Figure 3-8. Enclosed trench storage pile (19).

The silo loading system has many desirable attributes. The silos generally range in capacity from 9072 to 13,600 metric tons (10,000 to 15,000 tons). These silos accomodate the necessary volume with a minimum of ground space and eliminate losses of windblown coal dust, which may be a major consideration in certain localities. Protection of the coal from rain and snow may eliminate pollution of streams with solids and/or dissolved constituents. Figure 3-9 illustrates loading of a unit train from a silo. All

Figure 3-9. Typical unit train loading from a silo (17).

Source: 1974 Keystone Coal Industry Manual

storage can be live (active), and availability of coal at train time does not depend on mechanical equipment, since only the chutes and gates stand between storage and coal cars.

Front-end loaders, such as the one shown in Figure 3-10, are the most versatile of loading equipment. The machines may be bought for assignment to continuous loading or be borrowed from other jobs during loading periods. They can move easily to different coal piles and are practical for smaller loading operations.

Figure 3-10. Front-end loading on a rail car (17).

Source: 1974 Keystone Coal Industry Manual

Unloading --

The unit train concept has made its greatest contribution in unloading procedures. The idea has led to rotating car dumpers, illustrated in Figures 3-11 and 3-12, with swivel couplings that allow the cars to be turned into track hoppers without uncoupling or breaking an air line. The hopper allocates the coal onto a conveyor belt, which moves it toward the power plant storage pile. An older and more commonly used system for unit train unloading features bottom discharge hatches, as shown in Figures 3-13 and 3-14, which are opened and closed either manually or automatically. Some form of shaker or vibrator is usually required for complete discharge of the contents.

Freezing and Thawing --

Contrary to some claims, a unit train can freeze rapidly even on short, fast hauls. Speed does not reduce the likelihood of freezing, since the freezing rate depends upon the velocity of air over the cars and their cargo. A train running at 80 km/hr (50 mph) is in effect, exposed to an 80 km/hr (50 mph) wind. Therefore, even at temperatures of -1 to 4°C (30 to 40°F), cars may freeze because of the chilling effect (8).

When a unit train is subjected to freezing temperatures, a thawing shed is required to melt the bond between the car and the frozen coal. A good thawing system will allow unloading at normal rates. Two modern systems for thawing are the gas infrared, shown in Figure 3-15, and the electric infrared. Although both claim advantages, the electric version may find increasing favor as our gas supplies dwindle. A coal shaker is also needed where hopper cars are involved, and in some units a frozen-coal cracker is installed in the throat of each track hopper.

Barges

In 1973, the Mississippi River System and Gulf Intracoastal Waterway carried about 18 percent of U.S. coal shipments. Total tonnage transported on these waterways increased 36 percent since 1962. The most heavily traveled rivers were the Ohio and Monongahela, as shown in Table 3-3.

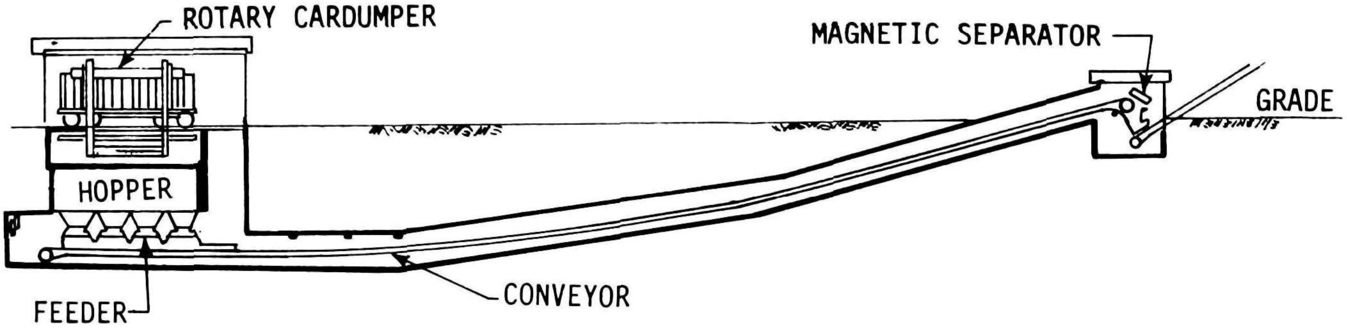


Figure 3-11. Illustration of a rotary car coal dumping system (15).

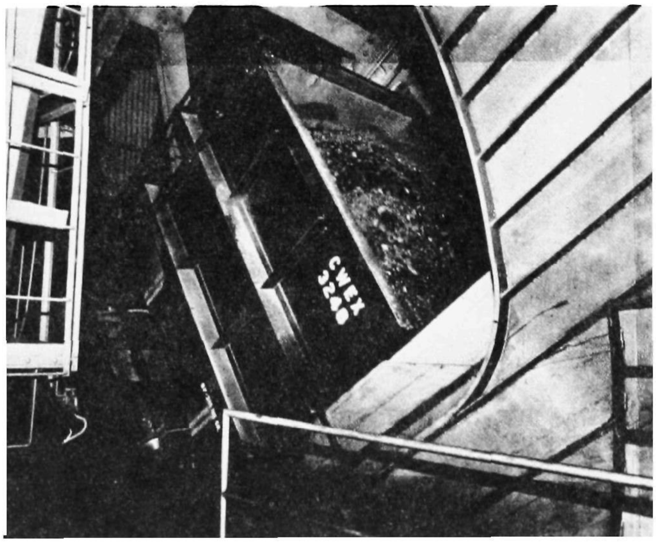


Figure 3-12. Link belt unit-train car dumper (17).

Source: 1974 Keystone Coal Industry Manual

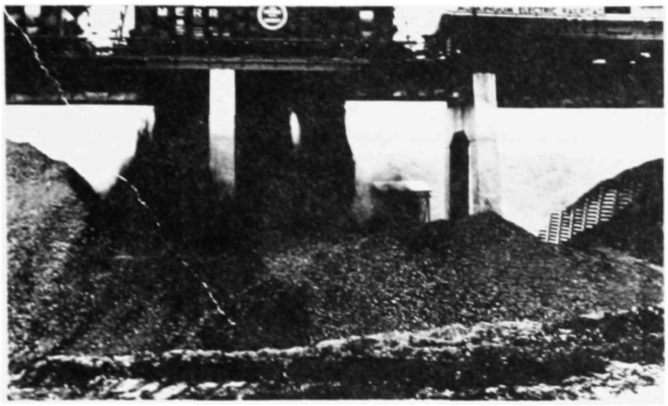


Figure 3-13. Unit-train unloading by use of trestle system (17).

Source: 1974 Keystone Coal Industry Manual

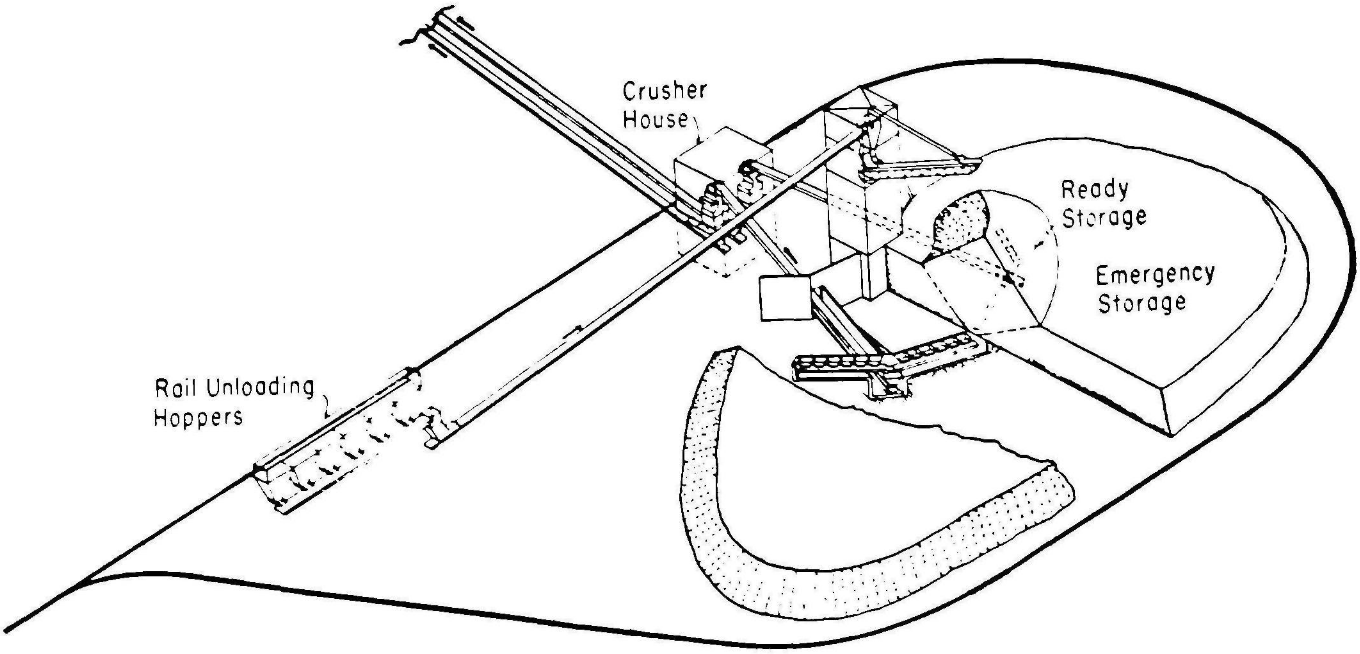


Figure 3-14. Coal handling combines high-capacity unloading and ready storage with automated reclaim (17).

Table 3-3. COAL BARGE TRAFFIC ON RIVERS

SERVING THE APPALACHIAN REGION, 1973 (20)

River system	Coal hauled (1000's net tons)
Mississippi	23,555
Ohio	65,137
Allegheny	2,351
Monongahela	29,634
Kanawha	7,325
Green & Barren	15,458
Cumberland	4,632
Tennessee	11,572
Warrier & Tombigbee	5,509
Total	165,173

Metric conversion: 1 ton = 0.90718 metric ton.

Tonnages of coal on the Great Lakes and Tidewater Waterways have declined since 1963 by small percentages. In 1973 Great Lakes shipments of coal equaled 35.8 million metric tons (39.5 million tons) and about 6.6 million metric tons (7.3 million tons) was moved by tidewater waterways. Hampton Roads, Virginia, was the primary shipping area (21).

Of the coal shipped by barge in 1973, over 69 percent was moved over the Mississippi River and Gulf Intracoastal Waterway. The remaining 26 percent and 5 percent were moved over the Great Lakes and tidewaters, respectively.

Most barges today are open-hopper designs with capacities ranging from 900 to 1800 metric tons (1000 to 2000 tons). It is expected that the trend will be toward barges in the range of 900 to 1350 metric tons (1000 to 1500 tons). The number of barges in tow (10 to 36) is determined by the lock sizes and also by the capacity of the river. As with unit trains, most barges return empty when the distance is 800 km (500 miles) or less (17).

Figure 3-16 shows a 30-barge tow on the Mississippi River.

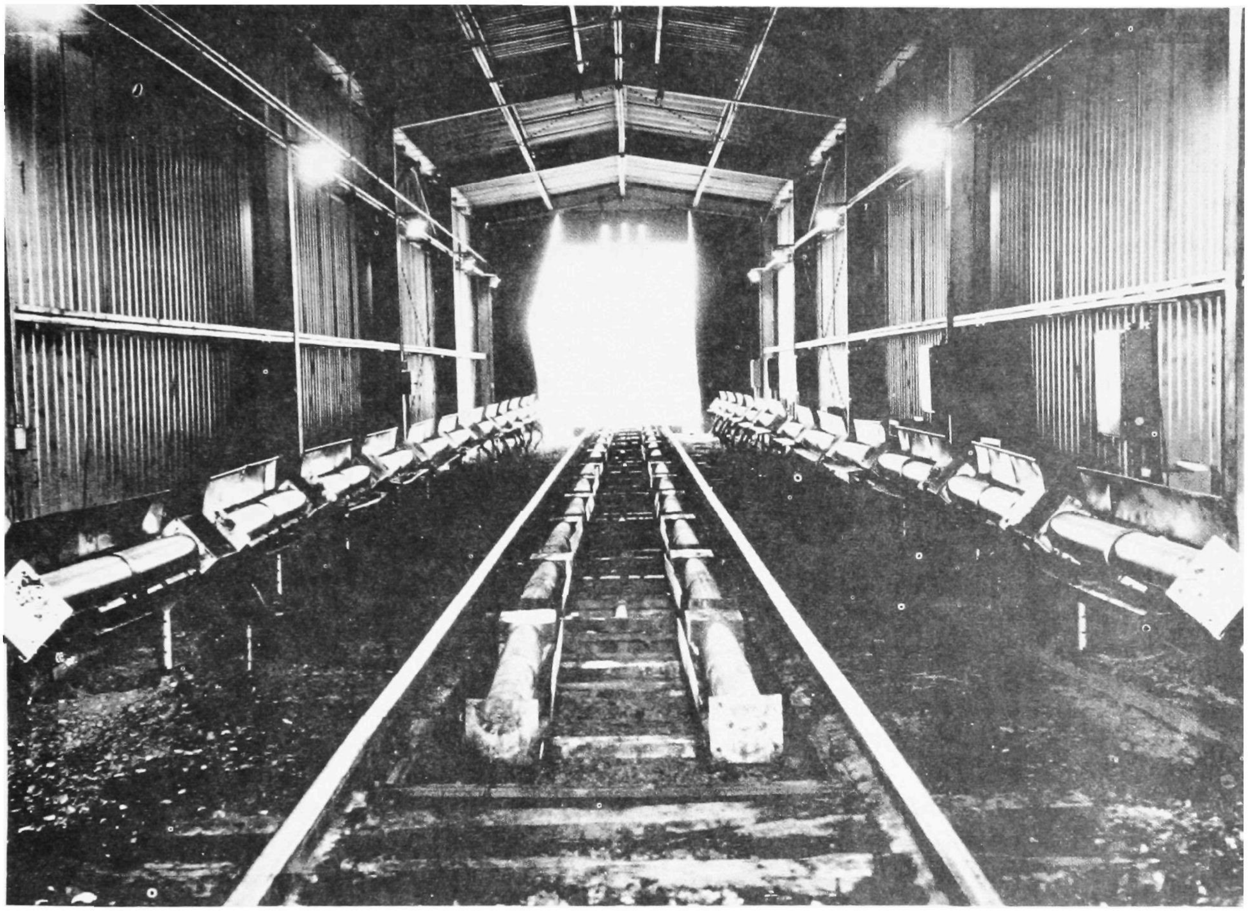


Figure 3-15. Radac gas-fired Infra-red thawing system in use at Electric Utility generating station (17).

Source: 1974 Keystone Coal Manual

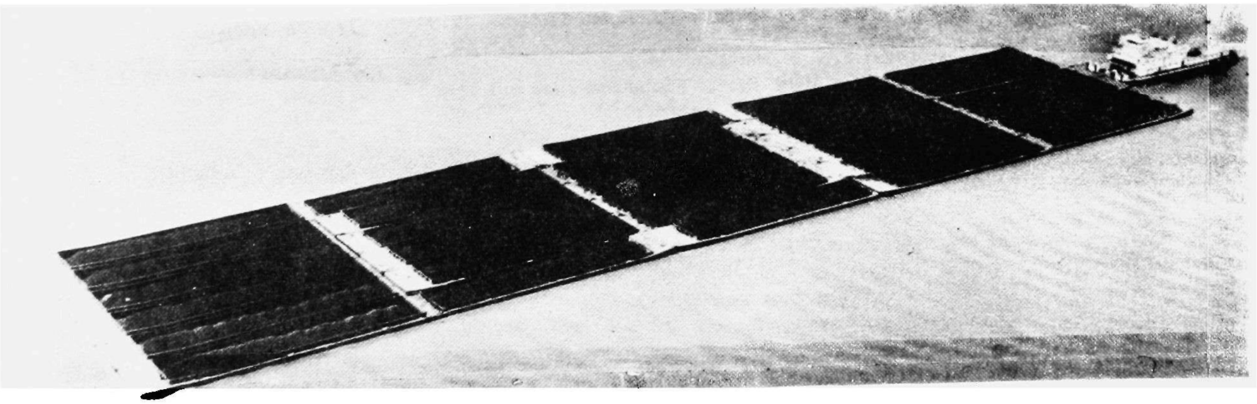


Figure 3-16. 30 Barge tow on the lower Mississippi River (17).

Loading and Unloading --

Generally, coal is transported by train from the mine to a barge, which transports it to a power plant near the river bank. Flood loading of barges involves both silo and ground storage of the coal, usually in higher ranges of capacity than storage for unit trains, e.g., 12,700 metric tons (14,000 tons) for a single silo and 68,000 metric tons (75,000 tons) for a ground-storage facility fed by traveling stacker. The 1974 Keystone Coal Industry Manual designates the following five classes for barge-loading plants:

1. A simple dock from which trucks dump into the barge when water conditions permit.
2. The stationary-chute type, which is simple and low-priced and works well where the river does not fluctuate greatly and banks are steep.
3. Elevating-boom type, with barges moved back and forth in the river beneath. The elevating boom allows more loading time if river elevation changes greatly. This type is advantageous where the bank of the river is a considerable distance from the channel and the elevating boom and conveyor belt can be combined for travel across the flood plain.
4. Floating-barge type, with the loading boom mounted on a floating, or spar, barge and pivoted for easier loading. This method requires a steep bank or fill to permit retraction and extension of the main conveyor with changes in water level.

5. The tripper-conveyor type, in which the barges are stationary and the loading chute moves back and forth to load and trim.

In unloading, clamshell buckets are generally used to transfer the coal from the barge to a hopper and thence to conveyor belts and the stockpile.

To speed the turnaround time of river tows, operators developed continuous bucket unloading systems, as shown in Figures 3-17 and 3-18. A Dravo Corp. study of various unloading operations resulted in an excellent high-capacity unloading system. The system integrates a continuous ladder unloader, conveyors, and shuttle-barge hauling system, providing a maximum-efficiency operation (8).

The unloader consists of two continuous bucket ladders suspended from a twin-girder cantilever, allowing the digging ladders to be raised and lowered vertically along the fixed structure. On the first pass, the bucket ladders are positioned together at the center of the cantilever and dig a trough through the center of the coal as the barge is being moved beneath the unloader. During the second pass, the ladders are spread to the sides of the hopper and dig to the barge innerbottom, leaving a small area down the center to be removed on the cleanup pass.

The coal is transferred from the unloader to a dock conveyor belt, which moves the coal to the main yard conveyor belt or to a temporary stockpile nearby.

Conveyor Systems

Conveyor systems are used in all sections of the country at mines, power plants, bargeloading stations, and industrial sites. They are most often found within a processing area, moving crushed coal 30 or 60 meters (100 or 200 feet) to a storage area, a cleaning station, or a loading station.

Popularity of longer belt systems is growing. Belts running up to 16 km (10 miles) from the active mine directly to the consumer are more common than a few years ago, and plans are being studied for belt systems as long as 240 km (150 miles).

A conveyor system is versatile, easy to operate, generally reliable, relatively maintenance-free, and repairs can be done quickly. Though the systems are usually fixed

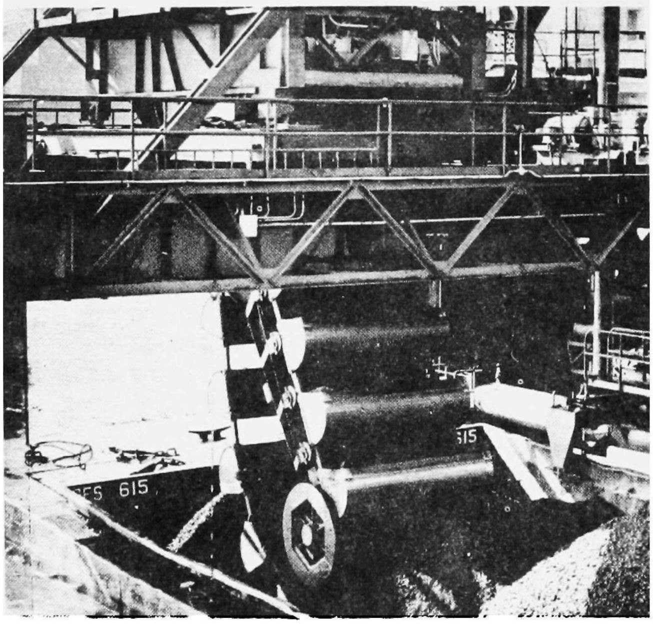


Figure 3-17. Barge-unloader elevator carriage showing transverse and longitudinal drives for scopping patterns (17).

Source: 1974 Keystone Coal Industry Manual

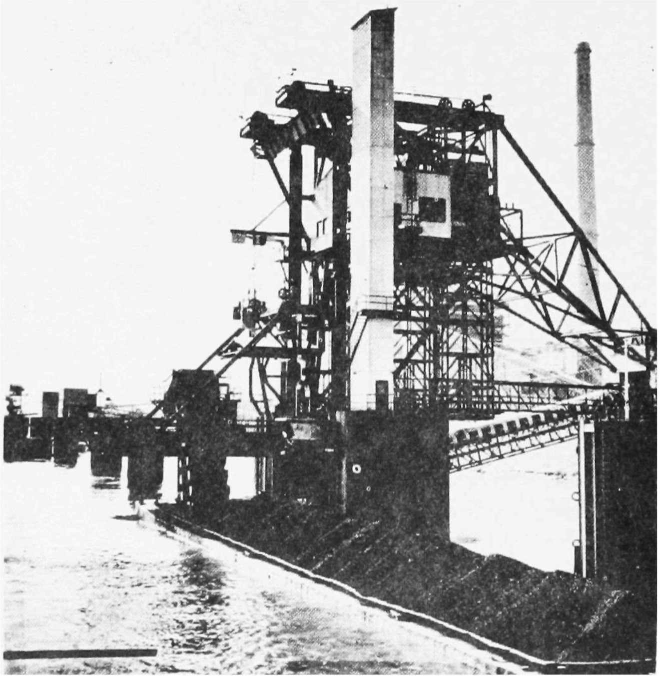


Figure 3-18. Continuous-bucket elevator transferring coal to conveyor system for outside live storage (17).
Source: 1974 Keystone Coal Industry Manual

some surface mines are using shiftable conveyor systems that can follow the coal digging equipment.

One advantage of an overland conveyor is that it can be built over difficult terrain with minimum costs for earthwork. A conveyor system is feasible in some areas where construction of a road or railbed with an acceptable grade could cause controversy on environmental grounds. Figure 3-19 shows a portion of the Kayenta mine conveyor belt in Kayenta, Arizona.

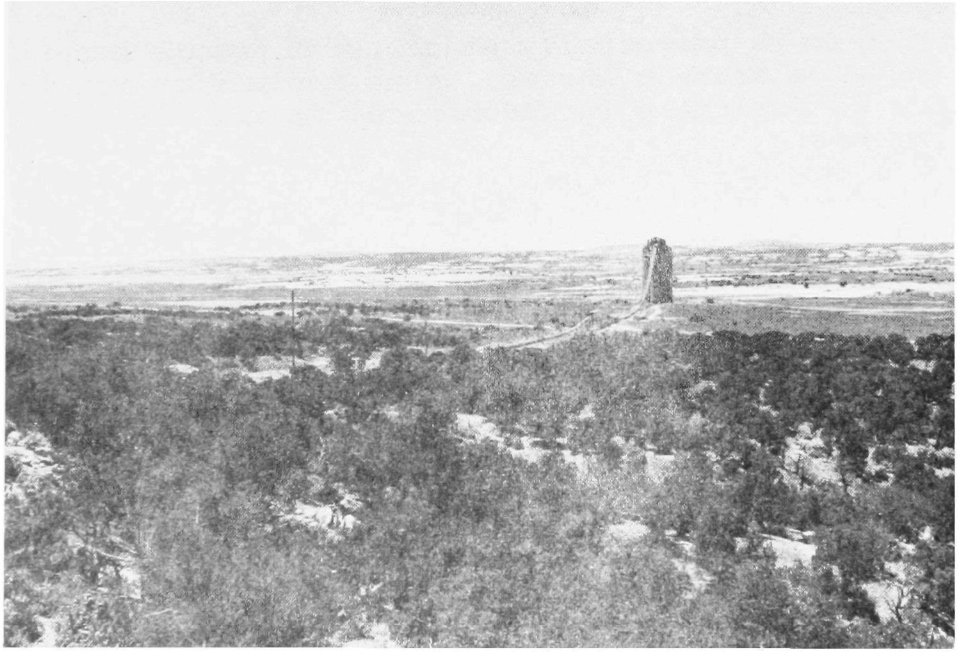


Figure 3-19. A portion of the Kayenta mine conveyor belt in Arizona.

Before it is moved on a conveyor belt, coal is reduced to a specific size by crushers. Short conveyors generally move the coal to a storage facility or feed it directly to the next conveyor stage. If the coal is placed in open storage, a reclaim conveyor, fed by a traveling rotary plow feeder, transfers the coal to the main overland conveyor. All coal is weighed on a belt scale before traveling to its loadout point.

Major capital and operating costs of an overland system are the conveyor components and supports, which include idlers, structures, foundations, belting, and drives. Requirements for all of these components are influenced by the width of the system, which varies directly with the speed of the belt. On the longer systems heavy-duty idlers are used to allow greater spacing between them. On the 16-km (10-mile) conveyor belt feeding the Gavin Plant in Ohio, the spacing between idlers is double that of conventional systems, with 305-cm (10-ft) spacing on the troughers and 610-cm (20-ft) spacing on the return (21).

Belt wear is principally at transfer points because of impact and acceleration forces. Thus minimizing the transfer points is desirable for economical as well as environmental reasons.

Trucks

Trucks comprise a very minor part of the long-haul market. They are used mainly for initial or final shipment over short distances. The relatively low capital investment for trucks and their greater flexibility are the major reasons that smaller mine operators use them. In addition, many of the small operators move their coal through a tipple operated by someone else, where the coal is loaded for movement by rail or water. Table 3-4 lists truck shipments of bituminous coal in 1973.

Since the railroads generally expect mine operators to finance spur lines into the mine site, the large cost of building the spur must be justified by high-volume, long-term production. A small mine operator, who moves relatively often, cannot justify this large expenditure. The increasing number of strip mines, the increasing cost of rail trackage, the shortage of coal cars, and the availability of public roads influence more and more coal operators to use trucks (22). Often, the trucking is done by a private

Table 3-4. TRUCK SHIPMENT OF BITUMINOUS COAL,

BY STATE, 1973 (18)

(thousands of net tons)

	Shipments originated	Shipments received
Alabama and Mississippi	3,003	4,847 (a)
Alaska	115	(b)
Arkansas, Louisiana, Oklahoma, and Texas	142	244
Colorado	746	1,259
Delaware and Maryland	553	689
Georgia		
Illinois	3,393	5,540 (a)
Indiana	3,682	5,847
Iowa	439	459
Kansas	74	
Kentucky	6,094	9,979
Missouri	90	3,304 (a)
Montana and Idaho	28	80
New Mexico	3	7,330
New York		1,330
North Carolina		14
North and South Dakota		2,887 (a)
Ohio	11,555	15,836 (a)
Pennsylvania	17,824	20,618
Tennessee	2,618	2,376
Utah	1,492	1,355
Virginia	1,285	106
Washington and Oregon	24	30
West Virginia	3,776	3,181 (a)
Wyoming	45	5,670
Origin-destinations not revealable		223
Total United States (c)	57,268	93,004 (a)
Total destinations via truck		68,114

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[a] Includes shipments by tramway, conveyor, and private railroad, as noted.

[b] Included with all rail shipments.

[c] Data may not add to totals shown because of independent rounding.

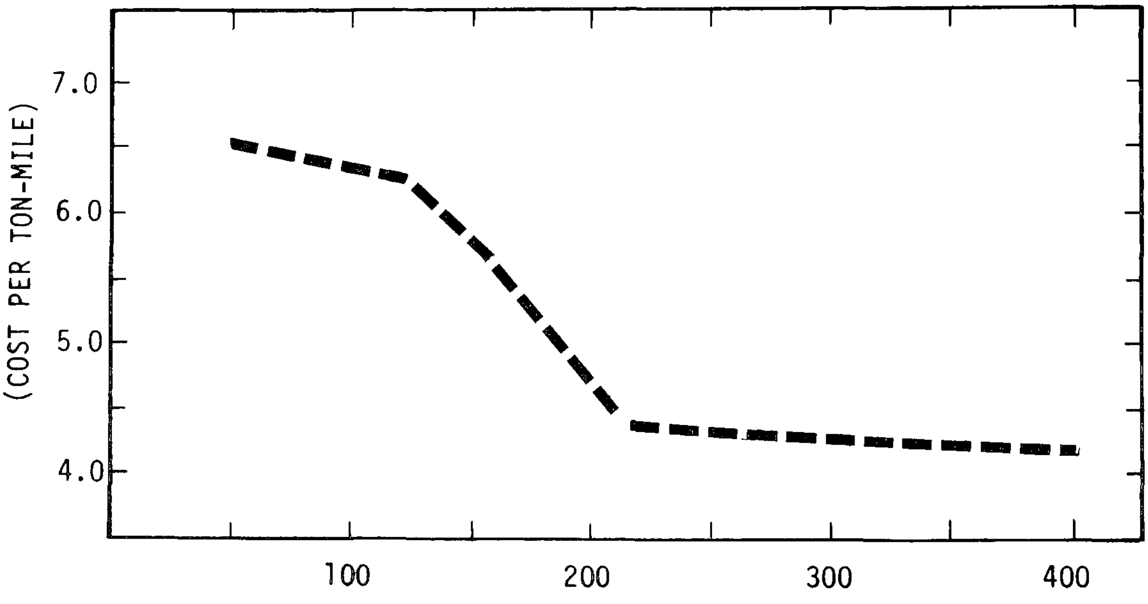
Metric conversion: 1 ton = 0.90718 metric ton.

individual or group under contract with the coal operator, who may find it economical to hire an outside trucker and concentrate on his mining operations.

Trucking came to be the major mode for short-haul transportation during the 1960's and early 1970's, largely because of the following factors:

1. Railroads offer no flexibility as old mines are closed and new mines are opened.
2. The efficiency and carrying capacity of trucks have increased.
3. National emphasis has been placed on building a superior highway network.
4. Other modes of transport are often unavailable.

Of all modes of transport, trucking is the most costly. Transportation under 240 km (150 miles) costs an average of \$0.04 per metric ton-km (\$0.06 per ton-mile). The cost curve for truck transport, shown in Figure 3-20, declines quickly with distance, but little increase in savings can be realized beyond distances of 322 km (200 miles) (22).



1 mile = 1.609 km

Figure 3-20. Cost of transporting coal by truck (22).

Most of the coal-hauling trucks on the highways are in the range of 18 to 27 metric tons (20 to 30 tons) capacity and travel about 8 km (5 miles) per gallon of fuel on the average. Trucks used for short, off-the-road hauls near or on mine sites are of various sizes, some as large as 154 metric tons (170 tons). Figure 3-21 illustrates a typical truck used for on-site mine coal hauls.

Figure 3-21. Typical truck used on-site at a coal mine.

Pneumatic Pipelines

A pneumatic pipeline represents relatively new technology for transporting coal. Basically, it is a pressurized pipeline into which granular coal is fed and conveyed in a suspended state by air pressure. Two major factors influence the economic feasibility: capital and operating costs of air compression equipment, and haulage capabilities. These factors in turn vary with characteristics of the pneumatic system: the diameter, length, and configuration of the pipe; and the size, size distribution, moisture content, and ash content of the coal (23).

Currently, the most feasible application of pneumatic pipelines appears to be movement of coal to and from a rail terminal, possibly allowing the railroad operators to abandon unprofitable spur lines and thus release money for upgrading their main lines.

Pneumatic pipelines could be particularly advantageous in the West because they require no water. An above-ground pneumatic system requires minimal ground prepartion, and it is almost portable if relocation is needed (24). Also, because gravity is not a large factor in pressure drop, a pneumatic pipeline can cover the steepest terrain by the most direct route.

Basically, a pneumatic pipeline system consists of a pump to supply air pressure, silos for storing the coal to be fed into the pipeline, and a cyclone and baghouse to remove it at the end. The optimal air pressure appears to be 10 atmospheres at a mass flow ratio (coal-to-air) of nearly 1 to 10 (23). Diameter of the pipe increases (telescoping) to accommodate the decrease in density (or increase in volume) as the pressure decreases along the pipeline. If a power failure occurs, the line must be temporarily closed down but the shutdown will not cause plugging of the pipes (23). At the terminal end a cyclone removes particles larger than 5 microns diameter at efficiencies of about 98 percent (23). The remaining particles may be removed in a baghouse. Estimated total operational cost is 1.4¢/metric ton-km (2¢/ton-mi).

Ozone, Inc., a Colorado company, has operated a pneumatic system with 10- and 15-cm (4- and 6-inch)-diameter pipes over a distance of 102 m (4000 ft). They are proposing a 34-km (21-mile) line from a mine in Carbondale to a coal spur. The line would operate at 10 atmospheres, transmitting 5440 metric tpd (6,000 tpd) of coal through a 36-cm (14-inch)-diameter pipe. The power requirement of approximately 3730 kW (5000 hp) would be supplied by one pump (23).

Very few tests have been conducted to determine optimal design. More studies must be made and test results analyzed before the extent of pneumatic pipeline utilization can be determined. To date such systems look very promising for short-distance transport to complement railroads and other modes of transportation. The potential for long-distance interstate pneumatic pipelines will be known only when tests are completed.

1985 PROJECTIONS FOR COAL PRODUCTION AND TRANSPORT MODES

Coal Production and Movement

It has been estimated that coal production will increase from the 1975 level of 581 million metric tons (640 million tons) to 1.09 billion metric tons (1.2 billion tons) in 1985 (24). Figure 3-22 shows 1975 and projected 1985 coal production by districts.

The origin and movement of coal, illustrated in Figure 3-23 A and B for 1975, is not expected to change dramatically but the flow of western coal to the east will undoubtedly increase as more mines are developed. These shipments will require substantially more energy per unit delivered than does transport from the interior region or Appalachia and thus will cause a significant increase in transport costs. These costs currently range from approximately 25 percent of the cost of the coal delivered from eastern coal fields to as much as 75 percent or more of the delivered price of coals shipped from Montana and Wyoming to electric utilities in the midwest.

1985 Projections for Coal Transport Modes

Approximately 67 percent of the bituminous coal and lignite production was shipped by rail in 1975. The inland waterway system, trucks, and mine mouth plants (tramway, conveyor, private rail) each accounted for about 11 percent of coal traffic. In addition, 3.8 million tons (0.6% of total) of coal was transported through the Black Mesa coal slurry pipeline. Table 3-5 presents a breakdown of coal transport by mode for 1975 and projections for 1985 (21).

SUMMARY OF COAL TRANSPORTATION COSTS

Table 3-6 summarizes the costs of coal transportation as derived from various published sources. The costs are presented in cents/metric ton-km (cents/ton-mile); they are based on hauling 22.7 million metric tons (25 million tons) of coal per year over a distance of 1610 km (1000 miles) except as indicated. The most controversial major studies are by the University of Illinois and Bechtel/ETSI which differ regarding costs of unit train and slurry pipeline transport of coal. The ETSI, "Chemical Engineering", and

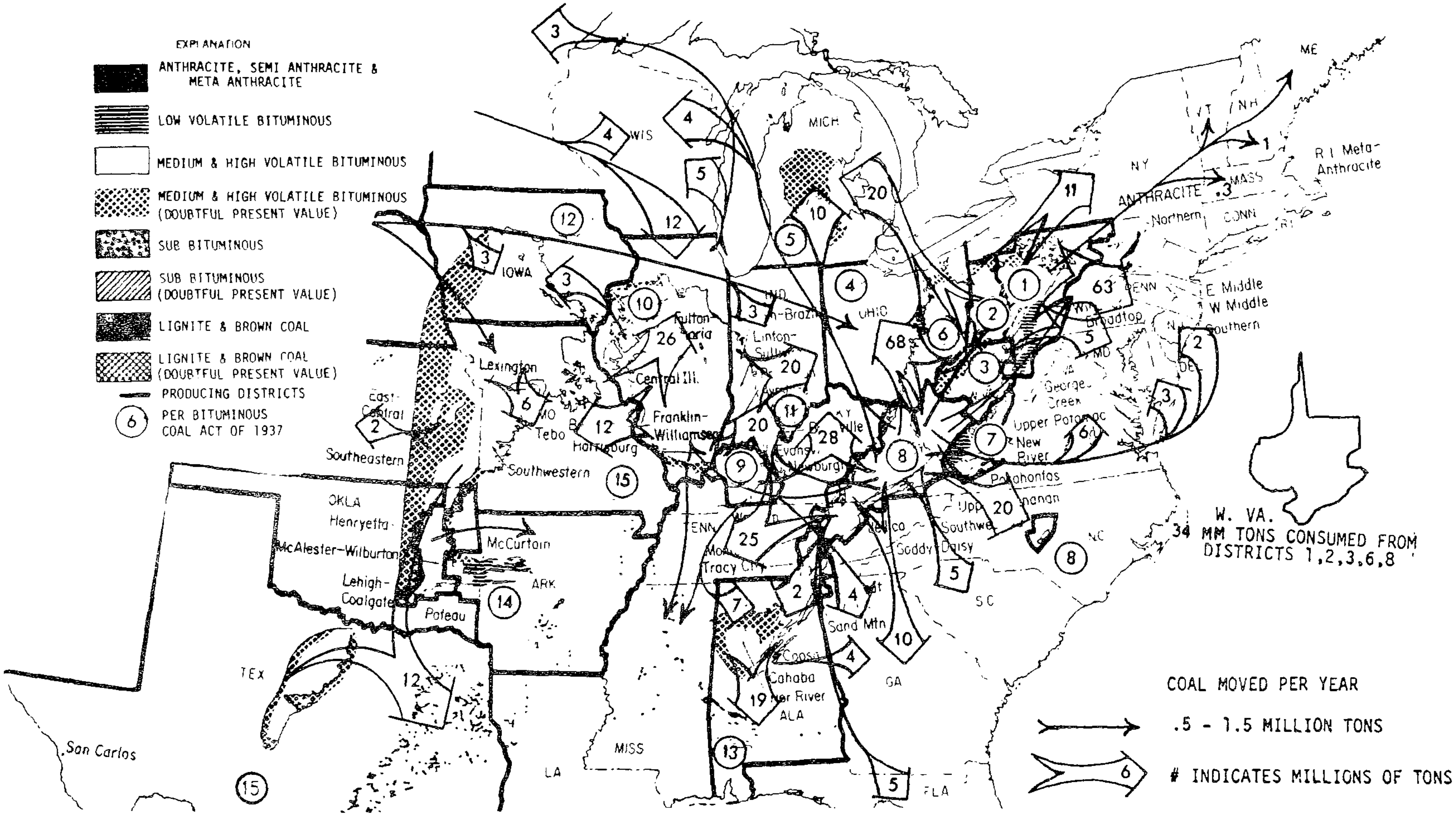


Figure 3-23A. Origin and movement of coal - 1975 (26, 27).

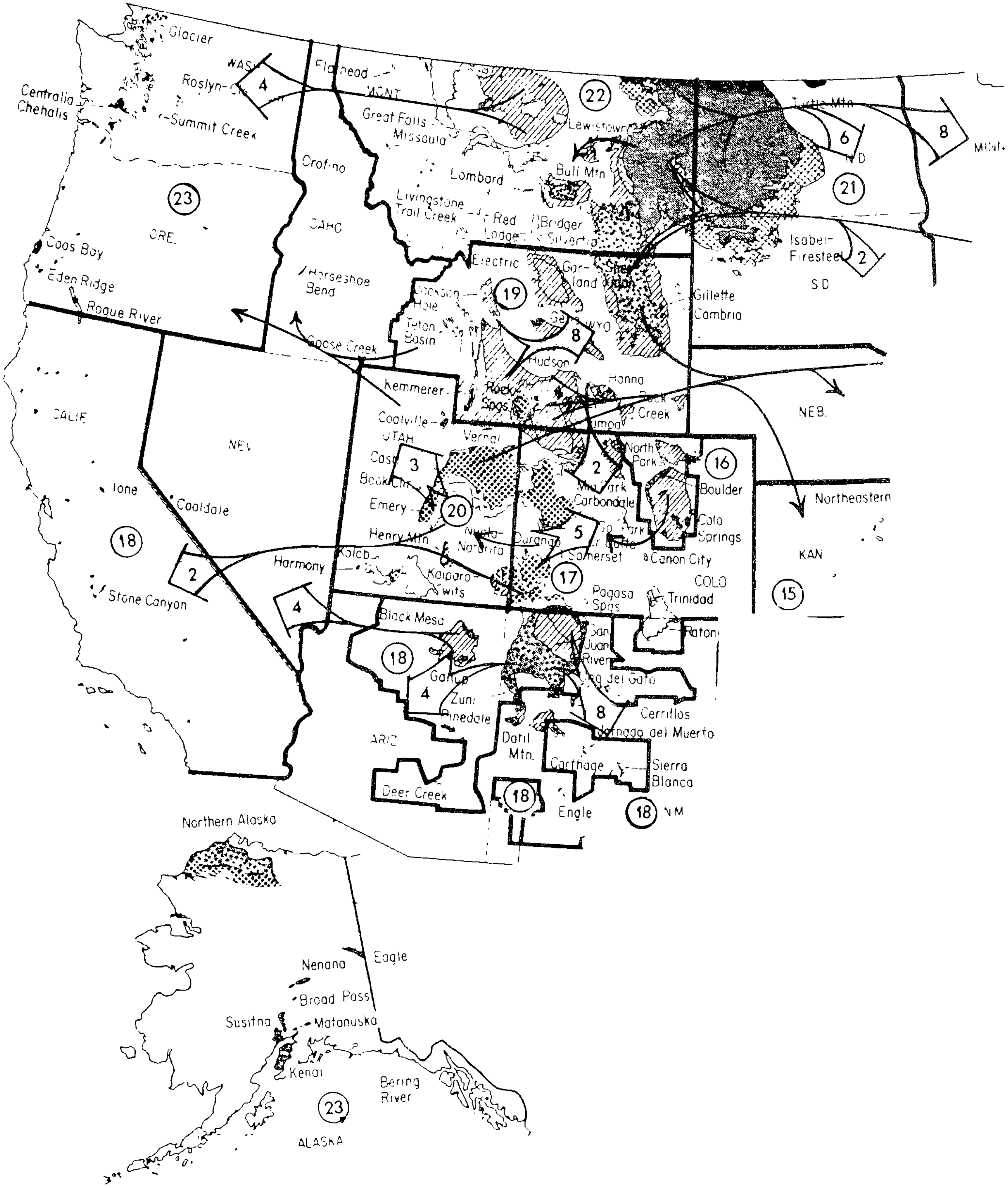


Figure 3-23B. Origin and movement of coal - 1975 (26,27).

Table 3-5. ESTIMATES OF U.S. COAL TRANSPORT BY MODE FOR 1975 AND 1985

Mode	1975		1985[a]	
	MM tons	%	MM tons	%
Rail	428	66.8	726	60.5
Barge	73	11.4	192	16
Truck	70	11.0	132	11
Pipeline	4	0.6	5	0.4
Miscellaneous[b]	65	10.2	145	12.1
Totals	640	100	1200	100

[a] Based on data from Bureau of Mines, 1985, projection, for their unconstrained mode (21, 25).

[b] Includes coal consumed at mine mouth: tramway, conveyor, and private rail; and overseas exports.

Metric conversion: 1 ton = 0.90718 metric ton.

Table 3-6. SUMMARY OF COST OF TRANSPORTING 75 MILLION TONS OF COAL PER YEAR A DISTANCE OF 1000 MILES

(except as indicated)

Source	Costs, cents per ton-mile					
	Rail	Slurry	Barge	Rail/Barge	Truck	Conveyor
Univ. of Illinois[a]	0.31	0.69				
ETSI[b]	0.80	0.51				
Bechtel[c]	0.70	0.39	0.34			
Ebasco[d]	1.00(2.88)	0.62(1.78)	0.45	0.80(2.30)		
Chem. Engineering[e]	0.4-0.9	0.3-0.7			5.0-8.0	2.0-6.0
Oil & Gas Journal[f]	0.6	0.36				
Elec. Lgt. & Power[g]	0.5-0.9		0.3-0.5 (inland waterways)			
Upper Midwest Council[h]	0.71	1.08				

[a] 1975 costs; 7% annual escalation rate for both rail and slurry; rail costs assume new rail 50-60 mph; slurry costs are for a new system.

[b] 1975 costs; new slurry line, existing rail facilities, includes purchase of hopper cars.

[c] 1975 costs for a 1978 installation date; assumes an annual escalation rate of 7% for rail and 4% for slurry pipelines. Rail = 147.04 (Distance) $^{-0.418}$ Barge distance = 600 mi. (70.93 (Distance)$^{-.285}$).

[d] Mid 1975 costs; Barges - 600 mi. distance, pipeline, all rail and rail/barge 900 miles; numbers in parentheses are costs based on 1980 starting date.

[e] 1971 costs; slurry, over 50 miles, unit train, over 400 miles, truck, no mileage given, conveyor belt, less than 15 miles.

[f] 1973 costs.

[g] 1973 costs.

[h] 1976 costs for transportation of 12 million tons per year of coal over a distance of 700 miles.

Metric conversion: 1 ton = 0.90718 metric ton
1 mile = 1.609 kilometer

"Oil and Gas Journal" sources were prepared by ETSI members at different times.

On the basis of these data, it is difficult to compare precisely the costs of transporting coal in a wide range of volumes and regularity of shipments to an even wider variety of destinations. The studies clearly indicate, however, that long-distance pipeline and rail shipments of coal are both feasible in a comparative cost sense. Therefore, both are viable possibilities, especially for shipment of western coal, where new mines will typically support large-volume movements. Although about 15 percent of coal tonnage moves on inland and coastal waterways, this traffic is limited to that originating from mines adjacent to existing waterways or coal shipped to waterways from distant mines. The cost of water shipment is typically lower than costs for the same service by rail (21).

In a choice between pipelines and railroads, neither seems to be superior to the other in a general evaluation. In specific cases, however, one mode might be preferred, though likely by a narrow margin. In any proposed cost analysis, therefore, the circumstances should be reviewed in light of the best current information.

Should the Bechtel/ETSI rationale prove to be realistic, use of pipelines can be expected for very large shipments, with the railroads continuing to dominate the field for transport of large but not huge volumes of coal.

On the other hand, if the University of Illinois rationale proves to be realistic, operation of slurry lines would be expected only where no rail facilities are available. If the railroads can handle the expected increase in coal production, they would have a definite cost advantage over the slurry lines, even if the existing rail lines had to be considerably upgraded.

ENERGY REQUIREMENTS FOR COAL TRANSPORTATION

Data are available from a number of sources on energy requirements for transporting coal by various methods. Table 3-7 summarizes these data, which show a wide range of energy requirements depending on the source and whether the estimate includes the entire transport system.

Table 3-7. ENERGY REQUIREMENTS OF VARIOUS COAL TRANSPORT MODES FROM PUBLISHED SOURCES

Transport method	g-cal metric ton-km	Btu/lb	Source
Pipeline	51,000	295	Energy Transport Systems, Inc. (24)
	170,000	980	Upper Midwest Council[a]
	310,680	1800	Rand Report (30)
Railroad	43,000	250	American Association of Railroads (24)
	129,000	750	Rand Report (30)
Barge	86,300	500	American Waterways Operators (30)
Truck	870,000	5040	Zandi and Kim (24)
	964,000	5583	Zandi and Kim (24)
	414,000	2400	Rand Report (30)

[a] Murphy, Michael V. Northern Great Plains Coal: Conflicts and Options in Decision Making. Upper Midwest Council. April 1976.

This section presents PEDCo's estimates of the energy required to transport coal by rail (unit train), slurry line, barge, truck, and conveyor belt. Rail and slurry line transport are the most important, since they are the most likely to affect the future of coal transportation. These comparisons are based on energy requirements for processes in each system in addition to the transportation portion. Data on the 440-km (273-mile) Black Mesa pipeline (1975) are used as a base, and energy requirements of unit trains and barges are adjusted to reflect a 440-km (273-mile) trip. Trucks and conveyors are assumed to travel short distances [8 to 32 km (5 to 20 miles)]. Energy requirements are presented in g-cal/kg (Btu/lb) and g-cal/metric ton-km (Btu/ton-mile). The g-cal/kg (Btu/lb) unit shows how much of the energy in a kg (lb) of coal is needed for various operations.

Slurry Pipeline --

Calculation of energy requirements for the Black Mesa line includes power consumption for slurry preparation, transportation, dewatering (including heating of the slurry), gas consumption to dry the slurry in the primary air ducts, and reduction in heating value of the coal finally fired due to the additional water it contains (heat of vaporization, sensible heat loss). A flue gas temperature of 280°F is assumed. Table 3-8 summarizes the estimated energy consumption of the Black Mesa pipeline.

Unit Trains --

Computations of energy requirements for unit trains are based in part on data from the Hittman Report (28). Included are the heating value loss due to diesel oil consumption; fugitive dust emissions (assumed to be 0.09%) in loading, unloading, and transit; and power consumption for crushing at the power plant. Heat of vaporization and sensible heat loss are included in 10,858 Btu/lb heating value used as a reference.

Table 3-9 summarizes energy requirements of a unit train, based on the same conditions used in the Black Mesa pipeline calculation. The two are not directly comparable since the Black Mesa line was built because the terrain was too difficult for trains; with terrain suitable to unit trains, however, the two would be comparable, although the rail distance required would probably be greater than that for the pipeline.

Table 3-8. SUMMARY OF ESTIMATED ENERGY REQUIREMENTS, BLACK MESA COAL SLURRY PIPELINE (1975 DATA)

Source of energy loss	Btu/lb	Btu/ton-mile[a]	% of energy transported
Power consumption (slurry preparation, pumping, dewatering)	78	576	0.72
Gas consumption (required to dry incoming coal cake to furnace to prevent coal "plastering"	130	950	1.2
Heat loss (slurry heating with steam to 140°F, to increase efficiency of centrifuges and pulverizers)	107	782	0.98
Coal quality loss (due to 29% combined moisture content of coal cake and underflow, includes latent heat of vaporization plus sensible heat loss)[b]	2,467	18,035	22.7
Total	2,782[c]	20,343	25.6

[a] 1.03×10^9 ton-mi in 1975 based on 3,765,000 contract tons shipped a distance of 440 km (273 miles).

[b] Assumes a flue gas temperature of 280°F.

[c] Additional energy required to generate electricity to run pipeline not included (approx. 156 Btu/lb).

Metric conversion: 1 Btu/lb = 114.3 g-cal/kg
1 Btu/ton-mi = 172.6 g-cal/metric ton-km

Table 3-9. SUMMARY OF ESTIMATED ENERGY REQUIREMENTS FOR 273 MILE UNIT TRAIN HAUL OF 3,765,000 TONS OF COAL ANNUALLY

Source of energy loss	Btu/lb	Btu/ton-mile	% of energy transported
HV loss due to fuel oil consumption[a]	95	694	0.87
HV loss due to fugitive emissions, loading, unloading in transit[b]	10	71	0.09
HV loss due to crushing at power plant[c]	30	219	0.28
Totals	135	984	1.24

[a] (28)

Fuel consumption = (0.005 gal/ton-mi)(1.03x10^{9} ton-mi/yr)

= (5.15x10^{6} gal./yr) (138,800 Btu/gal.)

= 7.15x10^{11}Btu/hr

= 694 Btu/ton-mi

[b] Assumed to be 0.09%.

[c] (29)

Metric conversion: 1 Btu/lb = 114.3 g-cal/kg.
1 Btu/ton-mi = 172.6 g-cal/metric ton-km

Table 3-10. SUMMARY OF ESTIMATED ENERGY REQUIREMENTS FOR 273-MILE BARGE HAUL OF 3,765,000 TONS OF COAL ANNUALLY

Source of Energy loss	Btu/lb	Btu/ton-mi	% of energy transported
HV loss due to fuel oil consumption	68	500[a]	0.63
HV loss due to crushing[b] at power plant	30	219	0.28
HV loss due to fugitive dust emissions[c]	7	48	0.06
Totals	105	767	0.97

[a] (30)

[b] (29)

[c] Assumed to be 0.06%.

Metric conversion 1 Btu/lb = 114.3 g-cal/kg.
1 Btu/ton mi = 172.6 g-cal/metric ton km.

Table 3-11. SUMMARY OF ESTIMATED ENERGY REQUIREMENTS FOR TRUCK TRANSPORT OF COAL (30-TON PAYLOAD, 20 MI. ONE WAY)[a]

Source of energy loss	Btu/lb	Btu/ton-mile	% of energy transported
HV loss, fuel oil consumption[b]	22	2,150	0.20
HV loss, crushing at power plant[c]	30	3,000	0.28
HV loss, fugitive emissions[d] from loading, unloading, in transit	10	1,000	0.09
Totals	62	6,150	0.57

[a] Coal as received at mine = 10,858 Btu/lb.

[b] Fuel use =

1.62×10^{-4} gal/lb trip

Energy required = (1.62×10^{-4})(6.8 lb/gal)(19,800 Btu/lb) = 22 Btu/lb.

[c] (29).

[d] Loading plus unloading = 0.04%; in transit = 0.05%.

Metric conversion: 1 Btu/lb = 114.3 g-cal/kg.
1 Btu/ton-mile = 172.6 g-cal/metric ton-km.

Table 3-12. SUMMARY OF ESTIMATED ENERGY REQUIREMENTS FOR CONVEYOR TRANSPORT OF COAL (10 MILES, 3 TRANSFER STATIONS)[a]

Source of energy loss	Btu/lb	Btu/ton-mile	% of energy transported
HV loss, power consumption[b]	4	800	0.04
HV loss, crushing at power[c] plant	30	6,000	0.28
HV loss, fugitive emissions[d] at transfer points (3) and in transit	7	1,400	0.06
Totals	41	8,200	0.36

[a] Coal as received at mine = 10,858 Btu/lb.

[b] (31).

[c] (29).

[d] Transfer points = 0.04 percent; in transit = 0.02%.

Metric conversion: 1 Btu/lb = 114.3 g-cal/kg.
1 Btu/ton-mile = 172.6 g-cal/metric ton-km

Table 3-13. ESTIMATED ENERGY REQUIREMENTS OF VARIOUS COAL TRANSPORTATION SYSTEMS

Mode	Btu/lb	Btu/ton-mile	% of total Btu transported
Slurry line[a,b]	315 (2782)	2308 (20,343)	2.9 (24.4)
Unit train[a]	135	984	1.24
Barge[a]	105	767	0.97
Truck[c]	62	6150	0.57
Conveyor[d]	41	8200	0.36

[a] Based on 273-mile trip; 3,765,000 tons coal per year; 10,858 Btu/lb as received at the mine.

[b] Numbers in parentheses include heat loss because of additional water content of fired coal.

[c] Twenty-mile one-way trip, 30-ton payload.

[d] Based on telephone conversation with personnel at American Electric Power for the Meigs Mine Conveyor; 10-mile trip, 2000 tons/hr.

Metric conversion: 1 Btu/lb = 114.2 g-cal/kg.
1 Btu/ton-mile = 172.6 g-cal/metric ton-km

SECTION 4

ENVIRONMENTAL IMPACTS ASSOCIATED WITH COAL TRANSPORTATION

IMPACTS FROM COAL PREPARATION AND ASSOCIATED ACTIVITIES

By whatever means coal is transported, some type of preparation always precedes shipping. Preparation can consist of (1) complete preparation - cleaning both coarse and fine coal, (2) partial preparation - cleaning only coarse coal, and (3) simple crushing of the coal to a specific size (32). This section describes the environmental impacts of coal preparation and the associated activities that occur before the coal is transported.

Coal Cleaning Operations

Pulsating air columns and thermal dryers are the major sources of airborne emissions from coal cleaning operations. Pulsating air columns (dry process method) release approximately 1.4 kg (3 pounds) of particulates per metric ton (ton) of coal. Thermal dryers release both particulates and combustion products. Coal is the primary fuel used to produce the hot gases that evaporate moisture from the product; fuel oil is used at some installations, especially during startup.

Dust loading of the effluent from a dryer operating at 65°C (150°F) with throughput of 0.085 to 56.6 m^3/sec (180 to 120,000 cfm) of 0.64-cm (1/4-inch) centrifugal coal and filter coke can exceed 5.7 g/m^3 (2.5 gr/ft^3), with the following particle size distribution (23):

0 to 2 micron	55% by weight
2 to 5	33
5 to 10	11
10+	1

Primary dust collectors are cyclones followed by wet collectors and demisters. Conventional scrubbers have not proved effective on thermal dryers, but high-energy venturi scrubbers with demisters have reduced the grain loading in several installations from a high of 2.3 g/Nm^3 to 0.017 g/Nm^3 (5.5 scf to 0.04 scf) (33).

Refuse piles are a constant source of combustion and dust-related air pollution. Emissions from the piles, in addition to blowing dust are H_2S, SO_2, and smoke. Other noxious gases released from burning piles include CO, ammonia, and carbon disulfide.

Contaminants in the process water from wet coal cleaning consist of suspended solids, which are chiefly fine clay and coal, and dissolved solids, which may contain iron, aluminum, calcium, magnesium, sodium, and potassium. Water effluents may also contain surface active organic compounds such as alcohols or kerosene, which are added in some coal cleaning plants to enhance frothing. Water contaminants in refuse pile runoff include sulfuric acid, sulfates, manganese, and iron, aluminum, and other heavy metals.

Open Coal Storage --

Stockpiles have been used widely at mine preparation plants and loading stations since the advent of the unit train. The intent is to store enough coal to load one unit train, usually 3630 to 9070 metric tons (4000 to 10,000 tons). Some of the stockpiles are designed to contain several days' production or up to five unit trains capacity (45,360 metric tons or 50,000 tons). At power plants the coal storage piles may contain a 60-day supply.

The two primary forms of air pollution from open coal storage piles are blowing dust and combustion products. Escape of fugitive dust is discernible, but the rate is unknown and variable. If the pile is in constant use, no stability is achieved, and effective chemical treatment is difficult.

Several activities cause fugitive dust emissions from the storage area (34). Midwest Research Institute (MRI) evaluates the four major emissions-producing activities in crushed-rock storage and their approximate relative contributions are as follows: (35)

Loading onto piles	12%
Equipment and vehicle movement in storage area	40%

Wind erosion	33%
Loadout from piles	15%

Although such percentages may vary with storage of different materials and with specific storage area configurations, the same activities constitute the major dust sources in all types of open storage.

In an earlier EPA study the Monsanto Research Corporation measured dust losses from a coal storage pile during two sampling periods. The coal pile produced emissions at rates of 0.0045 and 0.008 kg/metric ton (0.009 and 0.016 lb/ton). By use of additional information on the storage throughput rate (36), these values were converted to an annual emission rate of 0.027 kg/metric ton (0.054 lb/ton) placed in storage. No loading or unloading took place in the storage area during either sampling period.

Methods for control of dust from coal storage piles are limited in effect or are very expensive. As a minimum the piles should be capped with larger-size coals to prevent loss of fines due to wind. Bituminous coal should be packed and sealed to prevent fires. Some installations use concrete silos, which hold up to 9070 metric tons (10,000 tons) tons each and control dust effectively. An earthen impoundment also can contain and control the coal mass, as shown in Figure 4-1. This method also reduces dead space to a minimum, but is not entirely effective in controlling dust.

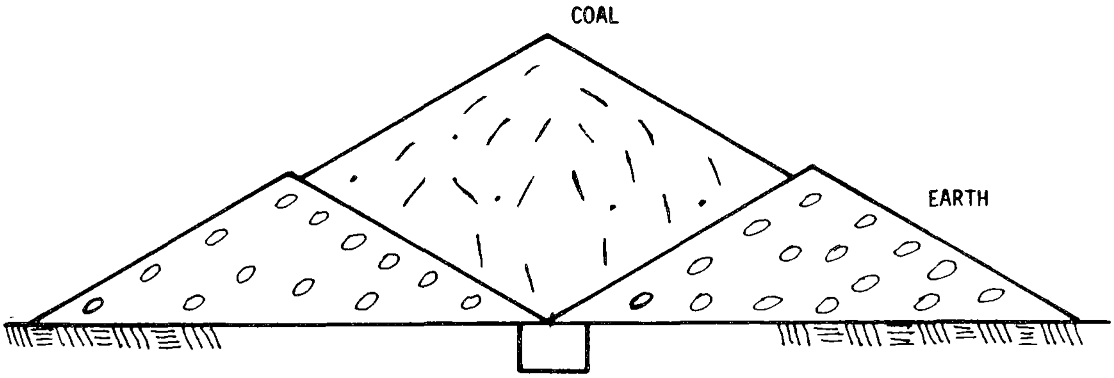


Figure 4-1. Earthern impoundment for control of dust from coal storage piles.

Unloading Bins --

Bins into which trucks dump coal, with feeders underneath to transfer coal to a conveyor, are very common. Dust can escape where the trucks dump at the top and where the feeders empty the coal at the bottom. The escape is substantial if the coal is dry and fine and if wind speed is high. Emissions are controlled at the bottom with sprays or a dust collector with bags or a scrubber. Enclosure of the top of the bin on three sides and with a sloping roof will contain the dust in most cases. If supplemental control is required, curtains can be hung to partially close the opening while a truck is dumping. A dust collector can then be used with some effectiveness.

In two other separate studies, PEDCo used a dust emission value of 0.01 kg/metric ton (0.02 lb/ton) for truck dumping, based on a 50 percent reduction in dust due to watering (35).

Sprays do not function well at bin-loading operations because the area is so large and the dust surge is violent and intermittent.

Crushers --

A crusher house usually contains vibrating screens to remove the undersize coal for bypass and a hammermill to reduce the large coal to specified size. Crushers may operate at the mine, the preparation plant, or the power plant. Crushers are used universally in all sections of the country, sometimes combined with a cleaning plant.

Crusher installations are extremely dusty and noisy and if not enclosed would lose 1 or 2 percent of the coal to the air, depending on wind velocity and the coal being crushed. Soft coal (typically Pocahontas No. 3) with a low moisture content would create the most dust, and Western subbituminous coal of 25 to 30 percent moisture would create the least.

The crusher is normally enclosed, but dust control equipment is not always provided. The basis for positive control is some combination of dry and wet cyclones, washdown equipment, and sprays. Baghouses are also suitable.

Loading Stations --

A loading station is a structure for loading a unit train at a rate up to 5440 metric tph (6000 tph) (one 100-ton car per minute). The station consists of a surge bin above the track large enough to hold incoming coal while cars are changing, a loadout chute, and a control room. Another type of loading station involves a 9070-metric-ton (10,000-ton) silo, under which the unit train moves for loading. These stations, or similar ones, are located everywhere unit trains are loaded (see Figure 4-2).

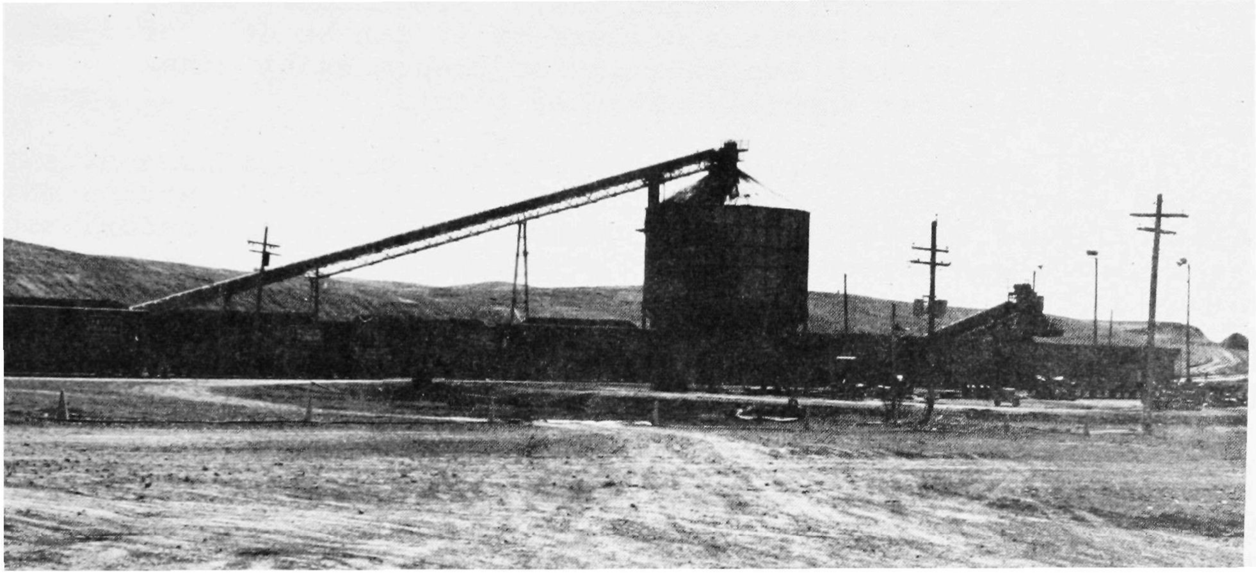


Figure 4-2. Loading station for unit train.

Use of a loadout chute can prevent an enormous amount of dust and spillage when coal is transferred to cars in such high volumes. The chute is a large, vertical telescopic device that travels to the car bottom with each new car, raises with the coal as the car is filled, stops and crowns the car, stops the flow of coal as cars are changed, and repeats the cycle. During loadings, the chute remains in contact with the coal in the car and thus prevents the escape of dust and spillage. Water sprays are not commonly used.

An uncontrolled emission value of 0.2 kg/metric ton (0.4 lb/ton) is used in Section 4 of this report for application to loading or unloading activities in all modes of transport; this value is based on information developed by Hittman Associates (37).

Emissions Estimate - Coal Preparation And Associated Activities --

Table 4-1 summarizes atmospheric emissions from a preparation plant that processes 5720 metric tons (6300 tons) per day of run-of-the-mine (ROM) coal (38).

Energy and Water Requirements - Coal Preparation and Associated Activities --

Energy required for coal cleaning plants is supplied as electrical energy and diesel oil. Electricity, the main energy source, is consumed at the rate of 3.4 kWh/metric ton (3.7 kWh per ton) of coal cleaned (38). Electricity can be generated by in-plant process boilers or it can be delivered by transmission lines. Availability of transmission lines can be a problem for remotely situated plants.

A coal preparation plant producing 9100 metric tons (10,000 tons) of cleaned coal per day needs about 2.2 million liters (580,000 gallons) per day of makeup water for wet cleaning operations (38). Water supply for such purposes may be a problem in the siting of large coal preparation plants, especially in arid sections of the nation.

IMPACTS FROM COAL SLURRY PIPELINES

Among the modes of coal transport in this study, pipelines transport the smallest volumes. The only pipeline now operating is the Black Mesa Pipeline, which began commercial operation in 1971.

The environmental impacts from pipelines are considered in relation to the periods of construction, operation, and abandonment of the system.

Construction of Pipeline

The terrestrial environment is likely to be the most affected by construction of a slurry pipeline. Construction of a 61-cm (24-inch)-diameter pipeline requires up to 25,150 m^2/km (10 acres/mile) of land; two pipelines sharing a common right-of-way would require approximately 30,200 m^2/km (12 acres per mile). The right-of-way would preempt any development. In most areas, this would be an unimportant effect.

Table 4-1. ATMOSPHERIC EMISSIONS FROM COAL PREPARATION AND ASSOCIATED ACTIVITIES[a]

Basis: 6300 ton/day ROM coal

Source	Emissions lb/day				
	Particulates	SO_2	CO	Hydrocarbons	NO_x
Primary crushing[b]	125				
Loading and unloading at the Preparation Plant[b]	50				
Thermal drying[c]	7	1292	34	17	612
Vehicle emissions from refuse hauling operations	0.9	1.8	15	2.9	25
Total	83	1294	49	20	638

[a] Based on data from (38).

[b] 80 percent particulate control by water spraying and dust control techniques.

[c] 99 percent particulate control by negative pressure apparatus plus wet scrubbers.

Metric conversion: one pound = .4536 kg
one ton = .90718 metric ton

Removal of vegetation and trenching cause various impacts on the environment. During construction all cover vegetation is likely to be removed and destroyed. Removal of the vegetation destroys wildlife habitat, which may not recover for a long period of time. Wetlands are particularly susceptible to such disturbance because of their high productivity and their intolerance to environmental upset.

Removal of cover vegetation also brings about the potential of erosion by water and/or wind. Microclimatic changes may occur along the right-of-way as removal of vegetation alters the humidity levels, surface temperatures, and wind fields. These changes also can affect the types of wildlife that inhabit the area.

Traffic by trucks and construction equipment hauling and stringing the pipe will cause emissions of fugitive dust. This increase in human activity in remote areas may adversely affect fauna that are intolerant of human beings and the disturbances they bring. Accidental spills of materials used in pipe coating may contaminate soils and hinder revegetation.

Further, fauna can die from ingestion of small foreign objects such as nuts, bolts, and metal shavings. Therefore, the area must be thoroughly monitored and cleaned when construction ends.

A pipeline may cross moving bodies of water at various points. Usually the pipe is placed in a trench in the river bottom and buried, rather than laid on a support bridge over the river. This phase of construction causes serious disruption of aquatic life. Benthic organisms would be severely disturbed at the site where the pipe is laid and high levels of suspended solids resulting from bottom disturbance can damage aquatic life downstream. At the same time, runoff of sediment from construction near the stream, if not properly controlled, will adversely affect aquatic life. Among the detrimental effects are clogging of fish gills, covering of benthic organisms and eggs, and reduction of photosynthetic capabilities because of increased turbidity.

All of these impacts in the construction phase can be prevented or greatly limited if proper precautions are taken. Removing as little vegetation as possible, keeping noise and vehicle movement to a minimum, policing the construction area, and promptly implementing revegetation programs will aid in preserving the environment.

Operation of Pipeline

Coal Enroute --

No air emissions are directly attributed to the transfer of coal by slurry pipeline under normal operating conditions. The pump stations, located 100 to 160 km (60 to 100 miles) apart, are electrically powered. Noise from the pump stations is not considered an offsite problem since these stations are usually located in remote areas and the buildings in which the pumps are housed provide a shield to reduce the noise.

Because availability of water in the western States is relatively low, the matter of water usage raises the most controversy concerning possible operational impacts of slurry pipelines. The exact impacts of water withdrawals for a slurry pipeline have not been determined. Each case must be evaluated in relation to the local conditions. Water used to slurry the coal will be pumped from local water supplies, and at present it is uneconomical to return it. Thus the local area will benefit only indirectly from use of the water, i.e., from any economic benefits of the pipeline. If the water supply is plentiful, then impact from water usage would be minimal. Appendix A discusses in greater detail the availability of water in the semiarid western states.

Another concern is the possibility of an accidental release of slurry by a pipeline break or pump station malfunction. The slurry could cause damage to agricultural crops and/or local vegetation, and the runoff could adversely affect nearby water bodies. Since pump stations are designed with holding ponds for use in case of malfunction, the major impacts would occur only in the case of a pipeline break.

A pipeline break could cause fine particles of coal to be spread over the surface of the soil and to be mixed with it. The surface particles may also prevent absorption of water into the soil. Additionally, the fine particles may be a source of fugitive dust.

Use of saline water in the slurry involves an additional environmental hazard. Under normal circumstances, one may assume that slurry would be discharged from any uphill sections of the pipe on either side of a break. In the worst case, a break would occur in a valley between two high ridges. Assuming a 96-cm (38-inch) pipeline, 100 km (60 miles) of pipe between ridges, a slurry of 50 percent solids, an average water depth of 15 cm (6 inches) over flat terrain, a pipeline break would inundate a total area of about 220,000 m^2 (50 acres), leaving about 388 grams/m^2 (36 grams/sq ft) of salt from transport water having saline content of 5000 mg/liter (9). Flooding of alkali soils in arid areas with this amount of sodium salts, even in a one-time release, could considerably worsen their suitability for vegetation. In good soils, however, absorption of salts would have little effect, and all effects would disappear with rainfall. A one-time spill of this quantity of saline water (about 4.16 million liters or 1.1 million gallons) into a local aquifer would be of little lasting consequence as a result of dilution. In some areas crops are irrigated with water containing up to 3000 mg/liter of total dissolved solids. The effect of discharge into a watercourse would be totally dependent on the stream-flow at the time. The added impact of saline water is greater in a watercourse than that of a fresh water slurry, since the salt effects extend over much longer reaches of the stream than the effects of coal fines.

The potential rupture of a coal slurry pipeline is an unsolved environmental problem, although the technology for monitoring breaks is sophisticated enough to prevent the occurrence of breaks under normal circumstances. Protection from internal and external corrosion is provided by use of high-grade welded seamless pipe of adequate wall thickness, by protective wrapping of the pipe, by use of corrosion inhibitors and cathodic protection during operation, and by placing the pipe deep enough in the ground. Figure 4-3 is a photo of the Black Mesa pipeline as it exits from a pump station. Accidental breakages caused by natural flows or flaws in the pipeline are theoretically reduced to a minimum.

Terminal At A Power Plant

At the power plant, the slurry must be dewatered. The dewatering process is a particularly difficult aspect of slurry pipeline operation. Common problems that have been encountered in dewatering slurried coal include loss of coal fines through the system because of inadequate flocculation and removal and plastering in the feed ducts and in the boiler because the coal remained too moist. The higher the moisture content of the coal, the greater the heat loss through the boiler, as illustrated in Figure 4-4.

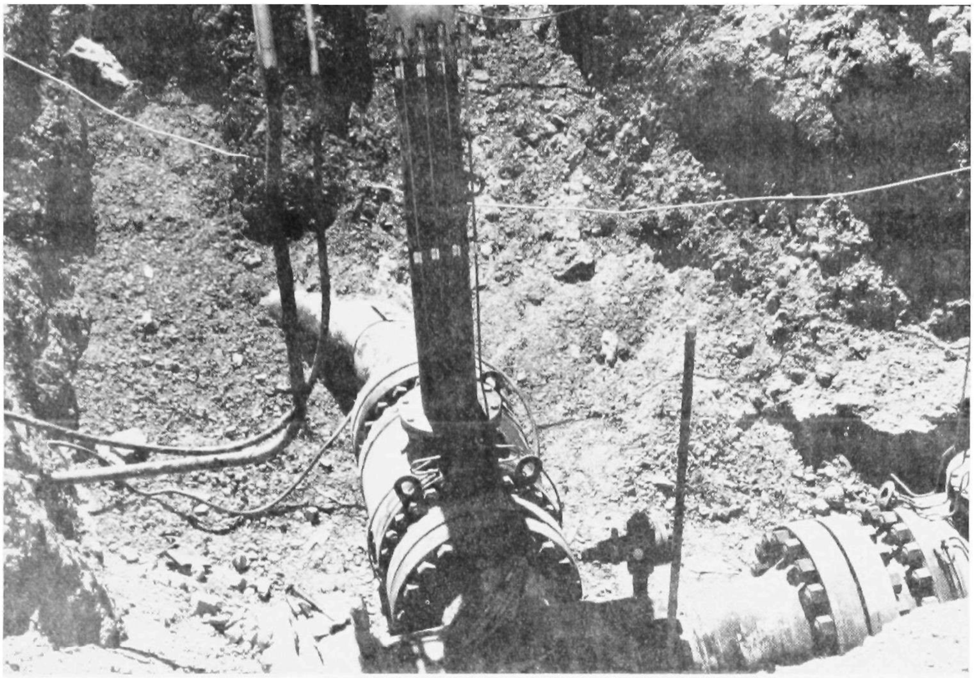


Figure 4-3. Photo of Black Mesa line as it exits from a pump station.

Coal fines discharged to a waste pond can cause fugitive dust emissions if the water is allowed to evaporate.

Another potential problem is lowering of the flue gas temperature below the acid dew point, which leads to corrosion of air heaters. The higher the moisture content of the coal, the higher must be the temperature of the flue gas to prevent corrosion. Change in ash composition can also be caused by leaching of soluble compounds. The subsequent effect on ash properties could result in fouling, slagging, and ash fusion.

The loss in heating value of the coal due to its excess moisture content was discussed in Section 3.4.

The dewatering of slurry and treatment of coal fines are continuing problems that will likely be encountered with future pipelines; at present these environmental problems remain unsolved.

Fate of Slurry Water --

The literature indicates that a variety of chemicals may be added to coal slurry to prevent corrosion of the pipeline, to improve the velocity of the slurry, and to maintain pH. The chemicals for this purpose include chromates, phosphates, and various organic compounds. Dose rates may be as high as 1000 ppm (39).

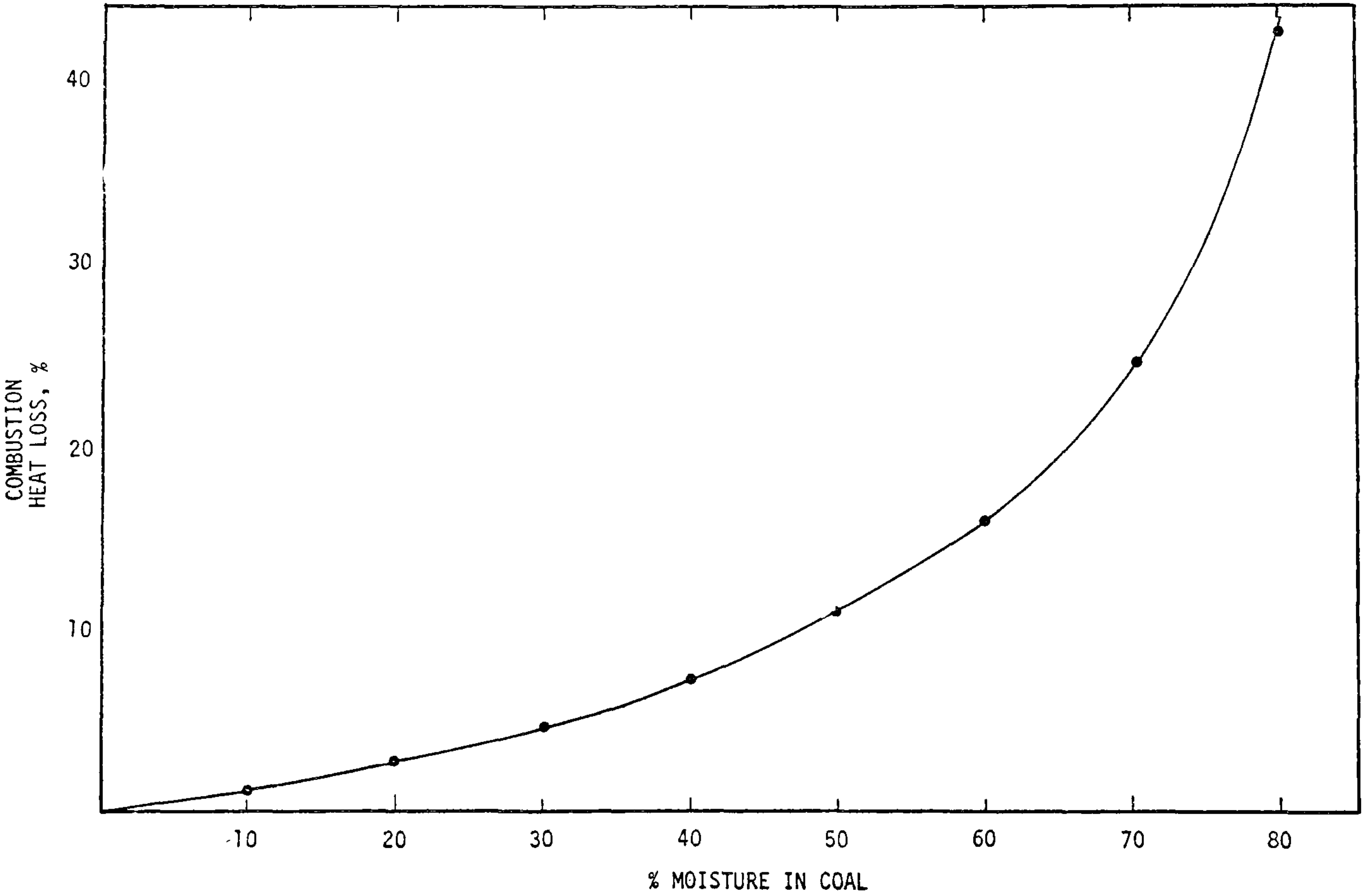


Figure 4-4. Combustion heat loss as a function of coal moisture content (350°F flue gas temp. assumed).

The total accumulation of dissolved solids in slurry water reflect the condition of the water in its natural state and the soluble components of organic and inorganic materials in the coal, corrosion products from the pipeline, and additives. Mineral species in the coal can include a range of soluble metals such as iron, aluminum, calcium, sodium, and manganese, and anions such as chlorides, sulfates, and carbonates. Dissolved organic compounds have not been specifically identified.

The dissolved species that occur in slurry water originate primarily from minerals in the coal. The major classes of minerals in coal, according to Spackman and Mores, and their potential for dissolution under various conditions are described in the following text (40, 41).

Shale group - The principal shale minerals found in coal are muscovite $K_2O \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot 2H_2O$; illite K (MgAlSi) $(AlSi_3)O_{10}(OH)_8$; and montmorillonite $(MgAl)_8(Si_4O_{10})_3(OH)_{10} \cdot 12H_2O$. These are complex silicates containing K, Al, and Mg in various ratios. In general, silicates are insoluble in water and weak acid solutions, an indication of low potential for dissolution in coal slurry lines.

Kaolin group - The principal kaolin mineral in coal is kaolinite $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$. This is an aluminum silicate, insoluble in water and acids, except HF. This mineral has a low potential for solubility in coal slurry pipelines.

Sulfide group - Two principal sulfide minerals in coal, pyrite and marcasite, have the same general formula FeS_2. Both minerals are virtually insoluble in water and dilute acids, except HNO_3. The sulfide minerals are susceptible to oxidation, however, especially in neutral or alkaline systems. The oxidation of pyrite has been studied in much detail because pyrite oxidation products are the principal contaminants in acid mine drainage. Oxidation of pyrite can occur by both chemical and biological mechanisms. The principal oxidation products are $FeSO_4$, H_2SO_4, and hydrous ferrous and ferric oxides, depending on the pH of the resulting solution. Sulfide oxidation occurs more rapidly under conditions of slight moisture and slightly elevated temperature, such as might occur in a coal storage pile. One method of preventing or minimizing the dissolution of sulfide oxidation products is to slurry freshly mined coal. Weathered coal almost invariably contains some sulfide oxidation products that are soluble in the slurry water.

Carbonate group - The principal carbonate minerals in coal are calcite ($CaCO_3$), siderite ($FeCO_3$), and related calcium, magnesium, iron carbonates. Carbonates are slightly soluble in water. They can react with acidic components in solution, however, and the resulting carbonate content of the solution can be significant. Although carbonates, per se, are not environmental problems, they can contribute to water hardness and to scale formation. The dissolution of iron carbonate may also discolor water.

Chloride group - Sylvite (KCl) and halite (NaCl) are both extremely soluble in water. The solutions formed are known to be corrosive. Removal of chlorides from the coal by dissolution may in fact improve the coal ash combustion characteristics. Chlorides in coal have been found to contribute to corrosion of boiler tubes. The mechanism of corrosion is more related to the Na and K content of the ash, i.e. the Na and K content of the chlorides.

Oxide group - Quartz (SiO_2), hematite (Fe_2O_3), and magnetite (Fe_3O_4) are the common oxides found in coal. Quartz is insoluble in water and acids and very slightly soluble in alkaline solutions. Both hematite and magnetite are insoluble in water but slightly soluble in weak acid solutions. The oxides have no significant potential for dissolving in slurry water.

Many other minerals are found in coal in trace or minor amounts. Characterization of the mineral content of the western coals, including the lignites and subbituminous coals, remains to be completed. Some of the lignite and subbituminous coals are reported to contain significant uranium-bearing minerals, oralate, and nitrate minerals, each of which has a different dissolution potential and thus a different effect on slurry water.

At the power plant, the use of clarified slurry water as part of the cooling tower makeup has the potential of releasing metals into the atmosphere. Disposal of this water as blowdown from cooling towers may also present a problem if the water is leached underground from the storage ponds. The potential for these types of problems depends on the trace metal content of the slurry water and the extent to which it is concentrated. Additional study is needed to determine the effects of metals discharge in coal slurry water.

Aesthetics --

A pipeline is probably the most aesthetically positive mode of coal transportation today. A buried pipeline is visible only at occasional pumping stations and overpasses, and is otherwise evidenced only by cut and fill areas.

After construction the right-of-way is returned to its natural state except through forest lands, where it is kept clear to allow surveillance. The land is free for travel by vehicles, people, and animals. Agriculture and irrigation may continue unobstructed when the pipe is buried deep enough. In some cases future irrigation may be impeded because the pipeline would obstruct ditches of a certain depth.

Cut and fill areas are minimal because slurry can continue to move through a pipe traversing steep terrain. River crossings may be accomplished by placing the pipeline below the riverbed. When the river has cut a large, steep-sided gorge, an overpass must be built.

The overall adverse aesthetic impact can be very minimal; in this respect the pipeline is superior to other modes of transportation.

Abandonment

Abandoning a coal slurry pipeline would present no major problems. Structures housing the preparation plant and pump stations could be removed. Equipment would be sold or reused and the steel recycled. The one disadvantage of abandoning the pipeline is that the pipe steel may not be recycled as economically as the steel in railroad rails.

IMPACTS FROM RAILROAD TRANSPORT OF COAL

Construction of Rail Line

Terrestrial impacts resulting from construction of a new rail line are similar to those involved in construction of a pipeline. Depending upon the terrain to be negotiated, construction of a rail line may cause impact of slightly greater magnitude. Since the pipeline can traverse terrain not negotiable by train, the more indirect routes required for railroad beds cover more ground and therefore cause more disturbance.

Removal of vegetation and increased human activity, noise, and fugitive dust will cause the same impacts as in pipeline construction. Again, policing of the construction site is required to prevent the death of wildlife from ingestion of small foreign objects.

The crossing of streams and rivers may pose a threat to aquatic organisms, as in the laying of pipeline. Construction of a permanent bridge is likely to kill benthic organisms in the immediate area, but colonies of such organisms probably will become reestablished.

Upgrading an existing rail line will cause little, if any, further adverse impact. The potential for disturbance lies in the movement of construction vehicles and in noise created by the vehicles and machinery.

Operation of the Rail Line

Operation of a rail line to transport coal can cause pollutant emissions, noise, potential for fires, leaching of chemicals, and detrimetal aesthetic effects. To illustrate the magnitude of airborne contaminants emitted by unit trains, we use as an example a 126-car train supplying 11,430 metric tons (12,600 tons) per trip (38). The unit train is loaded at the mine site onto nine 2240-kW (3000-hp) diesel locomotives for transport to the power plant 490 km (306 miles) away. The locomotives are of the two-stroke supercharged road variety. Upon arrival at the power plant the coal is unloaded from the cars through bottom grates. The total time for the haul from the mine and back is 48 hours. Emissions resulting from the 985-km (612-mile) round trip are summarized in Table 4-2.

Table 4-2. ATMOSPHERIC EMISSIONS FROM UNIT TRAIN[a] ON 985-KM (612 MI.) ROUND TRIP[b]

Pollutant	Air emissions kg (lb)/round trip
Particulate	345 (760)
SO_2	780 (1,720)
NO_x	4,855 (10,700)
HC	2,075 (4,570)
CO	935 (2,060)
Particulate, during loading	2,285 (5,040)
Particulate, during unloading	2,285 (5,040)
Fugitive emissions, in transit (0.05%)	5,700 (12,600)

[a] Load, one way: 11,430 metric tons (12,600 tons).

[b] Based on data from reference (46).

The atmospheric emissions are from the diesel fuel burned by the locomotives and fugitive emissions in transit and during loading and unloading. The diesel emissions are estimated on the basis of work output and fuel-based emission factors (35).

When an average load factor of 0.4 is used, the work output for the 965-km (600-mile) round trip is 386,600 kW (518,400 hp)-hr.

Because the work-output emission factors do not include the other four pollutants (particulates, SO_2, aldehydes, and organic acids) emitted from diesel trains, fuel-based emission factors are used to estimate these emissions. For a 0.4 load factor the fuel consumption for a 2240-kW (3000-hp) locomotive is 265 liters (70 gal.)/hr, or 114,500 liters (30,240 gal.) for the nine locomotives for the entire trip.

Railroad electrification provides a possible means of reducing the environmental impact of diesel-electric locomotives. It reduces the emissions in transit, the energy requirement (as petroleum), and the noise level. The emissions are contained in a power station and thus are more easily controlled. On the negative side is the need for additional mining and combustion of coal, unless electricity is supplied by some means other than coal firing.

Estimates of emissions during unloading are based on an emission factor 0.2 kg/metric ton (0.4 lb/ton) (uncontrolled) (35). Figure 4-5 illustrates bottom unloading of a unit train car over a hopper. If bottom dumping were done over a trestle, no effort would be made to suppress the dust; no emission factor is available for this method of unloading.

Estimates for discharge of particulates in loading are assumed to be the same as in unloading, although no data are available. Some loading operations include a negative-pressure hood, which vents into a bag filter and reduces emissions to a negligible amount; others provide no control.

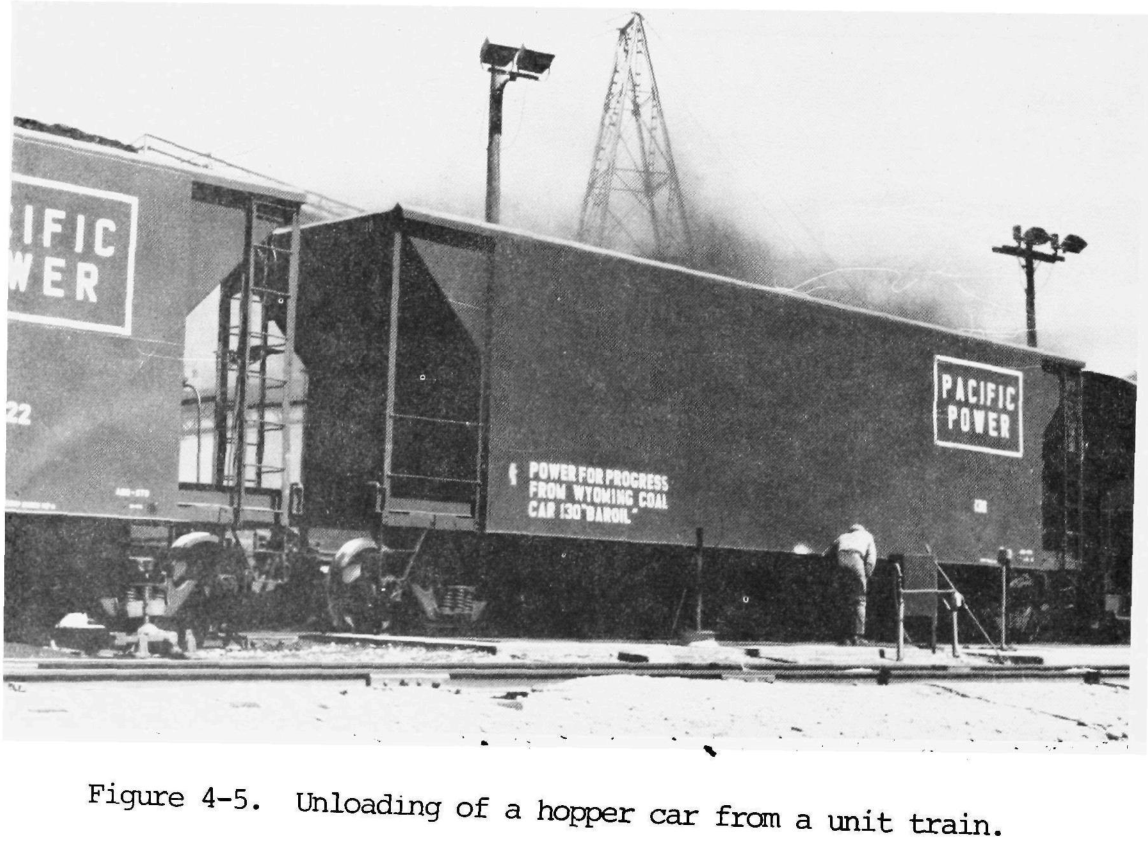


Figure 4-5. Unloading of a hopper car from a unit train.

Loss of particulates in transit varies with type of coal shipped, condition of the cars, moisture and fines contents of the coal, speed of the train, and wind speed. The estimates of wind losses range from negligible to 1.0 percent of the coal shipped. Some reports place the losses in certain situations at 5 tons per car during a trip over 480 km (300 miles) (42). The losses do vary widely, probably averaging between 0.05 and 1.0 percent of the total coal shipped. In the emission estimate given in Table 4-8, windage losses in transit are assumed to be 0.05 percent.

Windblown coal that is lost to the environment will cause some adverse impact. Coal dust will cover the leaves of nearby vegetation and reduce its photosynthetic capabilities. Also the coal dust could possibly have toxic effects on wildlife that might browse on this vegetation. The dust can clog the soil and prevent downward movement of precipitation.

Several suggestions have been presented for controlling wind losses. Wind guards 30 cm (12 inches) high are partially effective on rail cars. Washed coal retains much of its moisture, which aids in reducing wind losses; the moisture does evaporate, however, on a long, hot, arid haul. Sealing the surface of each load with a latex-polymer or an asphalt emulsion has been effective. Dustproofing the coal with oil or calcium chloride with other substances added is common. Corrosion inhibitors may be added to the chemical dustproofing agents to prevent possible attack of metal firing equipment and coal-handling parts. The quantity of material required to provide effective dustproofing depends upon the size and type of coal. The total surface to be treated increases as the size of the coal decreases. Therefore, more surfacing material must be applied to the finer coals. Porosity and other mechanical characteristics also affect the quantity needed. Application is most efficient while the coal is in the air, as during loading, and the use of properly designed hoods prevents waste of the dustproofing materials.

Another method of controlling wind losses is the use of removable tarpaulins on each car, as has been done with some trucks that haul coal. This practice would be difficult and expensive because of the labor required to attach and remove the covers and the high rate of wear. Use of disposable covers would be wasteful and would require incineration, which entails further environmental problems.

Flip-top lids for gondola cars (Figure 4-12) were designed by Betchel Engineers in San Francisco for the Milwaukee Railroad (43). The weight of the lids, 2.3 metric tons (2-1/2 tons), is said to be justified on the basis of preventing snow from settling in the cars on return trips from the Ottertail Power plant to the South Dakota lignite mines. Keeping the snow out reduces the freezing of coal to the bottom of the car and is expected to reduce freezing overall. The lidded cars have been in operation for less than a year, and future observations will determine their full value. Benefits derived from prevention of dust loss and spillage and from keeping rain out are considered added dividends and are thought to be insignificant.

Spillage deposits coal on the right-of-way, and a small portion becomes airborne as it falls from the car. Some spillage is caused by bumping. As each car is filled, it is released from the loading point to bump against cars already loaded. It is again bumped, perhaps several times, in the yard where the trains are assembled, at the scales, and near the point where the cars are cut out for local delivery at the destination. Each car is bumped while enroute by emergency braking and by each start-up of the train. Only bumps of unusual severity cause spillage. All bumps cause compaction, resulting in a smaller surcharge and exposing less coal to spillage.

Noise --

The sources of noise in a moving diesel-electric locomotive are listed below in descending order of noise level (44):

- horn
- diesel exhaust muffler
- diesel engine and surrounding casing, includes air intake
- cooling fans
- wheel/rail interaction
- electrical generators

Additional noise is produced by empty cars with loose chains or vibrating parts.

Sources of noise in electric locomotives are as follows:

- horn
- cooling blowers

- wheel/rail interaction
- electric traction motors.

Braking the locomotive from high speeds produces the most noise because of the brake-cooling blowers. Other than these periods of high-speed braking, the electric locomotive is considerably quieter than the diesel-electric locomotive.

Mufflers on the exhaust system can greatly reduce the noise from diesel locomotives. In addition, modified casing with acoustical absorbent material around the engine can successfully reduce overall engine noise. Studies of noise from wheel/rail interaction have tested the possibilities of a continuous welded rail, resiliant wheels, rubber rail heads, and rubber tires. The most successful approach thus far is use of the continuous welded rail, which achieves noise reductions greater than 5 decibels. It may be possible to incorporate this type of rail on portions of a route that run near or through an urban center. Otherwise, proper maintenance of the rail and bed will keep noise from this source sufficiently low.

Fires --

In some of the semi-arid western states, sparks from trains cause brushfires. Technology of roadside fire control is continuing at a steady pace. Locomotives traveling through countryside with abundant weeds and brush are being equipped with the latest designs in spark retention arrestors and nonsparking brake shoes (45). Composition brake shoes reduce sparking the most, high-phosphorous shoes are second, and the conventional cast-iron shoes cause the most sparking. Control of fires will reduce the amount of wildlife habitat destroyed by rail transport.

Vegetation Control --

Chemicals are used on rights-of-way to control the growth of vegetation for both safety and aesthetic reasons. Control of weeds and brush improves visibility, reduces fire hazards, and provides a safer working environment for railroad crews. There is some leaching of the herbicides and defoliants and also of the preservatives used to retard deterioration of wooden ties. Attention should be given to selection of chemicals that are not only effective in controlling vegetation but also nontoxic and nonpersistent.

Aesthetics --

The right-of-way constitutes a permanent commitment of the land surface, making the land unavailable for other uses. Travel of vehicles and people across the committed area is restricted. As with other forms of transportation, the physiography of an area determines the extent of visual impact and the means of minimizing detrimental impact.

Congestion at railroad crossings will increase as rail traffic grows to meet the projected sharp increases in coal production and consumption. Scheduling of the trains to avoid heavy traffic hours should alleviate this problem in most places. Although many railroad main lines already bypass congested areas, some locales will suffer more than others and additional bypass lines may be needed.

Abandonment

New methods for disposal of cross ties have been adopted because of restrictions on burning (45). Ties are now given away to persons who want them for architectural purposes or fences; most ties, however, are so far deteriorated that they must be hauled to approved sanitary landfills, to special curtain destructors (for smokeless burning), or to control locations where burning is allowed under special permit and supervision. Some are cut up into small chips at central points or at the site by mobile track machines. Old ties may be burned as industrial fuel to utilize the creosote content, but the resultant smoke is an environmental drawback. In research studies, cross ties have been produced by shredding old ties and reconstituting the chips. If mass production by this method is possible, this could be a feasible method for dealing with old cross ties. Some paperboard manufacturers have shown interest in the waste ties as raw material for their pulping processes. Until these new methods can be developed, present methods of utilization or destruction will be continued.

Rails contain 45 kg (100 lb) of steel per foot or approximately 280 metric tons/km (500 tons/mile) (23). When a line is abandoned, the rails may be used again or sold as scrap metal and remelted, depending on their condition. In current practice, the 30.5-meter (100-foot) right-of-way is abandoned and no effort is made to reclaim the land. A few abandoned roadbeds have been turned over to the public as paths for hiking or bicycling. Where this cannot be done, the right-of-way should be graded and revegetated to encourage reestablishment of native flora and fauna.

IMPACTS OF BARGE TRANSPORT OF COAL

Construction as Related to Barge Use

Certain construction activities are related either directly or indirectly to barge transportation. Dams and locks are often required to keep waterways deep enough to permit barge traffic. They are also built for other purposes, such as flood control and recreation.

In other situations, waterways are dredged to maintain navigable depths for barge transportation. Dredging produces some adverse impacts by eliminating certain benthic organisms and increasing turbidity, which in turn may reduce photosynthetic capabilities and possibly cause clogging of fish gills.

Barge transport also requires docking cells near which the barges are tied during loading and unloading. Usually no more than two cells are required per barge. A cell is simply a permanent pillar 60 to 90 cm (2 to 3 feet) in diameter. When the cells are installed, turbidity may increase temporarily, but little adverse impact is likely.

Barge Operation

Emission Estimate --

Barges are usually moved by a diesel tugboat. An average barge shipment of coal on inland waterways is 18,000 metric tons (20,000 tons) (46). In the example given here, the coal is loaded on barges at a site along the river. Ten barges transporting 18,000 metric tons (20,000 tons) of coal are lashed together, and a towboat with a 4475-kW (6000-hp) diesel-fired power plant pulls the shipment to its destination.

The average speed of the towboat/barge system is 9.6 km/hr (6 mph), and the average rate of travel is 230 km (144 miles) per day a two day trip is considered typical. after unloading at the destination, the tug returns the barges to the shipping port empty. The emissions summarized in Table 4-3 and discussed below do not include the return trip.

One source of air emissions from barges is the combustion of diesel fuel in the towboat. On the basis of an energy requirement of 139,000 g-cal/metric ton (500

Btu/ton) estimated by the American Waterways Operators, the average fuel consumption for a towboat burning 9.2 x 10 g-cal/liter (138,000 Btu/gal) diesel fuel is 39,400 liters (10,400 gal.) per day.

Table 4-3. SUMMARY OF ATMOSPHERIC EMISSIONS IN BARGE TRANSPORT OF COAL[a]

Basis: 18,100 metric tons (20,000 tons) of coal

	Air emissions, kg (lb)/day
Particulates	61 (135)
SO_2[b]	127 (280)
NO_x	1746 (3,850)
HC	203 (447)
CO	1061 (2340)
Particulate, during loading	3630 kg (8,000 lb)/trip
Particulate, during unloading	3630 kg (8,000 lb)/trip
Fugitive dust, in transit	1800 (4000)

[a] Based on data from (38).

[b] Based on a diesel fuel sulfur content of 0.2 wt percent.

A typical barge loading station would include a railroad car dump, thawing sheds, overland belt conveyor, loading conveyor, and loading chute. This system is used to transfer coal hauled from the mine on an inland railroad to barges on a major waterway. Such systems are located mainly on the Appalachian rivers, with a few recent additions on the Mississippi River. The development of western coal will require additional capacity on the Mississippi watershed.

Data on emission factors for uncontrolled loading of barges are not available; the emissions probably are similar to those estimated for unloading of rail cars, discussed earlier (0.20 kg/metric ton or 0.4 lb/ton). On this basis, for the 18,100-metric-ton (20,000-ton) barge shipment discussed here, 3630 kg (8000 lb) of dust would escape during loading.

Barge unloading stations are usually located in more densely populated areas than are the loading stations. They are at power plants, industrial sites, or at points for transfer of coal to a railroad or truck for inland delivery. They are located on the Ohio and Mississippi Rivers and on some of their tributaries.

A typical unloading station would include a clamshell to pick up coal from the barge, a receiving bin with feeders, and an overland conveyor to the stockpile.

Relatively small amounts of fugitive dust are generated as the clamshell removes coal from the barge and drops it into the bin. The amount of dust liberated in a high wind can be substantial. There is little available control of dust as coal is picked up in the barge.

The receiving bin can be equipped with sprays on the feeder discharge points to control the dust. The sides can be extended to permit lowering of the clamshell to a position protected from wind before discharging. Maintenance of a negative pressure in the bin to provide a downward flow of air from the top of the bin will reduce dust emissions, which can be further suppressed with a dust collector. It is assumed that uncontrolled emissions would be similar to those described earlier regarding railroad impacts (0.20 kg/metric ton or 0.4 lb/ton); thus in this example 3630 kg (8000 lb) would be lost during barge unloading.

A very small part of the coal transported in barges is lost accidentally. An occasional wreck can deposit several thousand tons of coal into the river. This coal would wash downstream and become a part of the river bottom. When this happens, the benthic life inhabitating the covered areas is likely to be eliminated. This should not be a long-term impact, because similar benthic organisms nearby will repopulate the disturbed area.

Fugitive dust escaping from a loaded barge during transit constitutes an unknown loss. This loss is very small because the velocity of the barge is low and only the peak portion of the loaded coal is exposed above the sides of the barge. Hittman Associates estimate that fugitive dust from barges in transit would be negligible (37). The barge emission estimate in Table 4-3 assumes windage losses of 0.02 percent, over the two day trip.

This source of dust could be eliminated by the use of covered barges, which are in common use for transport of other bulk materials.

Noise --

Towboats are probably the least important source in terms of noise impact on a community, although noise levels on board may be high. Most of the noise generated by the propulsion system is radiated into the water. Hull noises are primarily low-frequency. Horn blasts are generally the only loud noises that affect residents of a town or city.

Aesthetics --

The aesthetic impact of barge transport has two basic features: 1) the appearance of a dammed river as opposed to a free-flowing river and 2) the sight of barges moving back and forth on the river. Since river transport includes far more than coal movement, the return of major rivers to a free-flow state is impractical. The extent to which a river is used to transport coal may become a public issue if coal barge traffic increases at the projected rates.

IMPACTS FROM OVERLAND BELT CONVEYOR TRANSPORT OF COAL

Construction

Impacts of construction can be held to short-term effects with careful planning. The use of land for right-of-way requires room for the conveyor system, a service road, and power lines. Width of the right-of-way can range between 15 and 60 meters (50 and 200 feet), depending mainly on the type of terrain, which may necessitate cut and fill operations and diversion of the road from the belt. Land owners may require that the company buy an entire block of land rather than allowing a 15-meter (50-foot) right-of-way through it.

Construction work for conveyors, as with pipelines and railroads, results in several environmental impacts: erosion and sedimentation, air pollution, noise, and destruction and disturbance of flora and fauna.

Air pollution results from dust and diesel equipment, and a small amount from workers' automobiles emitting HC, NO_x, and CO. Dust can be controlled in part by watering the roads and reseeding exposed areas. After construction is completed, the belt conveyors are operated by electric motors and air pollutants are minimal.

Noise and human activity will affect fauna during construction, but these effects should be minimal along the belt line upon completion.

A completed conveyor system basically follows the terrain. Major cut and fill areas can be avoided, and ponds, streams, and drainage patterns left unaltered.

Operation

The primary impact of conveyor belt operation is spillage and fugitive dust emissions at feeding, transfer, and discharge points, and enroute on the belt.

Over a long distance, an uncovered belt conveyor could lose a significant amount of its load as fugitive dust in a high wind. Though the belts are covered along their length, they are not entirely surrounded by the covering as are shorter conveyors. Belts are covered mainly to prevent rain from wetting the coal and accumulating on the belt where it dips through a valley, and to prevent wind from overturning the belt. In our estimates, the fugitive dust losses from long-distance belts are assumed to be 0.02 percent.

Water and mud from the material being conveyed cling to the belt and fall from the return strand. Belt scrapers and wipers remove the main part of this material at selected points, and the remainder falls at places of natural accommodation.

Water and mud can be controlled by properly maintaining the belt cleaning equipment and by installing drip pans under parts of the conveyor as required to catch the remainder of the drip. Drip pans are normally installed where the conveyor crosses highways, roofs, or walkways. The drip pans must be cleaned occasionally by hand.

Transfer stations are usually enclosed to minimize discharge. Some are hooded and vented to a dust collector. Both the enclosure and the hooding greatly reduce fugitive emissions from transfer operations.

Spillage occurs while the conveyor is being aligned and adjusted and the belt is being trained. A break in the belt will also cause spillage, possibly requiring that the belt be unloaded by hand. Spillage must be recovered by hand from traveled areas when normal operation is resumed. Recovering coal spilled on the ground requires shoveling it by hand into a truck; accordingly, most of the spilled coal probably remains on the ground.

Control and safety features include electrical belt slip detectors, which measure drive speed with respect to belt slips on the drive pulley. Belt drift switches at each side of the belt react if the belt drifts out of line. Maintenance and wear can be reduced by use of mechanical turnovers at each terminal to present the clean side of the belt to the training idlers on the return trip. The turnover prevents the residual coal on the belt from coming in contact with the idlers.

Air Emissions Estimate --

Environmental Research and Technology (ERT) has provided an emission estimate of 0.10 kg/metric ton (0.20 lb/ton) for conveyors in coal processing operations (47). Since this value seems high in comparison with estimates for conveying other materials, it may be that the ERT emission factor for the processing area includes other unidentified particulate (34). The value is not compatible with the relatively high control efficiencies, usually at least 90 percent, associated with enclosed transfer and conveying systems.

Hittman Associates state that coal conveyor systems are either covered or operated at such a speed that dusting does not occur to any great extent (37). Their report also cites the relatively small amounts of coal that are transported by conveyor. Their value for loss through spillage at conveyor transfer points is 0.04 percent or 0.4 kg/metric ton (0.8 lb/ton). At this rate, even if only a few percent of the spillage losses are in the form of dust, emissions from coal conveying would be comparable to those from coal storage piles.

Monsanto Research Corporation sampled conveying operations at a granite quarry and determined that fugitive dust emissions from conveying crushed granite are negligible (36). The report does not mention whether the conveyor was enclosed.

Fugitive emissions can be estimated on the basis of an example operation: the 16-km, 122-cm (10-mile, 48-inch) conveyor from the Meigs Mine to the Gavin plant, near Gallipolis, Ohio. This belt operates at a rate of 1800 metric tons (2000 tons) per hour and on a typical day transports 29,000 metric tons (32,000 tons) of coal. Assuming that the windage losses through conveying are 0.02 percent, and using an emission factor of 0.075 kg/metric ton (0.15 lb/ton) controlled for spillage at transfer stations (there are three along the belt), the amounts of coal lost per day would be 5760 kg (12,800 lb) by windage and 6530 kg (14,400 lb) from all transfer points combined.

Aesthetics --

A conveyor system traverses a relatively narrow right-of-way. However, it is also a continuous operation that remains a permanent part of the landscape. Its intrusion on the visual scene is especially noticeable at the sites of large trestles, overpasses, and cut and fill areas. Total aesthetic impacts, of course, are highly variable.

Abandonment

Belt conveyors are supported on concrete piers, which are usually abandoned rather than removed and constitute a continuing eyesore as well as a hazard.

Removal of all steel and concrete structures and a small amount of grading and reseeding would restore the land to near its original state.

Truck Operation

Most environmental studies are directed at the effects of trucks using the highways. The use of large trucks in off-highway transport involves many of the same noise and emission problems and additional environmental impacts related to building, maintaining, and abondoning mine roads.

Transporting coal with a diesel truck involves two crossings of a given point for each truck load, one loaded and one empty. Increasing transportation of coal by truck would require redesign of many roads and would increase maintenance costs. It would also create more noise, pollutant emissions, and safety hazards.

Use of Trucks at Mine Sites --

Mine roads generally consist simply of graded and compacted soil, with occasional addition of crushed clinker. The roads are 15 to 24 meters (50 to 80 feet) wide and are designed for continuous use by heavy off-highway vehicles.

During construction of the roads, topsoil should be saved and banks seeded. Culverts are needed wherever the road crosses natural surface drainage channels. Settling basins should be constructed downstream from the culvert crossing to collect material that may wash from the haulage road or from mined areas not yet reclaimed.

The 180-metric-ton (200-ton) trucks pulverize the surface of the roads and create a layer of fine dust. When the dust falls on plant leaves, it reduces transpiration through stomata and decreases photosynthesis.

Control is recommended not only for environmental reasons but also to prevent damage to equipment. Control consists of watering the roads throughout the work day with truck-mounted spray equipment.

Emission Estimate - Trucks --

Sources of emissions from trucks are exhausts from diesel and gasoline engines, windage losses, and spillage. Emissions from truck transport are illustrated by use of the following example:

1) Diesel-powered uncovered truck with 27-metric-ton (30-ton) payload; 20 miles one way haul, empty return.

2) Diesel fuel consumption of 1.5 km/liter (3 1/2 mi/gal.) loaded and 2.1 km/liter (5 mi/gal.) empty = 37 liters (9.72 gallons)/truck.

3) Loss of coal in transit assumed to be 0.05 percent of total payload; loss in unloading and loading assumed to be 0.04 percent.

Table 4-4 summarizes atmospheric emissions from truck transport of coal. The emission factors are the same as those used for barges (35).

Table 4-4. ATMOSPHERIC EMISSIONS FROM TRUCK TRANSPORT OF COAL

(Payload of 27 metric tons (30 tons)

Pollutant	Emissions	
	Kg/trip	lb/trip
Particulate	0.06	0.13
SO_2	0.12	0.26
CO	0.98	2.18
HC	0.16	0.36
NO_2	1.62	3.60
Aldehydes (HCHO)	0.01	0.03
Organic acids	0.01	0.03
Fugitive dust in transit	27	60
Fugitive dust loading	14	30
Fugitive dust unloading	14	30

One pound = 0.4536 kg.

Dust Control --

Very little is done to reduce the production of dust during loading and transporting coal within the mining area (See Figures 4-6 and 4-7). When inherent moisture of the coal is 3 percent or greater, initial dust control may be unnecessary. A few coal companies use a large tank truck with a built-in sprinkler system to suppress dust in exposed coal beds as well as on mine roads.

Wind loss and spillage will occur during transport unless the top of the truck is covered. No data are available on the magnitude of fugitive dust emissions. The amount lost during a trip would depend on variables similar to those affecting fugitive dust emissions from a rail car. The example for trucks in this section assumes 0.05 percent of the load lost as fugitive dust. Hittman Associates estimate windage losses from loading and unloading to be 0.04 percent of the total coal transported but assume windage losses in transit to be negligible (37). Organic sealants would reduce wind losses but not spillage. Barring accidents,

Figure 4-6. Example of fugitive dust from unloading at a coal mine.

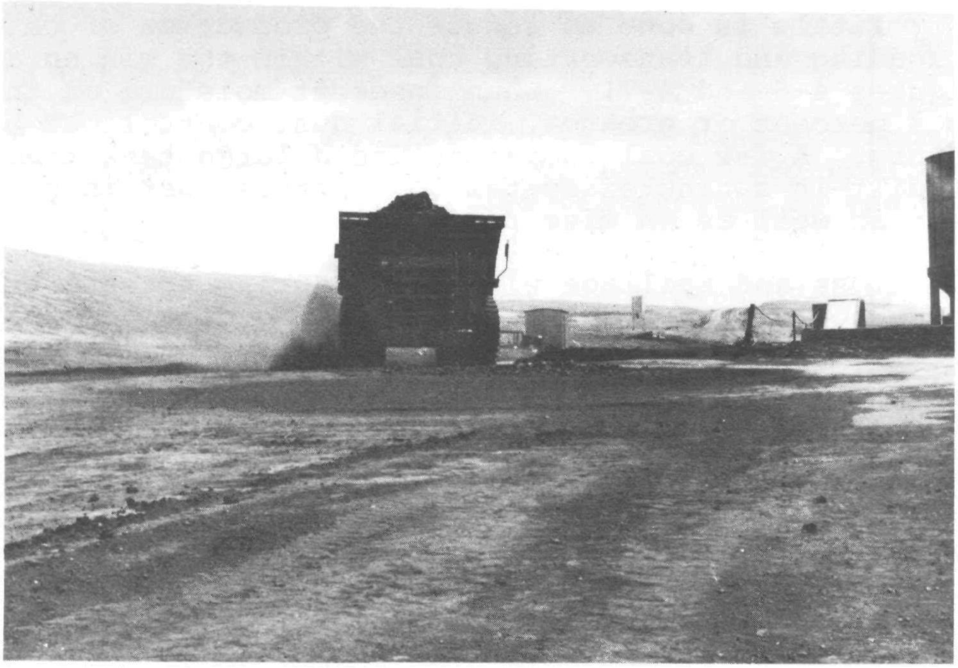


Figure 4-7. Dust from haul roads at a coal mine.

proper covering is the only way to contain the coal totally during transit. Better-designed trucks with covered aluminum bodies are now appearing on highways. Spillage and dust remain a problem with the older uncovered trucks; they could largely be eliminated by providing covers.

Damage to Roads --

A study by the Kentucky Department of Transportation indicates that damage to roads by trucks is the most destructive environmental impact associated with truck transportation. Many of the Kentucky highways used for coal hauling do not have an adequate base and therefore are unsuitable for heavy loads (48). The Department of Transportation estimates that bringing all roads but local ones up to an acceptable design standard for normal travel purposes would cost $1.9 billion and that $335 million would be needed to provide sufficient structural conditioning to support heavy coal hauling.

Noise --

The major sources of noise from trucks are from the engine, exhaust, cooling fans, and tires.

The high-compression diesel truck engine causes more vibration and thus produces more noise than does the spark-ignited gasoline engine. Experiments have been done with modifications of combustion chambers and timing and with block and crankcase reinforcement, but little success is reported. Engine covers and panels have proved to be the most successful short-term approach to reducing noise.

Exhaust noise dominates other truck noise, producing about 100 dB; exhaust noise can be controlled. Mufflers can easily reduce the noise level to 90 dB, and research is being conducted to reduce it to the 75-dB range measured at 15 meters (50 feet). Possible innovations include placing a resonator close to the exhaust manifold, exhaust pipe wraps, and double-wall or laminated exhaust pipe.

Noise from tires ranges from 80 dB to over 90 dB, and tires become the dominant noise-producing source at speeds above 80 km/hr (50 mph). With current technology, however, these noise levels cannot be reduced without significant impacts on operating cost and safety. The noise produced by cooling fans, intake valves, aerodynamic turbulence, and "rattles" is highly variable. Techniques for reducing noise from these sources are under study.

Abandonment

Abandoned roads must be reclaimed in a manner that will minimize erosion and encourage the reestablishment of native vegetation and wildlife habitat. If the road surface material is not suitable for revegetation, it should be removed and reused or disposed of within the mining area. Reclamation includes scarifying and shaping the roadway, adding topsoil as needed, and seeding the surface.

SECTION 5

RECOMMENDED RESEARCH AND DEVELOPMENT OF CONTROL TECHNOLOGY

Table 5-1 summarizes the adverse impacts of coal transportation for which controls are now lacking or inadequate. These impacts are rated on a scale of 1 to 3 (1 = highest priority) to indicate the relative importance of the research and development studies required to provide effective control technology. All of the adverse impacts of constructing and operating conveyor belts and barges (excluding diesel engine emissions) can be rectified by application of controls now available. Proposed studies dealing with the other aspects of coal transport are discussed briefly in the following paragraphs. It is assumed that each of the proposed research and development efforts would include a detailed cost study that indicates trends and provides a basis for cost/benefit analysis.

COAL CLEANING

Research is needed on means of reducing NO_x emissions from thermal dryers by modification of the combustion process (38). A survey should be conducted to evaluate effectiveness of scrubbers, de-dusters, and other equipment used for particulate control on thermal dryers.

Because coal refuse piles often cover many acres of ground, means of preventing combustion of refuse piles should be developed and implemented.

Effluents from coal cleaning plants should be characterized with respect to trace elements, both qualitatively and quantitatively. If toxic elements are found at dangerous levels, technology should be developed for treating these effluents before discharge.

Table 5-1. PRIORITIES FOR RESEARCH AND DEVELOPMENT OF ENVIRONMENTAL CONTROLS FOR COAL TRANSPORTATION

Mode	Impact	Priority
Coal cleaning	Particulate and NO_x emissions from thermal dryers	2
	Fugitive dust, refuse piles	2
	Water effluent - toxic properties	1
Coal storage	Fugitive emissions	2
	Water runoff - toxic properties	1
Crushing loading, unloading	Quantification of emissions	2
Pipelines	Breakage	1
	Availability of water	1
	Reslurrying methods	2
	Slurry dewatering	1
	Fines treatment	1
	Slurry water - toxic properties	1
	Corrosion inhibitors - toxic properties	2
Railroads	Noise	2
	Fugitive dust, spillage	2
	Diesel engine emissions[a]	2
Trucks	Road damage	1
	Fugitive dust, spillage	2
	Noise	2

[a] Also applies to barges and trucks.

<u>Priority key</u>
1 = High
2 = Medium
3 = Low

COAL STORAGE

Control of windage losses from open coal storage piles is most feasible for application to dead storage. Since live storage involves continuous addition and removal of coal, effective control with chemicals is difficult. Research on control of fugitive losses from dead coal storage piles should continue, with emphasis on development of an innocuous chemical that holds the coal in place yet allows it to break up easily when it is reclaimed from the pile.

Characterization of the runoff from coal storage piles should be completed. As with coal slurry water, when the toxic elements of coal pile runoff have been identified, appropriate control methods and regulations can be determined.

CRUSHING, LOADING, AND UNLOADING

Studies are needed to determine the range of emissions from the crushing, loading, and unloading processes associated with all modes of coal transportation. Another PEDCo report (50) provides recommendations for research and development on means of reducing fugitive dust from crushing and loading at coal mines. The recommendations, which are applicable also to such other operations as loading and unloading at rail and barge facilities, emphasize the need for quantifying emissions to provide an accurate data base.

Established control methods such as water sprays and hooding should be used at locations where crushing, loading, and unloading activities constitute a hazard to health or cause damage to vegetation or structures.

COAL SLURRY PIPELINES

Pipeline Break

Emergency procedures should be developed for cleanup of an area affected by a pipeline break, especially in or near a body of water. Environmental impact statements for proposed pipelines should include an emergency procedure for cleanup. In planning of future coal slurry lines, emphasis should be placed on situating the lines in locations remote from sensitive receptors such as agricultural lands and densely populated areas.

Water Availability

Much additional study is needed on availability of water for proposed pipelines and the effects on adjacent areas, especially in the semiarid western states. The data now available concerning aquifers in the semiarid western states (the Madison Aquifer in Wyoming, for example) are generally inadequate and conflicting. Proponents of a pipeline may specify a fixed quantity of water, in hectare-m (acre feet) per year; however, during the early years of operation additional water may be needed if the line is not pumping coal at full capacity.

The availability of water and the effects of water usage are crucial factors that will determine whether pipelines can become a feasible transport alternative.

Reslurrying at Pump Stations/Power Plants

An economical method is needed for keeping in suspension the coal that is dumped from a line during emergency. Use of storage tanks with agitators might provide a better system than dumping the coal in a pond, especially in populated areas where leaching or runoff of coal slurry water may cause problems. The use of tanks would also eliminate emissions of fugitive dust from storage of dried fine coal.

Coal Slurry Dewatering and Treatment of Coal Fines

Operation of the Mojave power plant indicates that dewatering of the coal slurry is a major problem. Extensive modifications of the centrifuges, such as the use of ceramic materials for face plates on the screw flights and other high-wear areas, are just beginning to be applied. Research is needed on other means of dewatering coal slurries, such as the deep cone thickener used in England and improved versions of the old plate and frame filter press (38).

Treatment of coal fines needs further development. Cleaning of the fines or the entire coal slurry at the power plant followed by drying could possibly increase the Btu content of the coal and provide a means of utilizing the coal fines.

Studies are also needed on (1) the effects of coal slurry firing on boiler combustion; (2) effects of changes in ash composition due to leaching of soluble compounds on fouling, slagging, and ash fusion; and (3) performance of air pollution control equipment.

Chemicals in Slurry Water

Characterization of the soluble salt content of coals should be completed; we should further determine how much of these salts will leach into transport water, especially in western coals. The dissolved organic compounds also should be identified.

When sufficient data on minerals and organics in slurry water are available the possible toxic effects of slurry water on groundwater or streams can be evaluated. Potential release of trace elements from cooling towers using slurry water could be studied.

The effects of corrosion inhibitors on the toxicity of slurry water also should be determined.

If the Clean Water Act requires zero discharge for slurry water, application of technologies such as ion exchange membrane separation and forced evaporation should be researched.

RAILROADS

Noise

Locomotive builders are studying ways to attenuate diesel locomotive noise and noise caused by switching operations and wheel-rail interaction. These studies should concentrate on solving the noise problem at the source. Techniques for noise reduction in switching operations and wheel-rail interaction are needed mainly where trains pass through urban areas.

Fugitive Coal Dust and Spillage

More data are needed to determine the seriousness of blowing dust and spillage, since many railroad operators indicate that fugitive emissions are not a significant problem. In many cases blowing dust is receiving attention for economic rather than environmental reasons. It is known that blowing dust from trains can cause nuisance problems. Spillage of coal from trains depends on the condition of the cars and the methods of handling during loading and during transport.

Research into control of fugitive coal dust from trains is directed toward developing sprays that will hold the coal fines in place at a reasonable cost, are innocuous with respect to the ultimate use of the coal, and allow the coal to break up readily when the rail car is unloaded.

Diesel Engine Emissions

Diesel engine manufacturers are working on reducing emissions of NO_x, hydrocarbons, and particulates from stationary and mobile diesel engines. Following are other areas that require additional research and development (38, 51):

1. Materials to inhibit NO_x formation that could be introduced into the combustion process through a fuel additive.
2. Engine refinements such as derating engine output, adjusting variable compression ratio; injection modification; use of precombustion chambers.
3. Reduction of the peak combustion temperature by introducing an inert material such as exhaust gas or water.

TRUCKS

The unsolved environmental problems of truck transport are damage to roads, fugitive emissions, and noise.

Road Damage

Damage to Kentucky roads caused by coal trucks indicates that similar problems can be expected in other areas where highways are not designed for such heavy loads. One direct method for eliminating the damage is to forbid operation of coal trucks on roads not designed for their use. Other suggestions focus on meeting the cost of upgrading the roads (48):

1. A tonnage tax for use of county roads.
2. An export tax on coal.
3. A ton-mile tax specifically for the coal hauler.

Dust Control

Newer designs of coal trucks minimize fugitive emissions and spillage on public highways, although emissions are not controlled for in-mine hauls. More emphasis should be placed on proper maintenance of older trucks to minimize spillage and on provision of covers or use of chemical sprays to reduce emissions in transit. These recommendations are most applicable to use of public roads for coal hauling.

Noise

Reduction of truck noise is complicated, and finding satisfactory methods may require considerable time. With increased public and legislative pressure, truck designers are developing new procedures and designs, some of which are discussed in section 4.6, that will reduce noise levels (52).

Research should continue on reducing noise from truck engines, exhausts, and tires to the lowest level possible without detrimental effects on operating safety and cost. Emphasis should be placed on reducing noise at the source rather than on use of shields or covers as secondary noise-reduction devices.

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APPENDIX A

GROUNDWATER RESOURCES AND THE RELATIONSHIP TO USE OF COAL SLURRY PIPELINES

CENTRAL WESTERN RIVER BASINS

Total water resources in the United States are sufficient for projected energy growth. In some locales, however, particularly in the western states, water supplies are limited. In the East, South, Midwest, and along the seacoast, water supplies generally are adequate for industrial and domestic use. West of the 100th median, industries must compete for the limited available water supplies. Figure A-1 indicates the relative abundance and deficits of water resources across the United States. Water abundance is defined as rainfall greater than evaporation rate, and water deficit, as the opposite.

Water needs in the central western states are currently met by a combination of surface and groundwater withdrawals. Although surface water supplies in the southernmost states of Arizona and New Mexico are limited, supplies in the northern states are relatively abundant. In the southernmost states, groundwater is being overdrawn to compensate for deficiencies in surface water supply.

The western states of major concern with reference to water availability for coal development are North Dakota, Montana, Wyoming, Colorado, New Mexico, and Arizona. Of the eight river basins in these states, only those of the upper Missouri the upper and lower Colorado, and the Rio Grande are of concern.

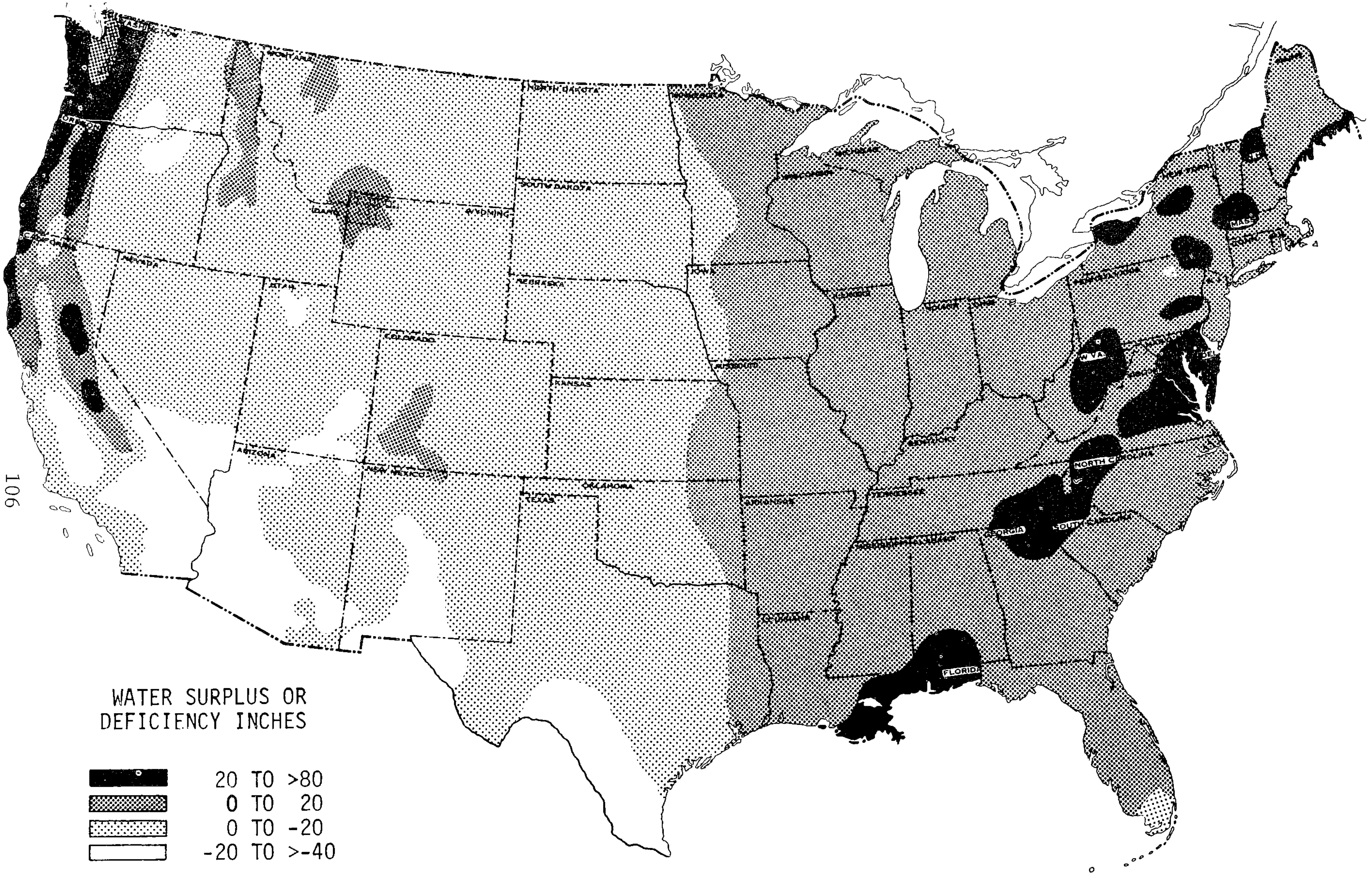

Figure A-1. Abundance of water in the U.S. (Source: Ref. A-1).

Upper Missouri River Basin

The Fort Union Powder River Basin Coal Region is the major energy source in the Upper Missouri River Basin (Figure A-2). It is estimated that this coal region contains 34 billion tons of strippable coal deposits (Ref. A-1). Surface water, however, is poorly distributed in time and space. Use of surface water in coal development in parts of the area would require storage reservoirs and distribution systems, whereas in other parts the surface water is fully appropriated and its use in coal development would deprive the present users.

Preliminary investigations conducted by the U.S. Geological Survey and by State agencies of Wyoming, Montana, and South Dakota indicate that Madison Limestone and associated rocks may provide a significant percentage of the water requirements for future coal development. Preliminary data indicate that the yield of wells pumping from the Madison aquifer may range from about 1.3 liter/s (20 gal./min) to 570 liter/s (9,000 gal./min); most, however, are less that 63 liter/s (1,000 gal./min) (Ref. A-2).

Although various institutions and authors have conducted hydraulic studies, few reports provide quantitative data on the hydraulic characteristics of the aquifer; on the relation of the aquifer to springs, streams, and the underlying or overlying aquifers; or on the recharge to, movement through, and discharge from the aquifer.

The sparse data available are primarily from tests for oil within the study area. Some information is available on water wells, many of which were originally drilled for oil tests and then completed as wells. Information is virtually nonexistent that could be used for determining regional values for recharge, discharge, transmissivity, storage, vertical leakage, water use, and water-level fluctuation. Values of these parameters will be needed for evaluation of the water supply potential of the Madison aquifer.

Overcoming the data-base deficiencies will require collection of new data on surface and subsurface hydrologic, geologic, geophysical, and geochemical features. Analyses of these data will then be used in predicting the possible effects of proposed withdrawals on the hydrologic system.

The objectives of a proposed study of Madison aquifer would be as follows: (Ref. A-2)

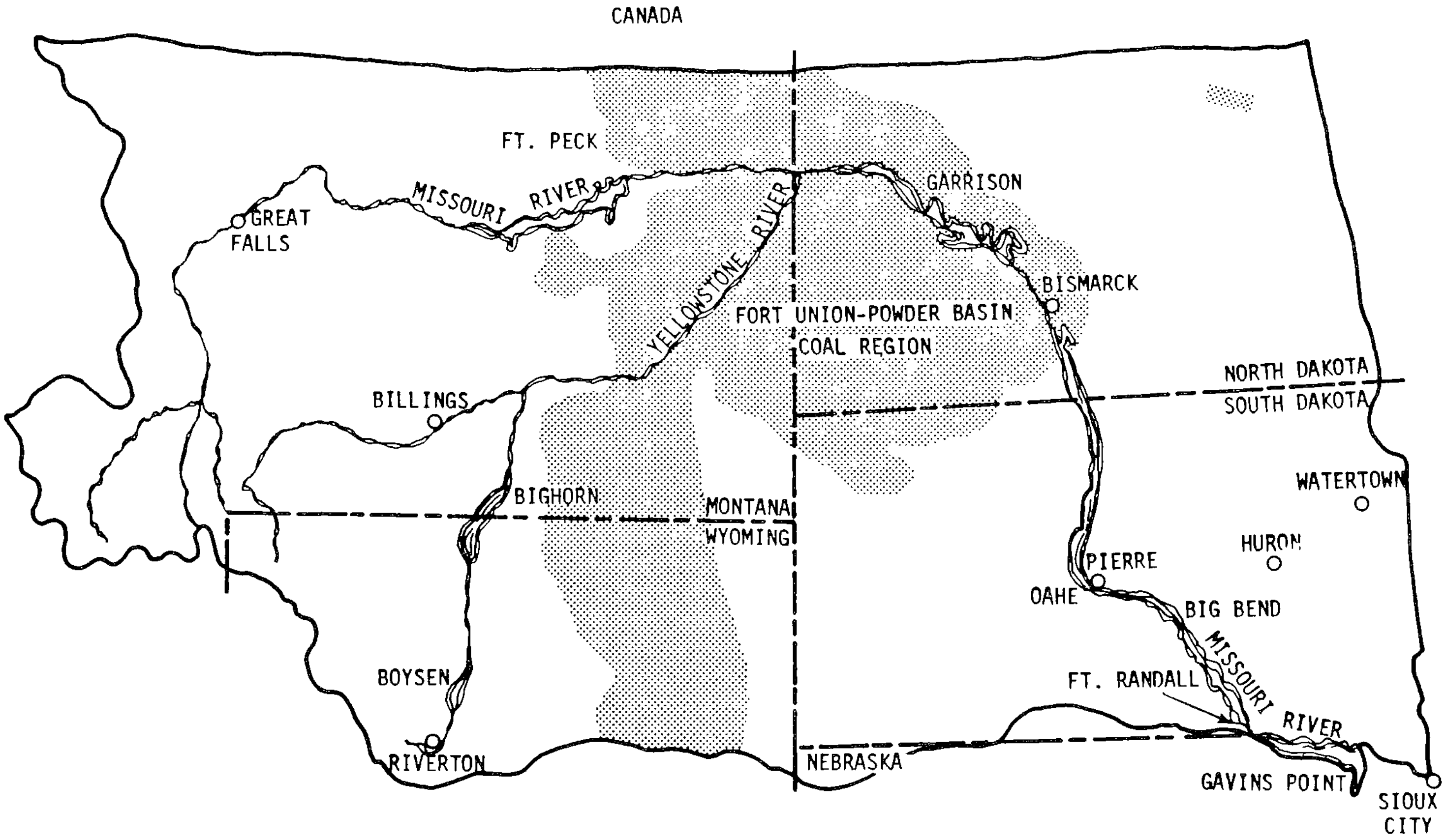

Figure A-2. Upper Missouri Basin (Source: Ref. A-1).

1. Determine the quantity of water that may be available from the Madison aquifer.

2. Define chemical and physical properties of the water.

3. Determine the effects of current developments on the potentiometric head, storage, recharge and discharge, springs, streamflow, and pattern of groundwater flow.

4. Predict the probable hydraulic effects of proposed withdrawals of water for large-scale developments at selected rates and locations.

5. Determine the location of wells and the type of construction and development of deep wells that would provide optimum yields.

6. Design a network of observation wells and stream gages to monitor the effects of additional developments on the hydraulic systems.

It is estimated that 3 million acre-feet of water will be required on an annual basis for all types of coal development in the Upper Missouri River Basin. The major impact of meeting such a demand would be on river navigation (Ref. A-1). The normal 8-month season may be shortened and possibly nonexistent in dry years. Additionally, instream fisheries may be affected to an undetermined degree. Water supplied in this manner would have to be transported over 161 km (100 miles) to the coal fields.

At present only one proposal for a coal slurry pipeline would entail water withdrawal from the Missouri River Basin. This is the pipeline proposal initiated in late 1973 by Energy Transportation Systems, Inc. The coal slurry pipeline would pump coal from Gillette, Wyoming, to White Bluff, Arkansas (Ref. A-3). This pipeline would require approximately 22.7 million m^3 (18,400 acre-feet) of water per year to transport its design load of 22.7 million metric tons (25 million tons) per year. Therefore, less than 2 percent of the water required for coal development will be dedicated to coal slurry transport.

Upper Colorado River Basin

The Upper Colorado Basin stretches from the headwaters of the Colorado River to Lee's Ferry, a point approximately 19 km (12 miles) below Glen Canyon Dam. Average annual precipitation is as high as 36 cm (8 inches) in lower parts of the basin. The major coal and oil shale resources, as well as river systems, are shown in Figure A-3.

Surface water supply in the Upper Colorado River Basin has ranged from an annual flow of 6.9 billion m^3 to 29.6 billion m^3 (5.6 million acre-feet to 24.0 million acre-feet) with an average of about 18.5 billion m^3 (15.0 million acre-feet) (Ref. A-4). Because of the Colorado River Compact, however, only 7.16 billion m^3 (5.8 million acre-feet) of that water is available for consumption in the basin. Above Lee's Ferry the current consumption is about 4.57 billion m^3 (3.7 million acre-feet). This includes depletion for all uses including agricultural, municipal, industrial, and storage.

Table A-1 shows supply and demand figures for the Upper Colorado River Basin. As the table shows, the supply of water for electrical power and minerals is adequate in Colorado and Utah but not in Arizona or New Mexico (Ref. A-5). It is projected that New Mexico will be short by 0.11 billion m^3 (90 thousand acre-feet) in the year 2000; some agricultural allocations, however, could be transferred to industrial use. On the other hand, Arizona is expected to be short by 34.1 billion m^3 (27.6 thousand acre-feet) per year of meeting projected demand for the year 2000; Arizona has no allocation of any kind remaining to meet this demand. Groundwater could offer a possible supplemental or short-term source of water. The minimum amount of groundwater in storage in the upper 30.5 m (100 feet) of saturated hydrogeologic units, based on available specific yield data, ranges from 61.7 to 141.9 billion m^3 (50 to 115 million acre-feet). The average annual recharge in the basin is estimated at only 4.9 billion m^3 (4 million acre-feet) annually.

At present, two coal slurry pipelines in the planning stages would withdraw from the Upper Colorado River Basin. These are the Gulf Interstate-Northwest Pipeline and the Houston Natural Gas Colorado to Texas system (Ref. A-3). These two pipelines would require annually about 14.6 million and 8.1 million m^3 (11,800 and 6,600 acre-feet) respectively.

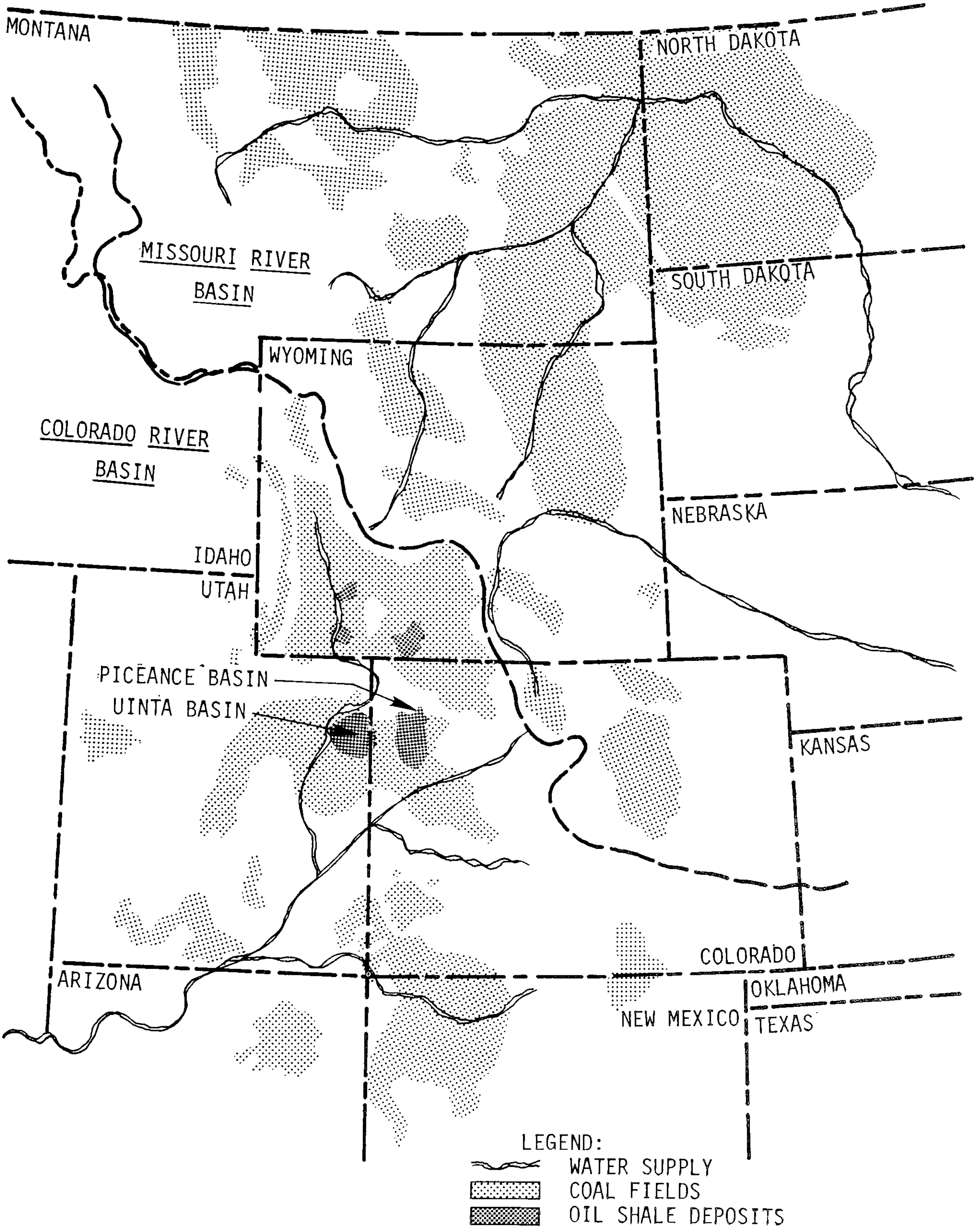

Figure A-3. Major coal, oil shale, and river systems in the Upper Colorado River Basin.

Table A-1. ESTIMATED SUPPLY/DEMAND FOR UPPER COLORADO RIVER WATER IN THE YEAR 2000

(Thousands of acre-feet per year)

	Ariz.	N. Mex.	Utah	Colo.	Total
Projected Water Requirement for Energy (Consumptive Use)					
Electricity (Coal-fired plants only)	62	120	24	–	206
Coal	–	60	–	–	60
Oil Shale	–	–	18	112	130
Total	**62**	**180**	**42**	**112**	**396**
Apparent Water Availability					
Electric Power	34.1	90.0	261.8	108.2	494.1
Minerals	.3	17.4	10.3	128.3	156.3
Argiculture	7.6	329.0	660.6	1,778.2	2,775.4
Other	8.0	141.3	314.0	1,004.7	1,468.0
Total	**50.0**	**577.7**	**1,246.7**	**3,019.4**	**4,893.8**

Source: ref. A-5.

Conversion for metric unit: one acre-ft = 1233.489 m^3

This water usage would, therefore, utilize about 31 percent of the projected water requirement for coal development or less than 1 percent of the apparent water availability (Table A-1).

Lower Colorado River Basin

The Lower Colorado River Basin extends from Lee's Ferry to the Gulf of California. Annual precipitation in this area ranges from 10 to 76 cm (4 to 30 inches), and evaporation averages about 254 cm (100 inches) (Ref. A-6). Water resources are scarce in Arizona and New Mexico. It is estimated that no more than 67.9 million m^3 (55,000 acre-feet) remains uncommitted in New Mexico. Nearly all the water in Arizona is currently committed. Indications are that the projected water demand for energy in Arizona and New Mexico is approximately 0.33 billion m^3 (269,000 acre-feet) per year. If this demand is to be met, no additional demands for municipal, irrigation, or other use could be placed on this basin (Ref. A-1). Water for energy use might be obtained by purchase of some Indian water rights. Several hundred million cubic meters (several hundred thousand acre-feet) of "perfected rights" are now allocated to various reservations and are not being used.

The Black Mesa Pipeline is now operating and is withdrawing groundwater from this basin. The withdrawals are purchased from Indian Water Rights. An additional coal slurry pipeline proposal known as the Nevada Power-Utah/Nevada system is in progress. This pipeline will require approximately 9.13 million m^3 (7,400 acre-feet) per year. This volume is equal to approximately 2.8 percent of projected water demand for energy purposes.

Rio Grande Basin

The Rio Grande Basin is the major drainage basin in New Mexico. The basin extends from the Continental Divide in the mountains of Colorado to the flat, arid lowlands of southern New Mexico. Annual precipitation ranges from 20 to 60 cm (8 to 24 inches), and average annual evaporation is about 254 cm (100 inches) (Ref. A-6). The development of associated energy resources is generally similar to that discussed for the Lower Colorado River Basin.

INTERNATIONAL PIPELINE

A coal slurry pipeline currently in the planning stages is known as the Interprovincial Lakehead System. The pipeline would originate in Edmonton Alberta, Canada, and traverse 3389 km (2100 miles) to the northern midwest and eastern United States. The water withdrawals to maintain this pipeline at design capacity would be 13.6 million m^3 (11,038 acre-feet) per year. Although this water would be withdrawn from Canadian sources, the withdrawals could affect downstream water resources in the United States.

SALINE GROUNDWATER SUPPLIES

The saline groundwater underlying most parts of the United States contains at least 1,000 milligrams per liter (mg/liter) of dissolved solids; this solids content varies throughout the states, as do the quantities and degree of accessibility. It is possible that as much as 166,620 km^3 (40,000 mi^3) of saline groundwater is stored at various depths in rock aquifers in some parts of the country (Ref. A-7). Relatively little information is available on the location of saline groundwater in the west; the little information that is available appears promising.

Saline groundwater reserves ranging in depth from less than 150 m (500 feet) to more than 1520 m (5000 feet) are found in the coal-bearing regions in western North Dakota, the northwest corner of South Dakota, eastern Montana, and the northeast corner of Wyoming. The north-central Montana coal reserve region is underlain with saline water at depths less than 150 m (500 feet) to more than 300 m (1000 feet). Saline groundwater is found at depths generally less than 300 m (1000 feet) in the northwest corner of Colorado. The northeast corner of New Mexico is underlain by saline groundwater at depths of less than 150 m (500 feet), and coal regions in northeast Arizona have saline groundwater at depths of 150-300 m (500 to 1000 feet) (Ref. A-7).

To generalize on yields from large regions can be misleading, especially with the lack of good data on the western saline aquifers. Some of the aquifers of interest in projected major coal-producing areas can be characterized in this light. The Madison Limestone Aquifer, which underlies eastern Montana, northeastern Wyoming, and western North and

South Dakota, contains water with salinity ranging from 1000 to 100,000 mg/liter, but more typically 1000 to 3000 mg/liter. The water outputs for individual wells in the Madison Aquifer are expected to range from large yields of hundreds of liters per second (thousands of gallons per minute) near the outcrop to tens of liters per second (hundreds of gallons per minute) where limestone is deeper and more saline (Ref. A-7).

Dakota Sandstone is a saline-water-bearing stratum capable of producing moderate to large amounts of highly saline water that has been known to flow under artesian pressure. It is located in North and South Dakota, Nebraska, Kansas, Wyoming, and Colorado. The Coconino Sandstone in northern Arizona can yield only moderate amounts of saline water for industrial purposes. The Redwall Limestone aquifier of north-central Arizona supports several large springs in that area. It probably could be used to produce saline water either from the springs or well fields (Ref. A-7).

Although these saline waters have little value for domestic use, care must be taken in withdrawals, which over a long period might change the regional flow patterns and pressure distributions. If saline waters and fresh waters are not hydrologically isolated, pumping of the saline strata might cause flow changes in the fresh water aquifer or even intrusion of fresh water into the salt water. Land subsidence and contamination of moderately saline groundwater with more highly saline water from deeper aquifers are also possible environmental impacts. Therefore, any use of saline groundwaters should be closely monitored.

REFERENCES - APPENDIX A

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A-6. Chow, Ven Te. Handbook of Applied Hydrology. A Compendium of Water-Resources Technology. McGraw-Hill. 1964.

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APPENDIX B

COMPARISON OF COSTS OF TRANSPORTATION METHODS

A number of recent studies compare costs of transporting coal by rail, slurry pipeline, barge, truck, conveyor belt, and pneumatic pipeline. The greatest emphasis is on railroads and slurry pipelines. This appendix analyzes results of some of these studies and, in most cases, presents a comparison of coal transportation rates on the basis of cents/metric ton-km (cents/ton-mi). The values are derived from annual operating expenses, which are based on a fixed capital cost required to put the transportation system into operation.

Two major studies comparing rail and slurry pipeline costs are based on the controversial Wyoming to Arkansas pipeline proposal. The slurry line would be approximately 1610 km (1000 miles) long and would move 22.7 million metric tons (25 million tons) of coal annually. The two major studies are 1) the Bechtel Corporation study for Energy Research and Development Administration and 2) the University of Illinois study for the National Science Foundation (NSF). A discussion of these and four other studies follows.

BECHTEL CORPORATION STUDY FOR ERDA

Bechtel Corporation has prepared a coal transportation cost model that compares pipelines, railroads, and barges. Transportation rates for each of these modes were developed and used as inputs for a linear programming model.

Unit Trains

The transportation costs for unit trains, trains containing approximately 100 cars and capable of handling 9070 kg (10,000 tons), were determined by Bechtel's Metals Division. These rates, as shown in Table B-1, may vary depending on such factors as degree of competition, annual tonnage volume, train and car sizes, type of car, loading and unloading methods, terrain, and track conditions. Eastern rates are estimated to be about 40 percent higher and southern territory rates about 25 percent higher than those in Table B-1. A hyperbolic curve fitted to the data in Table B-1 yielded the following equation:

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

where,

C = Unit train rate in 1974 dollars (mills/metric ton-km) or (mills/ton-mi)

D = Short-line rail distance, miles

For a 1600-km (1000-mile) one-way trip, assuming that 22.7 million metric tons (25 million tons) of coal were hauled annually, this equation would yield a transportation rate of 0.56¢/metric ton-km (0.82¢/ton-mi).

Barges

Bechtel used the barge transportation rates listed in Table B-2 to develop the following equation:

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

where

C = Barge transportation rate (based on 1970 dollars), mills/metric ton-km (mills/ton mile)

D = One-way barge distance, km (miles)

In addition, a charge of 36 cents per metric ton (40 cents per ton) was included for all barge/rail or rail/barge transfer.

For a 960-km (600-mile) barge trip, the above equation would yield a transportation rate of 0.23¢/metric ton-km (0.34¢/ton mi). For a distance of 1610 km (1000 miles) the rate would be 0.20¢/metric ton-km (0.29¢/ton mi). Rates for barge transportation are the lowest among the modes for coal shipment, but barging is limited to major navigable waters and to locations that have loading and unloading facilities.

Table B-1. RAIL RATES FOR UNIT TRAINS

WESTERN RAILROADS - 1974

One-way distance, km (miles)	Rate, mills/metric ton-km (mills/ton-mile)
160 (100)	13.7 (20)
320 (200)	11.0 (16)
480 (300)	8.9 (13)
640 (400)	8.2 (12)
800 (500)	7.5 (11)
960 (600)	6.9 (10)
1290 (800)	6.2 (9)
1600 (1000)	5.5 (8)
2400 (1500)	4.8 (7)

Source: Ref. B-1

Table B-2. BARGE TRANSPORTATION RATES - 1970

One-way distance, km(miles)	Rate, Mills/metric ton-km (mills/ton-mi)
80 (50)	4.8 (7.0)
160 (100)	3.6 (5.2)
320 (200)	2.9 (4.2)
480 (300)	2.6 (3.8)
640 (400)	2.5 (3.6)
800 (500)	2.4 (3.5)

(Source: Ref. B-1)

Slurry Pipelines

In developing cost estimates for new slurry systems, Bechtel included in the capital costs facilities for slurry preparation, live storage, dewatering, and pipeline transport; they excluded costs of water supply and cleaning facilities. Operating costs encompassed the power, labor, contract maintenance, and supplies required for operation and maintenance of the included facilities.

Because moving coal by slurry pipeline entails a large amount of unit operations at the first pump station and dewatering terminal, costs were segregated into fixed and variable components. The fixed component covered those costs dependent upon capacity only; the variable component was a function of both capacity and length. Curves were fitted to these data for generation of equations relating the cost to capacity and an inflation index. Addition of an inflation index, in this case the GNP implicit price deflator index obtainable from the President's Economic Report for 1973, allowed synthesis of past costs for correlation with earlier data bases. Prediction of future system costs by application of the overall inflation rate to this index is also possible.

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

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

where

Cf = Fixed unit transport cost (capital charge plus operating cost), ¢/ton

Cv = Variable unit transport cost (capital charge plus operating costs), ¢/ton-mile

GNP = Gross National Product implicit price deflator index:

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

T = Capacity, million tons delivered coal/yr

Metric conversion: One ton = 0.90718 metric ton
¢/ton-mi = 0.685¢/metric ton-km

Differences in elevation of line terminals, in terrain, and in soil conditions were evaluated for impacts on the cost relationships. For most cross-country coal slurry pipelines, none of these factors would affect the projected costs to a significant extent (all less than ± 10 percent). Economic factors, such as interest on debt and amortization period, were also checked for impact. Again, these effects were not significant (± 10 percent) within the ranges of 7.5 to 12.5 percent interest and 20- to 35-year amortization.

The only factor imposing a substantial effect on unit costs was the operating load factor. The fixed unit transport costs were multiplied by the following factor for operating loads less than design rate:

$$F = 0.7\ (LF/100) + 0.3$$

where LF is the operating load in percent of design rate. The load effect on the variable unit cost was negligible.

Bechtel noted that their figures were based upon hypothetical designs and typical coals. Unusual features of terrain and/or coal types could modify these cost estimates.

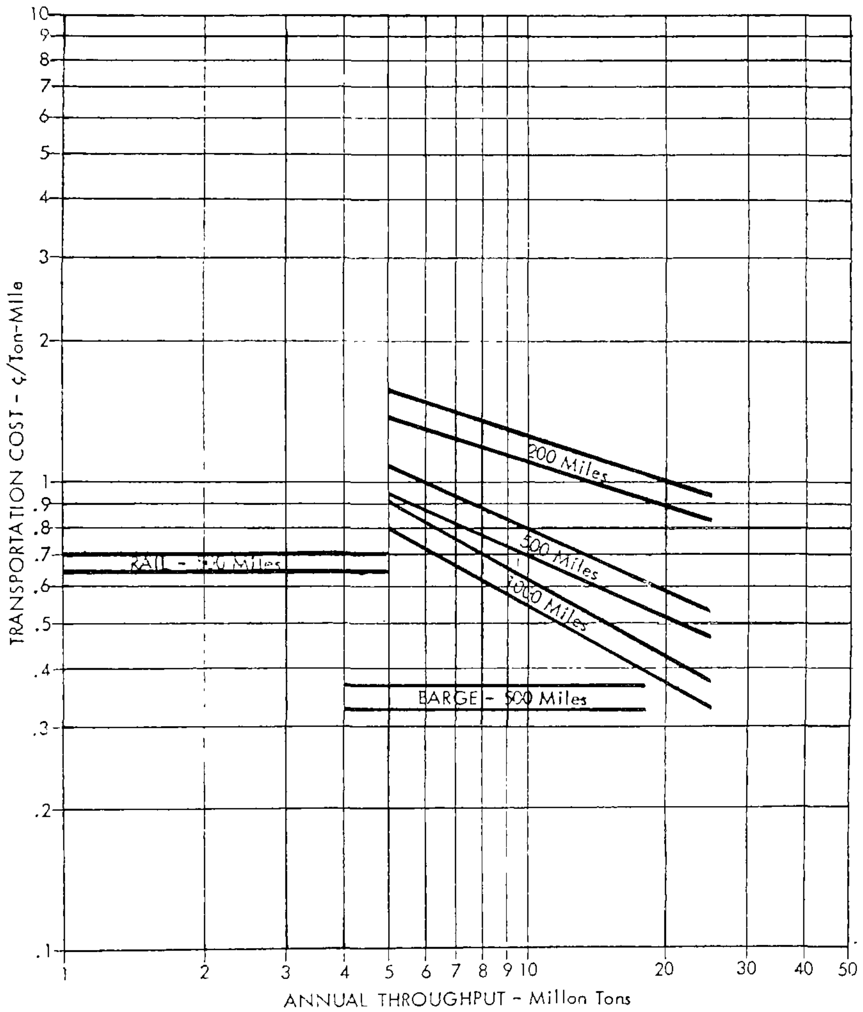
The variable unit transport cost for a 1610-km (1000-mile) pipeline, transporting 22.7 million metric tons (25 million tons) of coal annually, using the above formula, would be 0.18¢/metric ton-km (0.27¢/ton-mi). Adding the fixed unit cost of 0.08¢/metric ton-km (0.12¢/ton mi) gives a total unit cost for the pipeline of 0.27¢/metric ton-km (0.39¢/ton mi). These costs are shown graphically in Figure B-1.

UNIVERSITY OF ILLINOIS STUDY FOR NSF

Unit Trains

The University of Illinois study is based on computer modeling of unit train component costs to calculate unit train shipping costs (Ref. B-2).

The model showed obvious trends, such as 1) higher rates with increase in construction costs and 2) lower rates



1¢/ton-mi = 0.685 ¢/metric ton-km

Figure B-1. Coal transportation costs.

(Source: ref. B-1)

with increase in tons hauled per year. Costs not considered were expenses for strikes and insurance and for overpasses and crossings. The added costs for road bypasses and crossings will probably be required because in transport at a rate of 63.5 million metric tons (70 million tons) of coal per year, a train would pass by a given point every 40 minutes. Costs of overpasses or underpasses, which range from $400,000 up, are shared by the railroad and highway, the former usually paying 10 to 20 percent.

The study points out that the use of human resources may be more or less favorable than capital investment, depending on the unemployment situation and interest rates. It also says that, considering track upgrade only, the shipping rate of 22.7 million metric tons (25 million tons) of coal per year would pay out about 45 percent of the $60 million annual costs to direct labor. This would mean a $27 million payroll for 1800 jobs at $15,000 a year; at an inflation rate of 7 percent, cost would double every 10 years. Thus, a large part of the unit train rates would continually be subjected to this increase.

Another major cost is the capital needed to build a unit train system. The study estimated that 2060 additional cars of 93 metric ton (103.5 ton) capacity would be needed for a system to ship 22.7 million metric tons (25 million tons) of coal per year; also required would be ninety 2240-kW (3000-hp) diesel locomotives or thirty 7460-kW (10,000-hp) gas turbine locomotives, requiring 68,000 metric tons (75,000 tons) of steel. The double track would require about 500,000 metric tons (550,000 tons) of steel to last 25 years. The capital required for a unit train system of this size for 48-km/hr (30-mph) hauling, including only track upgrade, was estimated at $116.8 million; if starting with new ties and rails, the estimated cost would be $394.4 million.

Table B-3 presents the University of Illinois summary of costs and resources needed for unit trains. The Wyoming to Arkansas route is numbered (5)-(6). The costs are based on estimates for upgrading an existing railroad to handle unit trains traveling 80 km/hr (50 mph) loaded. The upgrading would include new rails and ties.

Coal Slurry Pipelines

The second part of the University's analysis was an estimation of slurry pipeline costs for shipment over the

Table B-3. COSTS AND RESOURCES FOR UNIT TRAINS

(SOURCE: REF. B-3)

[Costs in million dollars; (25×10^6 tons/year or 22.7×10^6 metric tons/year); new rails and ties; 50 mph (80.5 kmph) loaded and 60 mph (96.5 kmph) unloaded]

	Routes (from fig. 1)[1]				
	(5)–(10) (7)–(8)	(5)–(6)	(9)–(8)	(9)–(6)	(9)–(19)
Miles 1-way	1, 200	1, 100	900	500	250
(Kilometers 1-way)	(1, 930)	(1, 770)	(1, 450)	(804)	(402)
Miles total double track	1, 424	1, 324	1, 124	724	474
(Kilometers total dbl track)	(2, 290)	(2, 130)	(1, 810)	(1, 160)	(762)
Capital costs:					
Roadbed	320. 0	298. 0	253. 0	163. 0	107. 0
Equipment	90. 0	83. 0	72. 0	50. 0	36. 0
Total capital costs	410. 0	381. 0	325. 0	213. 0	143. 0
Average fixed charge on debt:					
Average rate base	205. 0	190. 5	162. 5	106. 5	71. 5
Debt Retirement (0.134)	27. 5	25. 5	21. 8	14. 3	9. 6
Federal tax (28 percent)	7. 7	7. 1	6. 1	4. 0	2. 7
Depreciation (25 yr)	16. 4	15. 2	13. 0	8. 5	5. 6
Total average fixed charge on debt	51. 6	47. 8	40. 9	26. 8	17. 9
Operating costs:					
Fuel costs	15. 2	13. 9	11. 4	6. 3	3. 2
Labor costs	27. 0	23. 5	19. 8	12. 6	8. 4
Supply costs	6. 6	5. 8	4. 9	3. 1	2. 1
Total operating costs	48. 8	42. 7	36. 1	22. 0	13. 7
Total annual cost	100. 4	90. 5	97. 0	48. 8	31. 6
Unit costs:					
Dollars per ton	4. 02	3. 62	3. 08	1. 95	1. 26
(Dollars per metric ton)	(4. 32)	(4. 01)	(3. 40)	(2. 16)	(1. 39)
Dollars per ton-mile	. 0033	. 0033	. 0034	. 0039	. 0050
(Dollars per metric ton-km)	(. 0023)	(0. 023)	(. 0024)	(. 0027)	(. 0034)
Dollars per 10^9 Btu-mile[2]	. 206	. 206	. 142	. 162	. 213
(Dollars/10^{12} Joule-km)	(. 122)	(. 122)	(. 084)	(. 096)	(. 126)
Energy requirements:					
Locomotive (horsepower)	530, 000	450, 000	417, 000	245, 000	175, 000
Million barrels fuel	1. 80	1. 65	1. 30	0. 75	. 40
(Percent energy delivered)	(2. 64)	(2. 27)	(1. 54)	(0. 79)	(0. 35)
Steel required for 25 yr in tons (and metric tons):					
For locomotive	75, 000 (68, 000)	70, 000 (63, 500)	60, 000 (54, 500)	40, 000 (36, 000)	25, 000 (23, 000)
For rails	550, 000 (500, 000)	510, 000 (460, 000)	435, 000 (395, 000)	280, 000 (254, 000)	185, 000 (170, 000)
Employment:					
Capital per worker	0. 227	0. 243	0. 246	0. 254	0. 260
Number of jobs (at $15,000 per year)	1, 800	1, 570	1, 320	840	560
Jobs in rail and train production	310	290	245	160	90
Total jobs	2, 110	1, 860	1, 565	1, 000	650

[1] (5)–(10) is Wyoming to Chicago; (7)–(8) is Colorado to Texas; (5)–(6) is Wyoming to Arkansas; (9)–(8) is Illinois to Texas; (9)–(6) is Illinois to Arkansas; (9)–(10) is Illinois to Chicago.

[2] 12,000 Btu Illinois coal and 8,000 Btu western coal.

same routes. Table B-4 summarizes capital and operating costs of a slurry pipeline in comparison with unit train costs.

In comparison of a new slurry pipeline with the best upgraded railroad, the slurry pipeline costs 0.47¢/metric ton (0.69¢/ton-mile) and the railroad 0.23¢/metric ton (0.33¢/ton-mile).

This comparison shows that slurry pipelines initially cost half as much as a new railroad but double the cost of the best upgrading of an existing railroad. The rail advantage is even greater if one considers that the railroad may carry other (noncoal) shipments, while the slurry pipeline is a one-material shipper. The study states that over the long term, the slurry may become cost-competitive with an upgraded rail system because a slurry pipeline is more capital-intensive than unit train operations.

For the Wyoming to Arkansas shipment, depreciation of a unit train model is estimated at 8.6 percent of its cost as compared with 27.4 percent depreciation for slurry. Table B-3 allocates 26.9 percent of the owning and operating cost of unit train operation for labor; Table B-4 allots 4.3 percent for the slurry pipeline. The initial labor rates are 9000 man-years for rail and 7500 man-years for slurry. The continuing labor is likewise higher for rail at 1800 man-years, whereas slurry operation calls for 245 man-years.

EBASCO STUDY

Ebasco Services, Inc. in a paper given at the American Power Conference in April 1976, calculated investment and operating costs of coal transport by slurry, rail, and rail-barge; the analysis considered transportation of energy blocks in increments of 1600, 3200, 6400, and 9000 MW over distances of 800, 1450, and 2400 km (500, 900 and 1500 miles).

Costs were based on a single terminal point for each transportation system. However, the 6400 MW and 9000 MW generating facilities could be comprised of several large stations in an energy center transmitting to a large industrial city. The transportation system would, therefore, split into several branches as it nears the terminus.

The distances selected represent probable haulage routes. For example, from the west Kentucky or southern

Table B-4. COSTS OF SLURRY PIPELINE IN COMPARISON TO RAIL (Costs in Million Dollars)

	Ohio (1)-(2)	Black Mesa (3)-(4)	Wyoming - Arkansas (5)-(6)	Colorado - Texas* (7)-(8)	Illinois - Chicago (9)-(10) Illinois - Arkansas (9)-(6)	Illinois - Texas* (9)-(8)
CAPITAL COSTS:						
A. Preparation equipment and wells		50	90		90	90
Tons/year	1.5×10^6	5×10^6	25×10^6	25×10^6	25×10^6	25×10^6
B. Piping and installation	10"(108mi)	18"D(273mi)	38"D(1040mi)	38"D(1200mi)	38"D(300mi)	38"D(700mi)
Electrical transmission (1 pumping station/90 miles)		60	894	1,133	261	609
C. Separation plant and water disposal		40	50	___	50	50
TOTAL CAPITAL COSTS		150	1,034	1,133	401	749
ANNUAL COSTS:						
A. Annual fixed charge on debt. Average rate base.		75	517		200.5	374.5
Debt Retirement						
Rate base (13.4%)		10.1	69.3		26.9	50.2
Federal Tax (3.3%)		2.5	16.9		6.6	12.3
Depreciation (25 years)		6.0	41.4		10.0	30.0
(State Tax, 2% on Inv.)		(2.0)	(20.7)		(8.0)	(15.0)
Total Debt Retirement		21.6	148.3		51.5	107.5
B. Operating Labor Direct (no. of men		1.6 (84)	4.6 (245)		2.9 (152)	3.6 (19.1)
Administrative		0.8	2.3		1.4	1.8
C. Material and maintenance supplies		1.0	6.0		4.0	5.0
Total of B and C		3.4	12.9		8.3	10.4
D. Power (installed horsepower)		1 (21,000)	15.9 (190,000)	(210,000)	7.4 (55,000)	12 (128,000)
E. Water (acre/foot/year)		0.5 (3,000)	3.5 (15,000)		3.5 (15,000)	3.5 (15,000)
TOTAL ANNUAL COSTS		26.5	180.6		70.7	133.4
(Total annual costs w/o state tax)		(24.5)	(159.9)		(62.7)	(118.4)
F.						
a. \$/ton including state tax		5.30	7.22	9.11	2.83	5.33
b. \$/ton excluding state tax		4.69	6.40	8.12	2.51	4.70
c. $\$/10^9$ Btu-mile including state tax		1.21	0.43	0.48	0.39	0.32
d. $\$/10^9$ Btu-mile excluding state tax		1.07	0.39	0.43	0.35	0.28
e. ¢/ton-mile including state tax		1.94	0.69	0.76	0.95	0.76
f. ¢/ton-mile excluding state tax		1.72	0.62	0.68	0.84	0.68
Hold-up in Pipe in tons at 3.5 mph		46,000	855,000	1,000,900	250,000	580,000
Comparison to Rail in cents/ton-mile						
New road, 50-60/30-60 mph			1.15/1.12	1.14/1.13	1.78/1.13	1.19/1.17
New rail, 50-60/30-60 mph			0.33/0.31	0.33/0.32	0.50/0.49	0.34/0.32
Track upgrading, 30-60 mph			0.19	0.20	0.30	0.20
Trains on the road, 50-60/30-60 mph			13/16	13/16	3/5	10/14
Total locomotive horsepower:						
50-60 mph			450,000	530,000	175,000	420,000
30-60 mph			250,000	300,000	90,000	240,000
Cost $\$/10^9$ Btu-mile, new rail 50-60 mph			0.206	0.206	0.162	0.142

* Difficult Terrain

(Source: Ref. B-3)

Metric conversion:
\$/ton = 0.90718 \$/metric ton
$\$/10^9$ Btu-mi = 0.00247 $\$/10^9$ g-cal-km
¢/ton-mi = 0.685¢/metric ton-km
mph = 1.609 km/hr

Illinois coal fields to a plant site on the lower Mississippi would be about 800 km (500 miles). A 1450-km (900-mile) route is equivalent to the distance between east Kentucky and the Dallas-Fort Worth area; 2400 km (1500 miles) is equivalent to the distances between Wyoming and the lower Mississippi and Gulf Coast areas.

Ebasco used levelized cost figures calculated on an 8.0 percent discount rate for the rail and rail-barge system and an 11.4 percent rate for the coal slurry lines. They also used a 30-year amortization period and 6 percent annual escalated rate.

In addition, the following basic assumptions were made in computing the costs for each system.

a) Railroad and Rail and Barge Systems

1. Existing rail lines were available to deliver coal from the mines to the plant or the barges.

2. Unit train and barge rates for such large volume movements were not available from a published tariff schedule. The rates used in this study represent those that Ebasco believed could be negotiated with the carriers and are based on other known unit train and barge freight rates.

3. Hopper cars costs were obtained from a manufacturer. Maintenance costs were based on published data on cars in unit train service.

4. Based on the long-term trend, rail freight rates and barge rates were assumed to escalate at the rate of 6 percent per year, as were car maintenance costs.

b) Coal Slurry Pipelines

1. Ebasco estimated investment costs in detail for a specific case and then adjusted, on an order-of-magnitude basis, for the other alternatives.

2. Fixed charges were taken at the rate of 14 percent, based on 80 percent debt, 20 percent equity financing, i.e., nonutility-type financing.

3. Energy costs were based on actual utility rates. For example, energy costs for the 2400-km (1500-mile) line included preparation plant energy costs based on a western utility company's rates.

4. Material costs were escalated for 1980 initial operation at 6 percent per year; labor costs were escalated at 8 percent per year.

Transportation Costs

Transportation costs include investment, fixed charges, and annual operating and maintenance costs. In the case of rail or rail and barge transportation, the freight charges remain the major component, with relatively small amounts for investment and maintenance.

The rail freight rates used in the study and shown in Table B-5 are based on mid-1975 conditions and utility-owned coal cars. The rail-barge rates, calculated on the same basis, are shown in Table B-6.

Table B-5. RAIL FREIGHT RATES - 1975

Distance, miles	Freight rate, $/ton	(mills/ton-mile)
500	5.50	(11.00)
900	8.50	(9.45)
1500	13.50	(9.00)

(Source: Ref. B-4)

Metric conversion:
1 mile = 1.609 km
$/ton = 0.90718 $/metric ton
mills/ton-mi = 0.685 mill/metric ton-km

Table B-6. RAIL-CAR FREIGHT RATES - 1975

Distance, miles	Freight rate, $/ton (mills/ton-mile)		
	Rail	Barge	Total
500 (100 rail - 400 barge)	2.20 (22.00)	1.80 (4.50)	4.00 (8.00)
900 (300 rail - 600 barge)	4.30 (14.32)	2.70 (4.50)	7.00 (7.79)
1500 (1000 rail - 500 barge)	9.50 (9.50)	2.20 (4.40)	11.70 (7.79)

(Source: Ref. B-4)

Metric conversion: 1 mile = 1.609 km
$/ton = 0.90718 $/metric ton
Mills/ton-mile = 0.685 mill/metric ton-km

Ebasco believes that the rates shown are about what would be arrived at in negotiations with carriers. These rates were escalated using the long-term trend of 6.0 percent per year, resulting in the levelized rates shown in Tables B-7 and B-8.

Table B-7. LEVELIZED RAIL FREIGHT RATES - 1980

Distance, miles	All-rail freight rate, $/ton (mills/ton-mile)	
500	15.82	(31.64)
900	24.47	(27.19)
1500	38.81	(25.87)

(Source: Ref. B-4)

Metric conversion: 1 mile = 1.609 km
$/ton = 0.90718 $/metric ton
Mills/ton-mi = 0.685 mill/metric ton-km

Table B-8. LEVELIZED RAIL-BARGE RATES - 1980

Distance, miles	Rail and barge rate, $/ton (mills/ton-mile)	
500	11.50	(23.00)
900	20.15	(22.39)
1500	33.65	(22.43)

(Source: Ref. B-4)

Metric conversion: 1 mile = 1.609 km
$/ton = 0.90718 $/metric ton
Mills/ton-mi = 0.685 mill/metric-ton-km

In the case of the capital-intensive pipelines, the major component of the annual costs are the fixed charges, operation and maintenance being relatively small. Fixed charges for the pipeline are about 73 percent of the annual costs; the balance is operating and maintenance costs. With 73 percent of their annual costs fixed, the coal pipelines are inflation resistant, only a small component of the annual costs being subject to escalation forces. Therefore, in any comparative evaluation with an alternative that is owning and operating intensive, the capital-intensive alternative is the more attractive, provided the state public service commission responds to requests for rate adjustment on a timely basis.

Pipeline transportation costs are presented in Table B-9. Table B-10 indicates the portion of the annual costs that Ebasco estimates are subject to escalation factors for each transportation system.

Table B-9. PIPELINE TRANSPORTATION COSTS FIGURES FOR 1980 INITIAL OPERATING DATE

Generation, MW	Coal delivery, tons per year	Distance, miles	Pipe diameter, inches	Investment, $1000	Levelized annual cost, $1000	Transportation cost, cents ton-mile
1,600	4,500,000	500	18	245,000	47,070	2.09
1,600	4,500,000	500	18	520,000	99,900	2.45
1,600	4,500,000	1,500	18	725,000	139,290	2.06
3,200	9,000,000	500	24	490,000	94,140	2.09
3,200	9,000,000	900	24	710,000	136,400	1.68
3,200	9,000,000	1,500	24	1,050,000	201,720	1.49
6,400	18,000,000	500	34	1,065,000	204,610	2.27
6,400	18,000,000	900	34	1,575,000	302,590	1.87
6,400	18,000,000	1,500	34	2,440,000	468,770	1.74
9,000	25,000,000	500	40	1,500,000	288,190	2.31
9,000	25,000,000	900	40	2,090,000	401,530	1.78
9,000	25,000,000	1,500	40	2,660,000	511,030	1.36

(Source: Ref. C-4)

Metric conversion:
1 ton = 0.90718 metric tons
1 mile = 1.609 km
1 inch = 2.54 cm
¢/ton-mi = 0.685¢/metric ton - km

(Source: Ref. B-4)

Table B-10. ESCALATION FACTORS FOR ANNUAL COSTS

System	Approximate percent of annual costs subject to escalation
All-rail	98.5
Rail-barge	99.0
Coal pipelines	27.1

(Source: Ref. B-4)

Table B-11 is a breakdown of the levelized annual owning and operating costs of the alternatives studied based on a 1980 initial operating date. Table B-12 tabulates the alternative costs based on differentials over the lowest cost alternative. The chart shows that coal pipelines are the most economical system in almost all cases. Rail and barge transportation systems are the next most economical alternative.

Conclusions

Ebasco came to the following conclusions:

1. In all but a few cases, pipeline transportation systems are the lowest-cost mode of energy transportation, followed by the rail-barge systems, as defined in the study. Coal pipelines are even more attractive if rail facilities do not serve the area under consideration.

2. Barge and rail transportation systems are worthy of consideration if (a) navigable waters for barge movements are available, and (b) the tonnage, distances, and split between rail and barge hauling distances are in the "right" proportions.

3. Coal pipelines are more inflation-proof than rail or rail and barge modes of transportation because of the low, overall operating and maintenance costs associated with pipe slurry. This should be weighed against the high operating cost of the rail and barge systems when selecting the transportation mode for a new coal-fired power plant.

4. If coal pipelines are to be viable, the right of eminent domain must be available to the user. In order

Table B-11. ANNUAL LEVELIZED UTILITY OWNING AND OPERATING COSTS

THOUSANDS OF DOLLARS

Distance, Miles	500	500	500	500	900	900	900	900	1,500	1,500	1,500	1,500
Capacity, MW	1,600	3,200	6,400	9,000	1,600	3,200	6,400	9,000	1,600	3,200	6,400	9,000
Railroad												
Fixed charges	1,400	2,800	5,600	7,800	1,700	3,500	6,900	9,700	2,100	4,200	8,400	11,700
Operating	73,520	147,250	294,500	413,700	114,760	228,890	458,000	637,950	181,430	362,850	725,710	1,007,970
Total	74,920	150,050	300,100	421,500	116,460	232,390	464,900	647,650	183,530	367,050	734,110	1,019,670
Rail-Barge												
Fixed charges	500	900	1,800	2,500	800	1,700	3,300	4,500	1,800	3,600	7,300	9,900
Operating	52,380	104,550	209,100	290,390	92,360	184,510	369,010	512,320	156,490	312,908	625,960	866,950
Total	52,880	105,450	210,900	292,890	93,160	186,210	372,310	516,820	158,290	316,580	633,260	876,850
Pipeline												
Fixed charges	34,300	68,600	149,100	210,000	72,800	99,400	220,500	292,600	101,500	147,000	341,600	372,400
Operating	12,769	25,538	55,507	78,190	27,101	37,003	82,085	108,926	37,785	54,723	127,167	138,633
Total	47,069	94,138	204,607	288,190	99,901	136,402	302,585	401,526	139,285	201,723	468,767	511,033

Metric conversion: 1 mile = 1.609 km

(Source: Ref. C-4)

(Source: Ref. B-4)

Table B-12. DIFFERENTIAL ANNUAL OWNING AND OPERATING COSTS

MILLIONS OF DOLLARS

Distance, Miles	500	500	500	500	900	900	900	900	1,500	1,500	1,500	1,500
Generation, MW	1,600	3,200	6,400	9,000	1,600	3,200	6,400	9,000	1,600	3,200	6,400	9,000
Annual costs												
Railroad	74.92	150.05	300.10	421.50	116.46	232.39	414.90	647.65	183.53	367.05	734.11	019.67
Rail and Barge	52.88	105.45	210.90	292.80	93.16	186.21	372.31	516.82	158.29	316.58	622.26	876.85
Pipeline	47.07	94.14	204.61	288.19	99.90	136.40	302.59	401.53	137.27	201.72	468.77	511.03
Differential												
Railroad	27.85	55.91	95.49	33.31	23.30	95.99	162.31	246.12	44.24	165.33	265.34	508.64
Rail and Barge	5.81	11.31	6.29	4.61	Base	49.81	69.72	115.29	19.00	114.36	164.49	365.82
Pipeline	Base	Base	Base	Base	6.74	Base	Base	Base	Base	Base	Base	Base

Metric conversion: One mile = 1.609 km

(Source: Ref. C-4)

(Source Ref. B-4)

to accomplish this, utilities must pursue this with their legislative leaders well ahead of time, since the subject is politically volatile.

UPPER MIDWEST COUNCIL STUDY

In April 1975, the Upper Midwest Council published a report dealing with conflicts and options in decision making. The decisions and policies considered dealt mainly with the factors affecting the transport of coal (or electrical energy).

In one section, the council compares costs and energy requirements. To illustrate some of the cost parameters, they created a hypothetical situation for comparing three modes of energy transport: railroad, slurry pipeline, and transmission lines. Coverage is restricted to the railroads and slurry pipelines. The model factors established that 10.9 million metric tons (12 million tons) per year were to be transported 1126 km (700 miles) to a 3 million kilowatt power plant. The following items were considered and values assigned (Ref. B-5).

CAPITAL INVESTMENT (1975 DOLLARS)

RAILROAD: Initially need 65 engines and 1573 coal cars. All would be replaced at the 15-year mark. Figure includes cost of initial equipment in 1975 plus dollars needed today to replace all equipment in 15 years discounted at 7% interest.[3]	$86,900,000
SLURRY: Includes construction and materials for coal preparation facility, a 96.5 cm (38-inch) pipeline and associated pumping and emergency storage systems, de-watering facility and right-of-way acquisition. Also includes cost of replacement materials over 30-year period.	$505,000,000

ANNUAL VOLUMES OF VARIOUS FUELS CONSUMED FOR TRANSPORTATION

RAILROAD: Liters (gallons) of diesel fuel at 9.3 x 10^6 g-cal/l (140,000 Btu/gallon) plus energy used in refining - 300,000 g-cal/l (4500 Btu's/gallon) of diesel oil produced.	54,125,000 liters (14,300,000 gal.)

SLURRY: Metric tons (tons) of Sarpy Creek coal at 4.67 x 10^9 g-cal/metric ton (16,800,000 Btu/ton) times 2.85 due to electric generating plant efficiency of only 35 percent.	1,334,000 metric tons (1,470,000 tons)

ANNUAL ENERGY LOSSES

RAILROAD: 43,150 g-cal/metric ton-km (250 Btu/ton-mile), including empty return of cars.[6]	4.86 x 10^{14} g-cal (1.93 x 10^{12} Btu)
SLURRY: 169,000 g-cal/metric ton-km (980 Btu/ton-mile), including energy used in coal preparation and dewatering.[1]	2.07 x 10^{15} g-cal (8.23 x 10^{12} Btu)

OTHER RESOURCE REQUIREMENTS

RAILROAD: Initial system development and component replacement over 30-year period.	101,650 metric tons (112,050 tons) steel
SLURRY: Initial system development and component replacement over 30-year period.	275,800 metric ton (304,000 tons) steel

TRANSPORTATION COSTS TO CONSUMERS - 1975

RAILROAD: Based upon 1975 tariff quote from Burlington Northern to Becker, Minnesota. Tariff quoted was $4.99 per ton.	2.9 mills/kWh
SLURRY: Based upon estimates developed for the proposed Wyoming-Arkansas coal slurry by Bechtel, Inc.	4.4 mills/kWh

Using their data, the cost of transporting coal by rail would be 0.49¢/metric ton-km (0.71¢/ton-mi) and 0.74¢/metric ton-km (1.08¢/ton-mi) by slurry line. An additional long-term cost consideration was that about 95 percent of the steel used by the railroads can be recycled when removed from use, whereas buried pipelines are hardly ever removed from the ground because the cost of removal is greater than the price of scrap steel.

The report stated that any decision to allow construction of pipeline slurry systems should be delayed until questions relating to economic impact on the rail industry are answered. The final consensus was expressed in general terms and did not favor one over the other. They believe that there is no single, simple answer to whether a railroad or a pipeline slurry is the best way to move energy. Overall, in relation to broad energy transportation requirements, either of the two systems is viable technologically and could be made feasible economically.

They state that when a particular utility is considering which transportation system is best for its specific needs, clear-cut choices would arise and a "best" system could be chosen for that particular situation.

COSTS PUBLISHED FROM OTHER SOURCES

Energy Transportation Systems, Inc. (ETSI), (1975) which is 40 percent owned by Bechtel, has presented a cost comparison for coal transport which is virtually identical to the recent Bechtel study. Cost estimates by members of ETSI have also appeared in Chemical Engineering (1971), and the "Oil and Gas Journal" (1973). The Chemical Engineering and the Oil and Gas Journal, costs are presented in Tables B-13 and B-14, respectively, and indicate clearly that trucks and conveyor belts are not competitive with railroads and slurry pipelines over long distance. However, trucks and conveyors have been proven over short distances and for special situations.

CONCLUSIONS

All of the studies discussed indicate that long-distance slurry pipeline and rail shipments of coal are both feasible in a comparative cost sense. Thus, both are viable candidates, especially for shipment of western coal where new mines will typically support large-volume movements. Although about 15

Table B-13. COST COMPARISONS FOR SOLID VOLUMES OF 1.8 TO 5.4 MM METRIC TONS (2 MILLION TO 6 MILLION TONS) PER YEAR

Carrier	Transport costs, cents per metric ton-km (ton-mile)	Conditions
Slurry pipeline	.2 to .5 (0.3 to 0.7)	Over 80 km (50 miles)
Rail	.3 to .6 (.4 to .9)	Unit train, over 645 km (400 miles)
Truck	3.4 to 5.5 (5.0 to 8.0)	One-way haul, empty return
Conveyor belt	1.4 to 4.1 (2.0 to 6.0)	Less than 24 km (15 miles)

Source: (Ref B-6)

Table B-14. TRANSPORT COSTS FOR COAL BY SLURRY LINE AND RAILROAD[a]

Fuel	(Cents/MM Btu/day 100 miles)
Coal slurry	(2.4)
Railroads (0.6 cent per ton-mile plus 10 percent greater distance)	(4.0)

[1] Transportation costs are presented for various 1-trillion-Btu-per-day movements over a distance of 1,000 miles.

[a] Data extracted from ref. B-7.

percent of the coal tonnage moves on inland and coastal waterways, this traffic is limited to that originating from mines adjacent to waterways. (Ref. B-8.) The metric ton-km (ton-mile) cost of water traffic is typically lower than rail costs for the same service. One of the reasons is that barge lines are not under the jurisdiction of the Interstate Commerce Commission (ICC), as are the railroads and truckers. In addition, the barge lines "right-of-way" is maintained and improved at no direct cost to them, but by taxes through the U.S. Corps of Engineers.

If the ETSI/Bechtel comparisons prove to be realistic, pipelines can be expected for very large shipments, with the railroads continuing to dominate the field for large, but not huge volumes. This, of course, depends on granting of the right of eminent domain to slurry pipeline companies, and on availability of adequate water supplies, especially in the western states, for pipeline development.

If the rationale of the University of Illinois study were to be followed, pipelines could be expected in areas where no existing railroads are now operating and terrain is unfavorable for new rail lines, a situation most likely to arise in the semi-arid western states. In most cases, however, the railroad would continue to dominate coal transportation.

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16. ABSTRACT

As a result of an increase in U.S. coal production to help achieve energy independence, much attention is being focused on regional-scale transportion of coal in volumes projected to reach 1.32 billion metric tons (1.2 billion tons) in 1985. Most transportation studies to date have centered on economics. Equally important, however, are the possible environmental impacts due to both normal operation and catastrophic events associated with preparation and transportation of coal. Many of the environmental impacts can be lessened by improvements in control technology; most of these impacts are not critical in terms of health and welfare; some, however, such as toxic properties of effluents from coal preparation plants, storage piles, and slurry lines, need further characterization. In addition, uses of energy associated with the transport modes should receive consideration in planning of coal transportation systems.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Barges Coal Mining Conveyers Railroads Trucks Transportation	Air Quality Coal Slurry Pipelines Coal Transportation Assessment Water Quality	43E 43G 85B

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