PN-AAW-[illegible]

A Training Manual
for Lesser Developed Countries

TECHNOLOGICAL, ECONOMIC AND ENVIRONMENTAL CONSIDERATIONS OF COAL DEVELOPMENT AND UTILIZATION

An Overview

Prepared for

AGENCY FOR INTERNATIONAL DEVELOPMENT
Office of Energy
Washington D.C.

W. KENNETH DERICKSON
President

INTENT, INC.

A Training Manual for Lesser Developed Countries

TECHNOLOGICAL, ECONOMIC AND ENVIRONMENTAL CONSIDERATIONS OF COAL DEVELOPMENT AND UTILIZATION

An Overview

Prepared for

AGENCY FOR INTERNATIONAL DEVELOPMENT
Office of Energy
Washington D.C.

Prepared By

W. Kenneth Derickson
INTENT, Inc.
417 North Reed Street
Joliet, Illinois

SPRING 1984

TABLE OF CONTENTS

I. INTRODUCTION

Preface	2
What is Coal?	3-11

II. TECHNOLOGIES

Exploration	2-3
Mining	4-22
Preparation	23-36
Transportation	37-45
Conversion	46-59
Utilization	60-85

III. BIBLIOGRAPHY 1-6

IV. WORK SESSIONS

Mining	2-4
Preparation	5-6
Transportation	7
Plant Applications	8-10

PART I

INTRODUCTION

Preface
What is coal?

PREFACE

This training manual is the result of a two month course conducted in early 1983 for the Association of Southeast Asian Nations by the Bureau for Asia, U.S. Agency for International Development. The course was designed to provide a broad overview of the economic, environmental and technological aspects of coal development and utilization programs. The emphasis was on applicable technologies for the ASEAN region and therefore some of the advanced technologies that will not be commercial for several years in the industrialized countries were either not included or only discussed briefly.

The course was conducted at Argonne National Laboratory by W. Kenneth Derickson (Director), W. Charles Redman (Section Leader-Technologies), Jerry L. Gillette (Section Leader-Economics) and W. S.(Bill) White (Section Leader-Environmental). The course staff, Robert F. Ichord (Asia/TR/USAID) and Donald Melville (ASEAN Liaison Officer/USAID-Manila) endeavored to understand the specific interests of each of the countries and tailored the content and emphasis of the course in a way to meet as many of these needs as possible.

The 28 course participants from Southeast Asia attended lectures daily for about half the day. The remaining time was devoted to working on practical application work sessions, site visits and providing presentations to the rest of the course participants on relevant aspects of their respective country coal development and utilization programs. The work sessions involved team work and team presentations to the class in order to provide the participants with an opportunity to be more active learners.

A great deal of very diverse informative information was accumulated during the course. Unfortunately, because of different styles of presentation and emphases, it was very difficult to make meaningful comparisons between technology options and economic and environmental considerations. Therefore, this manual is a first attempt to provide an overview of major economic, environmental and technological issues in coal development and utilization. When possible the important advantages and disadvantages are discussed and summarized for each technology so that the users of the manual are familiar with the issues prior to lectures on the specific details.

WHAT IS COAL?

FORMATION

Coal is an extremely heterogeneous combustible carbonaceous rock containing inorganic and organic materials. It is the result of a series of organic material deposits experiencing progressive changes in physical and organic properties following burial in a sedimentary environment. This process, termed coalification, requires anywhere from 30 million years for the younger coals (i.e., lignite) to 300 million year for the older coals (i.e., anthracite). In addition to time, temperature and pressure also influences the degree of coalification. The details of this process follow in order to provide the reader with a better understanding of the properties of coal and the influence of these on development and utilization strategies.

According to popular theory, vegetation deposited in swamps or other moist environments first underwent biochemical and then geochemical changes. During the biochemical stage, there was a gradual degradation of the plant materials, particularly cellulose and proteins, and a loss of hydrogen and oxygen. As a result of these changes, there was an increase in the carbon content of the deposited materials. The end product of these changes was peat, which is considered to be the precursor of coal. It is also during this stage that three paths of subsequent coalification are likely to be initiated: (1) the formation of fusain (coal material having the appearance and structure of charcoal), which progresses rapidly during the biochemical stage; (2) the formation of vitrain (coal material derived from the lignic and cellulosic substances in plant remains), which progresses more slowly during this stage; and (3) the waxy resinous remains, which undergo very little change during this phase.

Sediments accumulate over the peat burying it deeper and subjecting it to greater geological influences. The coals formed during this phase, geochemical, can be quite variable and depend on the original starting material and nature of changes experienced during the biochemical stage. The weight of overlying sediments, tectonic movements and increased temperatures, due to greater depth of burial or igneous extrusions or intrusions, changes peat into a progressively harder substance. At the same time the water and volatile material content decreases while fixed carbon content and calorific value increase. Increased temperatures affect the chemical composition of the coal by causing decreases of hydrogen and oxygen content. This in turn results in a higher fixed carbon content and calorific value. Persistence of these increased temperatures tends to accelerate the chemical changes. Excessive temperature increases caused by igneous extrusions and intrusions can convert coal to natural coke. Increased pressure generally affects the physical properties, such as hardness, strength and porosity. These physical changes are brought about by the reorientation of particular units due to the weight of the overlying sediments and/or tectonic movements. Tectonic movements appear to be particularly important to the formation of anthracite, since most major anthracite deposits occur in mountainous regions.

PROPERTIES

Rank

These biochemical and geochemical changes alter deposits of organic materials into coals of different rank. Although there are finer distinctions in coal rank, the four major coal ranks are lignite, subbituminous, bituminous and anthracite. These coals are ranked on the basis of their fixed carbon, volatile material, heating value and agglomerating characteristics. The higher ranked coals, anthracite and bituminous (low volatile and medium volatile) are separated on the basis of fixed carbon content, the lower ranked coals on the basis of their heating value. This information is summarized in Table 1:

TABLE 1. COAL RANKINGS.

COAL TYPE	FIXED CARBON[a] CONTENT (%)	VOLATILE[a] MATTER (%)	HEATING[b] VALUE (Btu/lb)	AGGLOMERATING CHARACTER
Anthracite				
Meta-anthracite	>98	<2		
Anthracite	92-98	2-8		
Semianthracite	86-92	8-14		Nonagglomerating
Bituminous				
Low-volatile	78-69	14-22		
Medium-volatile	69-78	22-31		
High-volatile A	<69	>31	>14,000	Commonly,
High-volatile B			13,000-14,000	agglomerating
			11,500-13,000	
High-volatile C			10,500-11,500	Agglomerating
Subbituminous				
A			10,500-11,500	Nonagglomerating
			9,500-10,500	
C			8,300- 9,500	
Lignite				
A			6,300- 8,300	
B			<6,300	

Source: U.S. Geological Survey Bulletin 1412.
[a] Dry, mineral-matter free basis.
[b] Moist, mineral-matter free basis.

Physical

Density, physical constitution, and heating value are physical properties that are of importance in the preparation and utilization of coal. Densities of coal vary from 1.3-1.5 with anthracite having the highest density and bituminous the lowest. The most commonly used methods of cleaning coal are based on separation by density. Physical constituents (plant remains commonly called macerals) include color, luster, constituent changes, porosity, strength and reflectance. Coals become darker and brighter with increasing

6

rank. There are fewer obvious plant remains and a higher reflectance with increasing rank. Coal strength is highest and porosity lowest in bituminous coals. These latter characteristics are particularly important in making coke for metallurgical applications. Heating value of coal has been described above. The physical characteristics for the major coal ranks are summarized in Table 2.

TABLE 2. PHYSICAL PROPERTIES OF COALS.

PROPERTIES	ANTHRACITE	BITUMINOUS	SUBBITUMINOUS	LIGNITE
Density	Highest <------	< Lowest >	---------->	Higher
Color	Black <----------	----------	----------<	Brown
Luster	Shiny <----------	----------	----------<	Dull
Constituents	Not Obvious <----------	----------	----------<	Obvious
Porosity	Higher <-------	< Lowest >	---------->	Highest
Strength	Lower >-------->	Highest <----------	----------<	Lower
Reflectance	Highest <----------	----------	----------<	Lowest

Chemical

Chemical properties of coal are determined by either ultimate or proximate analyses. Ultimate analysis quantifies elemental composition and proximate analysis various compounds. The elements typically measured are carbon, hydrogen, nitrogen, oxygen, sulfur and ash. Coal has a higher amount of ash relative to other fossil fuels making utilization much more difficult. Various trace elements (for example, chlorine, iron, sodium and potassium) present in either the organic or inorganic constituents of coal may also be measured to characterize ash behavior during combustion. The compounds usually quantified are water, volatile matter, fixed carbon and ash. Sulfur content and heating value may also be included in proximate analysis. These analyses are used for ranking coal and are particularly helpful in the selection of appropriate combustion and pollution abatement systems.

The percentages of the various elements and compounds found in coal show definite trends when compared with rank. The trends for fixed carbon, volatile matter and heating value are shown above in Table 1. The trends for hydrogen, oxygen, nitrogen, sulfur, water and ash are shown below in Table 3. Because of sulfur's significance as a major air pollutant, it is important to note that it occurs in both inorganic (pyrite) and organic forms. A significant portion of the inorganic portion of the sulfur can be easily removed during coal preparation; however, very little reduction in organic sulfur occurs with standard coal preparation techniques.

TABLE 3. PERCENTAGE RANGES FOR SELECTED CHEMICAL PROPERTIES OF COALS[a]

PROPERTIES	ANTHRACITE	BITUMINOUS	SUBBITUMINOUS	LIGNITE
Hydrogen[b]	1.8-3.4	3.9-5.9	3.8	2.8-3.1
Oxygen[b]	0.7-2.2	1.8-10.6	12.2-13.2	12.1-12.4
Nitrogen[b]	0.6-1.5	0.9-2.0	1.0-1.3	0.7-0.8
Sulfur[b]	0.5-1.7	0.5 4.3	0.3-0.4	0.5-0.7
Water[c]	2.1-5.4	1.4-14.1	19.6-23.2	33.7-34.8
Ash[c]	6.9-19.6	2.8-13.9	3.8-4.0	6.2-7.3

a Analyses done on coal as received.
b Percent ultimate analysis.
c Percent proximate analysis

Engineering

The coal properties described above are useful for establishing preliminary criteria in connection with design and performance parameters for coal utilization equipment and facilities. More specific information is needed on coal behavior under utilization conditions, however, before final criteria can be prepared. These data typically come from the engineering data for actual operations. This section will discuss the effects of various coal mining technologies, sampling procedures, preparation practices and properties on utilization.

Mining Technologies. The primary goals of any coal producer are high production rates, meeting the needs of the user, minimal production costs and satisfying the safety and environmental requirements of various regulatory bodies. No one coal mining technology is superior at meeting all these goals under all mining conditions. Therefore, the producer must weigh the advantages and disadvantages of each technology based on the conditions and constraints associated with each mine. Table 4 summarizes some of the major advantages and disadvantages of surface and underground mining.

Although mechanized mining technolcgies (surface, continuous and longwall mining) have several disadvantages, this is the current trend. The higher production rates, lower product costs, lower labor requirements and overall increased safety to miners outweigh the lower coal quality (due to the greater percentage of noncombustibles), increased dust and methane levels, and environmental problems. Underground machine mining produces smaller coal resulting in increased dust and methane levels at the coal face. For surface mining, large areas of land are temporarily removed from productivity and may be significantly altered from their original condition. These latter problems can be minimized by ventilation and reclamation. The increased costs associated with these mitigative measures do not increase production costs

sufficiently to warrant less productive technologies. Additionally, these technologies are less labor-intensive and therefore fewer miners are affected by mining accidents.

TABLE 4. RELATIVE ADVANTAGES AND DISADVANTAGES OF SURFACE AND UNDERGROUND MINING TECHNOLOGIES

PARAMETERS	UNDERGROUND				SURFACE
	MANUAL	CONVENTIONAL	CONTINUOUS	LONGWALL	
Production Costs	Highest	<----------			< Lowest
Labor Requirements	Highest	<----------			< Lowest
Production Rate	Lowest	>----------			> Highest
Mining Efficiency	Lowest	>----------			> Highest
Safety to Miner	Lowest	>----------			> Highest
Impacts to Environment	Lowest	>----------			> Highest
Equipment Failure Impact to Production[a]	Lowest	>----------			> Highest
Coal Quality	Highest	<----------			< Lowest
Coal Dust Production	Lowest	>----------		> Highest	NA[b]
Coal Size	Largest	<----------		< Smallest	NA
Methane Release Rate	Lowest	>----------		> Highest	NA

[a] For example, failure of longwall miner stops production until repaired.
[b] Not Applicable.

Sampling. The purpose of coal sampling is to determine the characteristics of coal under utilization conditions. The results from this sampling, in turn, are used for the design and operation of combustion systems and selection of preparation practices. Special-purpose-sampling and Commercial-sampling are the two procedures in general use. Special-purpose-sampling has a high degree of accuracy and is used to characterize coals from new deposits or aids in the development of new utilization facilities. Because of the high level of technical competence required and higher costs, this procedure is not used commonly. Commercial-sampling is more commonly used to monitor routine production quality for compliance with specified operating conditions. These latter procedures have been standardized by the American Society for Testing Materials (ASTM). Appropriate ASTM standards, specifications and definitions are shown in Table 5.

9

There are inherent properties of coal that make sampling and application of the results difficult, even with standardized procedures. Coal at rest in storage piles or rail cars will be subject to size segregation and may lose or absorb moisture. A series of samples of the same coal must be analyzed in order to minimize the effects of such biases. Sampling of coal in motion (conveyor belts and chutes) provides more representative results and is, therefore, more desirable.

Preparation. Raw coal generally undergoes varying degrees of preparation before utilization. The principal purposes of this preparation are to reduce shipping costs and to upgrade the quality of the mined coal by reducing noncombustible materials and moisture. These properties add weight and little or no heating value to the shipped coal and decrease utilization efficiences.

Upgrading of coal quality through preparation generally involves grinding, washing and drying. Grinding produces smaller more uniform coal and liberates the heavier, harder noncombustibles allowing them to settle out during washing with water or a dense medium liquid. The coal is then generally dried to remove water absorbed during washing. The resultant coal has a higher heating value per unit weight and produces less ash. Although these are very desirable conditions for keeping down shipping cost and increasing utilization efficiencies, they can create other problems. The drying of the coal can make it more difficult to grind prior to utilization. The greater surface area of the coal can also affect its moisture content during shipping and storage, altering its grindability and heating value. Therefore, it is important that the properties of prepared coal be known or specified before utilization equipment specifications or coal contracts are prepared.

Utilization. Combustion experiences to date indicate that coal grindability, moisture and ash properties are controlling parameters. Grindability and moisture are important parameters for onsite movement and pulverizing of coal, while moisture and ash influence utilization efficiencies.

As shown in Table 6, grindability is important in pulverized firing. The coal is generally pulverized in a mill just prior to firing. The mills are designed for coals with specified Hardgrove Grindability Indices (measures of coal softness compared to a standard of 100). Pulverizing coals that fall below the specified range can result in mills wearing out earlier or malfunctioning. This in turn can cause less than optimum combustion conditions or outages.

As mentioned in the previous section, moisture can affect the heating value of the coal and its grindability. Combustion systems generally operate most efficiently at certain temperatures and require appropriate quantities of coal to achieve these temperatures. Increases in moisture content require increased quantities of coal to maintain the optimal operating temperatures. This places an additional load on pulverizer capacity which can decrease its performance or exceed its ability to supply sufficient coal to maintain full load. Also, mills are designed to operate at certain Hardgrove Grindability Indices and variation in moisture can effect their performance since the index may decrease (coal becomes harder to grind) at both low or high moisture levels.

10

TABLE 5. ASTM DOCUMENTS RELEVANT TO COAL PROPERTIES.

ASTM Standards for Testing Coal			
D 1756	Carbon Dioxide in Coal	D 2639	Plastic Properties of Coal by Automatic Gieseler Plastometer
D 2361	Chlorine in Coal	D 197	Sampling and Fineness Test of Powdered Coal
D 291	Cubic foot weight of Crushed Bituminous Coal	D 271	Sampling and Analysis, Laboratory, of Coal and Coke
D 440	Drop Shatter Test for Coal	D 492	Sampling Coals Classified According to Ash Content
D 547	Dustiness, Index of, of Coal and Coke	D 2234	Sampling, Mechanical, of Coal
D 1857	Fusibility of Coal Ash	D 2013	Samples, Coal, Preparing of Analysis
D 1412	Equilibrium Moisture of Coal at 96 to 97% Relative Humidity and 30°C	D 410	Screen Analysis of Coal
D 2014	Expansion or Contraction of Coal by the Sole-Heated Oven	D 311	Sieve Analysis of Crushed Bituminous Coal
D 720	Free-Swelling Index of Coal	D 310	Size of Anthracite
D 409	Grindability of Coal by the Hardgrove-Machine Method	D 431	Size of Coal, Designating from its Screen Analysis
D 2015	Gross Calorific Value of Solid Fuel from Adiabatic Bomb Calorimeter	D 1757	Sulfur in Coal Ash
D 1812	Plastic Properties of Coal by the Gieseler Plastometer	D 2492	Sulfur, Forms of, in Coal
		D 441	Tumbler Test for Coal

ASTM Specifications			
D 388	Classification of Coals by Rank	D 323	Perforated-Plate Sieves for Testing Purposes
D 11	Wire-Cloth Sieves for Testing Purposes		

Definition of Terms			
D 121	Coal and Coke	D 407	Gross Calorific Value and Net Calorific Value of Solid and Liquid Fuels
D 2796	Lithological Classes and Physical Components of Coal		

TABLE 6 CONTROLLING COAL PROPERTIES FOR FIRING.

PROPERTY	PULVERIZED COAL FIRING	STOKER COAL FIRING	CYCLONE FURNACE FIRING
Grindability	YES	NO	NO
Rank	YES	YES	YES
Moisture (maximum %)	15	15-20	20
Volatiles (minimum %)	15	15	15
Ash (maximum %)	20	20	25
Ash-Softening Temperature	NO	YES	YES

Source: Steam, Babock & Wilcox Company, New York, 1972.

Ash remaining after coal has been fired represents the noncombustible mineral matter so common in coal. Approximately 95 percent of the ash is composed of oxides of silicon, alumina, iron, calcium and magnesium. Small amounts of oxides of sodium and potassium are also present and these act as fluxes in fusing ash. This ash is undesirable because it accumulates in the furnace and requires removal and disposal equipment. Because it can accumulate on furnace waterwalls and heat transfer surfaces, it affects furnace sizing (volume, plan area and fuel-burning zone), the amount of convective surfaces and their spacing, and the number of furnace wall cleaning devices (sootblowers). Depending on the ash properties and temperatures, these accumulations are referred to as slagging or fouling. Slagging results when ash becomes fluid, fuses and then bonds tightly to the furnace walls (or other surfaces exposed to predominantly radiant heat or excessively high gas temperatures). Fouling occurs when ash deposits are bonded on convective surfaces, such as superheater and reheater tubes and furnace walls at lower than slag-producing temperatures. Fouling can also lead to corrosion or erosion of the effected surface. Slag is very difficult to remove while fouling deposits are more easily removed with cleaning devices such as sootblowers.

The potential for corrosion, fouling and slagging can be assessed by measuring ash fusibility temperatures, iron content and type, base/acid ratio, iron/calcium ratio, active alkali content and quantity (pounds/million Btu). As a rule, lower ash fusibility temperatures are associated with higher slagging. Coals with a high iron pyrite level and non-uniform distribution of iron in the coal matrix produce ashes with a high slagging potential. Base/acid ratios of 0.4-0.7 and iron/calcium ratios of 0.2-10 are indicative of low ash fusibility temperatures; slagging potential decreases as these ratios becomes larger or smaller. Active alkala content is used to determine fouling potential and is usually expressed as the percent of volatile sodium. Values greater than three percent generally indicate a severe fouling potential. High sulfur levels and chloride levels greater than 0.3 percent can also increase fouling. Fouling can give rise to corrosion if the

deposited material is high in alkali-iron -trisulfate ($Na_3Fe(SO_4)_3$). Finally, the higher the ash content the greater the potential for corrosion, fouling and slagging.

Standard coal preparation practices can economically reduce ash by 50-75%. This reduction does not eliminate the problems created by ash and combustion systems and ash handling and disposal facilities will have to be designed accordingly. Although higher levels of ash reduction are technically possible, current costs are prohibitive and it is less costly to adjust the furnace sizing and convective surfaces to minimize corrosion, fouling and slagging effects.

PART II

COAL TECHNOLOGIES

Exploration
Mining
Preparation
Transportation
Conversion
Utilization

EXPLORATION

EXPLORATION

TECHNOLOGY CONSIDERATIONS

The major deposits of coal are associated with regions known to have been ancient coastal, deltaic (delta systems) and fluvial (lowland meandering streams) environments. Smaller deposits may be found in conjunction with erosional surfaces, glacially-derived depressions and sinkholes. Therefore, exploration efforts usually are focused on these regions. Within these, the sequence of exploration activities are:

1) review and evaluation of available geological and geophysical data;

2) identification of surface and mineral rights ownership in promising areas;

3) examination of the surface to detect coal outcrops and collect samples;

4) drilling in suspected deposits;

5) implementing drill sampling programs to determine the quantity and properties of the coal; and

6) mapping the coal resources and reserves.

The first three exploration steps are fairly straight forward. Drilling is the most commonly used method for determining the presence of coal (step 4), because of its simplicity, reliability and low costs. Other practices that may be employed include areal and surface photography, gravimetric and magnetic, seismic, tunneling and down-hole well logging. These practices provide information on relevant surface formations and outcroppings, geologic structure, subsurface conditions, and geophysical characteristics, respectively.

Once coal deposits have been located a sampling program is developed and implemented to provide more representative data on overburden and coal properties. The number of drill samples will be a function of the geologic complexity of the area, the amount of accompanying geophysical data and cost considerations. Table 7 summarizes the data typically derived from exploratory sampling programs. Using these data, the geologist can estimate the total coal resource and the fraction of the resource that is recoverable (reserves), given current economics and mining technology. They also help identify potential mine development problems, such as water, gas (methane), roof/floor stability, faulting, fracturing, intrusions, seam dipping, seam partings, pyritic zones and previous mining activities. Geologic maps, cross-sections, isopach (thickness) maps, fence diagrams, stratigraphic sections and geophysical logs summarize the findings of the exploratory sampling program for future use. The information contained in these documents is crucial to planning an effective mine operation.

TABLE 7. DATA DERIVED FROM AN EXPLORATORY SAMPLING PROGRAM

Coal-related	Overburden-related
Depth	Depth
Lateral Extent	Faulting
Number of Seams	Groundwater Hydrology
Seam Dipping	Stability
Seam Thickness	Structure
Chemical Properties	
Ash	
Carbon	
Moisture	
Sulfur	
Volatile Matter	
Physical Properties	
Density	
Heating Value	
Porosity	
Rank	

ECONOMIC CONSIDERATIONS

The costs associated with exploration are typically 4.5-11 percent of the total capital requirements of an underground or surface mine with an annual production rate of one million tons. The variability in these percentages is a function of the coal rank and seam thickness. As coal rank and seam thickness increase, the proportionate cost of exploration decreases.

Drilling costs are a major portion of the exploration costs. These are dependent on hole depth and size, drilling conditions, project size, and amount, type and sizing of coring. The construction of roads and buildings to support exploration activities and sample analyses are the other major costs.

ENVIRONMENTAL CONSIDERATIONS

Environmental impacts associated with exploration are minor and consist mainly of surface and subsurface physical disturbances and noise associated with work crews, drilling and tunneling.

MINING

MINING

Coal is mined either underground or at the surface depending on its depth, seam thickness, rank and properties of overburden materials. Until 1940 about 90% of all coal was produced by underground mines. During the 1960's, surface mining increased drastically as a result of the introduction of giant excavating equipment. In the U.S., surface mining currently accounts for approximately 60% of the total coal production. Generally, lower-ranked (6,000-9,000 Btu/lb) coal deposits located at depths less than 150 feet, or having an overburden to seam thickness of less than 15:1, are recovered by surface mining. Although this trend is expected to continue into the future, it will not persist over the long-term since about two-thirds of the recoverable resources are too deep to exploit economically with surface mining.

TECHNOLOGIES

Underground (Deep) Mining

The selection of a particular mining system or method is a complex process and must be done on a mine-by-mine basis since no single mining plan can be applied universally to all mines. Portal type and location, surface facilities, mine development and mining system are major considerations in any mining project. The independent and dependent variables listed in Table 8 have a significant influence on these considerations as shown in Table 9.

TABLE 8. INDEPENDENT AND DEPENDENT VARIABLES AFFECTING SURFACE AND UNDERGROUND MINING METHODS.

VARIABLES	UNDERGROUND MINING	SURFACE MINING
Independent		
	Seam Depth	Seam Height
	Seam Height	Overburden Depth
	Seam Hardness	Overburden Consistency
	Bottom Quality	Topography
	Roof Quality	Water
	Methane Liberation	
	Water	
Dependent		
	Pillar Sizes	Drilling and Blasting
	Entry Widths	Mining Pattern
	Advancing Distance	Spoils Handling
	Percent Recovery	Reclamation Practices
	Roof Supporting	Erosion Control

TABLE 9. CONDITIONS FAVORING DIFFERENT UNDERGROUND MINING METHODS.

CONDITIONS	CONVENTIONAL	CONTINUOUS	LONGWALL
Seam Depth (feet)	< 1000	< 1000	> 1000
Seam Height (inches)	< 65 inches	75-80	48-84
Seam Hardness	Hard	Soft	Soft
Seam Partings	Yes	No	No
Bottom Quality	Good	Poor	Poor
Roof Quality	Poor	Good	Poor
Methane Liberation	High	Low	Moderate

The three types of portals (drift, shaft and slope) for reaching the coal seam are depicted in Figure 1. Drift portals are limited to those seams that outcrop on the side of a hill or mountain. The choice between the more common shaft and slope is a function of seam depth, overburden condition, and economics. Slopes are generally used when the coal seam is 300-600 feet deep and coveyor or haulage from the mine is employed. Shafts are typical for seams at depths > 600 feet and when hoists are used to load out the coal. When ground conditions are poor, shaft portals will be used. The portal site should be located near the geopraphical center of haulage, free from flooding, accessible to the worker and near surface facilities. The surface facilites include bathhouses, parking spaces, preparation plant, refuse disposal and mine-water treatment ponds and supply yards. These should be located on the most favorable strata for proper support and maintenance.

Mining development is the systematic procedure for preparing a mine for services and an organized system of attack. Parallel underground openings, called entries, are generally driven from the portal in a central location of the mine. These entries are separated by blocks of coal to provide support and their width is usually a function of depth. As depth increases the pressure of the overlying materials also increases and the width of the entries must be decreased for safety reasons. The entries are comparable to the main streets of a city and provide power, piping, haulage, ventilation and other support services. A large number of these parallel entries are needed to keep the velocities of air within acceptable limits, usually 600-800 ft/min. Ideally the entries should extend to the property line with both sides being mined on the way back (full-retreat system). Using this system , no active openings need be maintained between caved ground, greatly simplifying roof control and minimizing roof falls which delay production. This system ties up considerable capital without compensating production. Producers unable to afford this use a half-advance, half-retreat system. With this system the main entries are driven in sufficiently and then panels 2,000-3,000 feet long are turned off to one side and extracted on retreat. Panels

20

on the other side of the main entries are extracted on advance. The development to production ratio is watched very closely because of the high costs of services relative to the low development extraction (~30%). The entries are only driven far enough ahead to maintain adequate production.

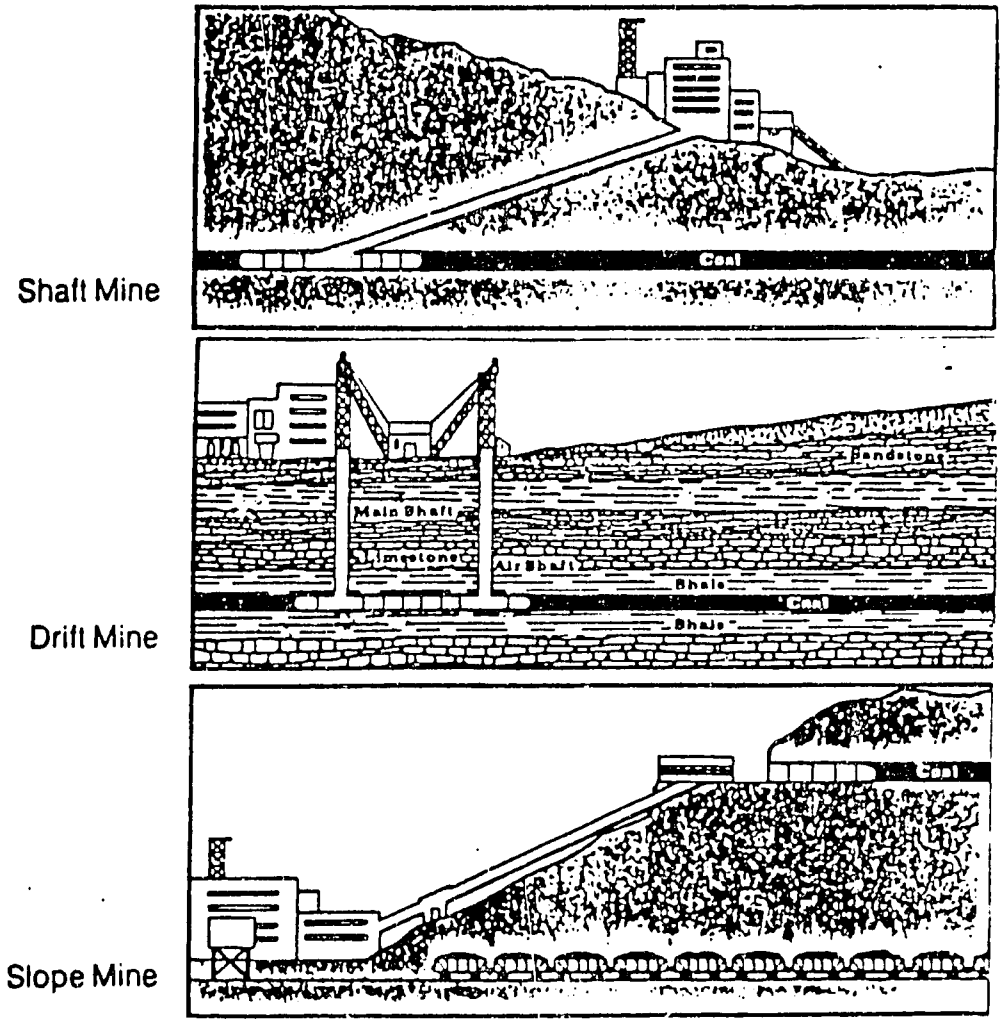


FIGURE 1. Three types of underground portals.

The two major mining systems are room and pillar and longwall. A third less commonly used system is shortwall, which is a modified version of longwall mining. The room and pillar system may use manual (hand drilling), conventional or continuous mining methods. Manual mining is very similiar to conventional mining; however, men rather than machines are used for the drilling and cutting operations. Selected operating features of conventional, continuous and longwall mining methods are listed in Table 10.

TABLE 10. OPERATING CHARACTERISTICS OF DIFFERENT UNDERGROUND MINING METHODS.

CHARACTERISTIC	CONVENTIONAL[a]	CONTINUOUS[a]	LONGWALL
Production (tons/shift)	290	300	1000
Production rate (tons/manshift)[b]	20	33	125
Recovery Efficiency (percent)	50-60	50-60	80-85
Face Crew Size	14	9	8
Face Unit Size (equipment)	6	4	4

[a] Seam thickness of 72 inches
[b] Production divided by Face Crew Size

Room and Pillar System.

The two mining methods currently used in this system are conventional and continuous (Figure 2). Conventional mining involves five different operations: cutting, drilling, blasting, loading and bolting. Continuous mining combines cutting, drilling, blasting and loading into a single operation done by a single machine.

Conventional mining. This method utilizes special machines in a sequential manner to cut, drill, load, haul and bolt. A coal cutter is used to undercut the mining face to facilitate blasting by providing room for expansion and allowing gravity to assist with breakage. The cut is typically about five inches wide and 8-14 feet in depth. After cutting is complete, the cutter moves to the next face to be extracted and the drilling machine takes its place. Blastholes are drilled and loaded with approved explosives. The most common explosive is ANFO (ammonium nitrate and fuel oil); however, ordinary dynamite (diluted with salt to reduce flaming), cartridges of compressed air, liquid oxygen or carbon dioxide are also used. The explosions from these explosives are slow and light, to break the coal into large lumps. A ramp-type loader moves in after blasting to load shuttle cars. Clawlike arms push the coal onto a conveyor in the middle of the ramp. The conveyor carries the coal up the ramp and out to a cantilever arm overhanging the shuttle. Loaded shuttles carry the coal to a transfer hopper that feeds the main haulage system. Two shuttles are typical, with one moving while the other is being loaded. Following removal of the blasted coal, a roof bolting machine moves in and drills holes 4-8 feet into the roof. Special bolts with expansive ends, flat washers and nuts are inserted and put under tension by tightening the nuts. These provide support to loose chunks of rock and tie overlying strata together into a thick beam.

The cutter, driller, loader, two shuttles and roof bolter make up a conventional mining face unit. Such a unit may work as many as 26 mining faces per shift with 14 miners producing as much as 1500 tons of coal.

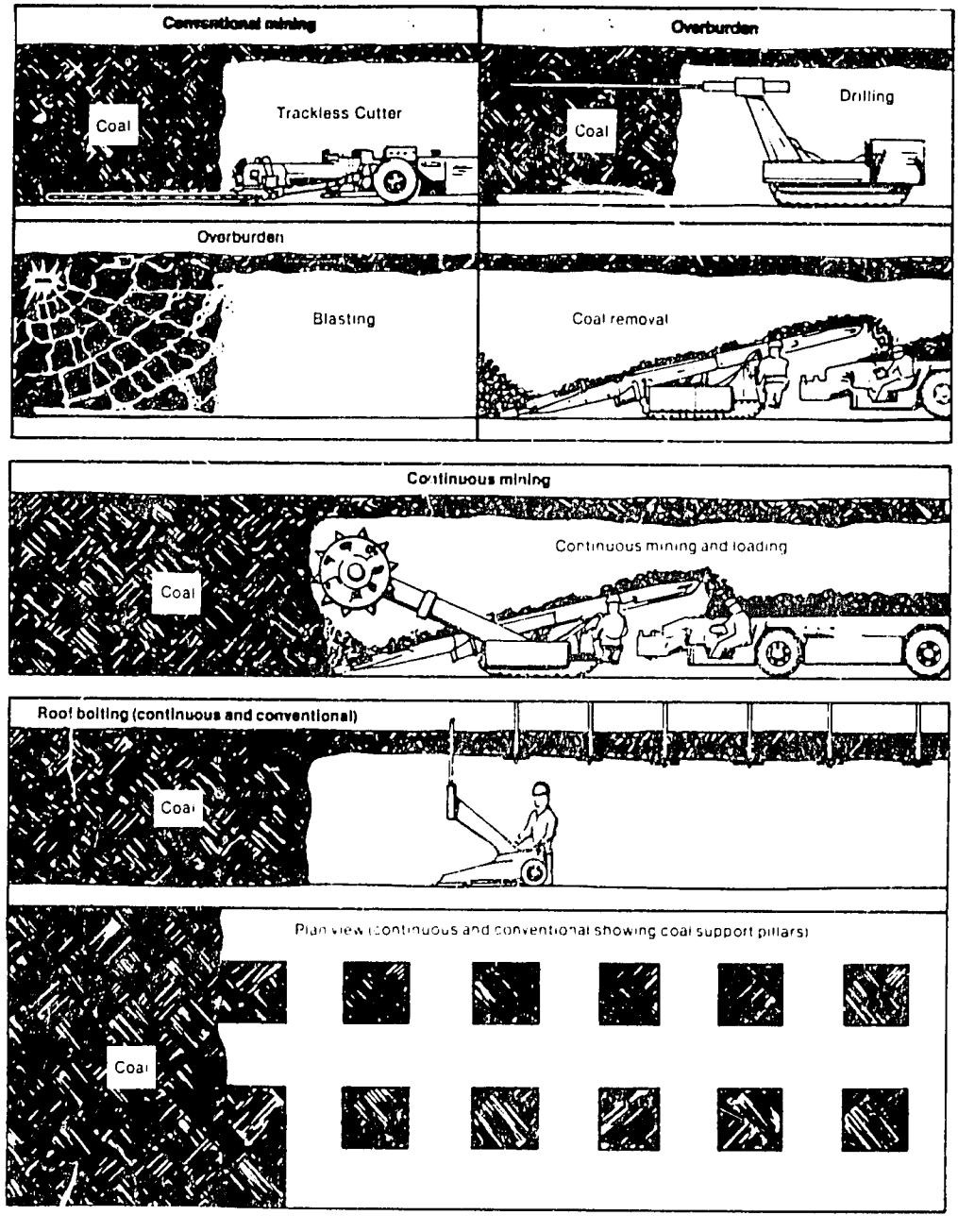


FIGURE 2. Conventional and continuous underground mining. (Source: U.S. Congress, OTA, 1979)

The sequencing of all these machines results in a lower productivity than other underground mining methods. This disadvantage is offset to a degree by a greater extraction selectivity, resulting in lower quantities of undesirable wastes introduced to the coal.

The efficient movement of the different machines is extremely important to maintaining an optimal production rate. Movement distances, cable handling, ventilation rerouting, equipment down-times and wait-on-shuttle times must be

kept minimal. Bottlenecks need to be eased or shifted by using additional machines or overtime work. Wait-on-shuttle time is a major factor in production and this can be minimized by using additional shuttles, larger shuttles, improved dumping facilities or multiple dumping points.

Continuous Mining. This method utilizes a continuous miner, haulage system and roof bolter. The continuous miner eliminates the need for the cutting, drilling and blasting operations of conventional mining. It is a basic ramp-type loader combined with high speed power driven wheels or chains that mechanically rip the coal from the face. There are two basic miners, rippers and borers; the rippers are the most popular. The ripper type miners have wheels, studded with cutting teeth, that can be lowered, raised or moved from side to side to work all parts of the face. Continuous miners are crawler-mounted and only work a single face during a shift. Ideally, the miner feeds an extendible-retractable or mobile bridge conveyor connected to the main haulage system. If these conveyors are not used, the miner wither dumps its load on the floor or directly loads a shuttle car. Either of these compromises involves extra equipment and is less efficient. After advancing a specified distance, the miner must leave the face in order to let the roof bolter provide the necessary roof support. Rock dusting machines may also be used to keep coal dust levels at acceptable levels.

Compared to conventional mining, there is less equipment and sequencing of activities to worry about. Only two faces are usually worked per shift with face crews of 9. Although the productivity is higher than conventional mining, the selectivity is much lower resulting in larger amounts of wastes being introduced to the coal.

Roof control, ventilation, haulage and maintenance cause major delays in the operation of the continuous miner. The available operation time of the miner averages about 34 percent. Contrary to conventional mining, operations at the face stop when a continuous miner is not operating. Therefore, when roof bolting, ventilation rerouting or shuttle cars are being repositioned, no mining is taking place. A system of concurrent bolting and extension of ventilation in place will increase miner operating time and production.

Longwall Mining. Longwall mining (Figure 3) consists of driving one or more entries or gates approximately 300-600 feet apart, mining an interconnection, and then mining the rib of the interconnection on a longwall. This longwall face can be mined on advance or retreat. In the U.S., the retreat system is used almost exclusively while in other countries the advance system is generally employed. The reasons for adopting longwall mining abroad are mainly technical, while in the U.S. the reasons are chiefly economical. Longwall possesses these advantages over other methods:

1. Productivity is not affected by mine depth.
2. Extraction efficiencies are very high, 80-85 percent.
3. Land subsidence typical of underground mining operations is better controlled.
4. Mining conditions are safer due to the use of continuous steel roof supports.

Supplies, ventilation and power are also simplified with a longwall since the working area is concentrated along a single face.

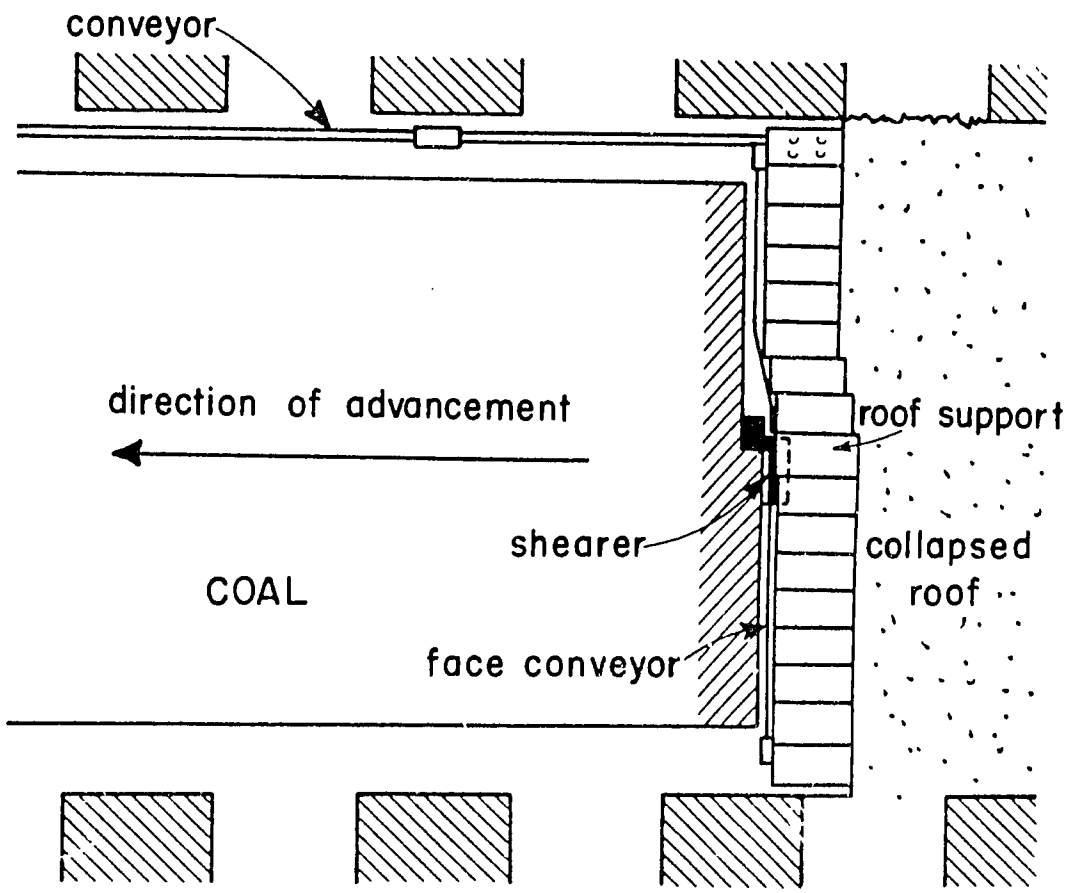


FIGURE 3. Longwall mining. (Source: Energy Alternatives, 1975)

The technical aspects of longwall mining permit greater latitude of operating under severe natural conditions. Mining can proceed to greater depths under poorer roof conditions. Productivity can be greatly increased through better machine availability and the elimination of roof bolting . As pointed out earlier these both have major impacts on production and hence economics. Because seams in the U.S. tend to be flat, contiguous and fairly uniform and the economics are more favorable, longwall is gradually replacing continuous mining.

The longwall system consists of a combination of three basic equipment components: a support system, the mining machine, and a haulage system. The support system is comprised of interconnected hydraulic jacks with roof and floor bars that are self-advancing and capable of advancing the face conveyor. Each support (either chock or shield types) will have 2-6 legs each with a capacity of 150 tons or more. Two types of mining machines are available, the planer and the shearer. The planer or plow rests on the floor and is pulled along the face in front of the armored conveyor with a chain. Shearers are narrow continuous miners which cut by means of rotating drums with cutting teeth. Each drum can make a 24-30 inch wide cut and the machine

rides on the face conveyor. Shearers may have single or double cutting drums that are either fixed or movable. The face conveyor is the most essential part of the system. Its primary function is to haul the cut coal from the face. To do this it must be flexible enough to allow snaking of the conveyor. It must also have sufficient strength to support the shearer which slides atop it. The length of this conveyor varies from 600 to 900 feet and it moves at 150-250 feet per minute. The conveyor is 30 inches wide and is made in sections five feet long. The face conveyor discharges onto an intermediate haul unit (stage loader) which dumps onto the main conveyor located in the head entry (along the side of the panel that the shearer starts mining coal).

After the shearer has moved past a section of supports, positioning cylinders are actuated pushing the face conveyor the width of the shearer cut closer to the face. Next the roof support is moved forward by first lowering the support canopy and then the positioning cylinder is actuated again to pull the support toward the face conveyor. Once in place the canopy is raised and pressurized against the roof.

A major disadvantage of the longwall retreating system is the inability to develop sufficient entries for longwalls, as well as maintain them. With high capacity jacks, roof control at the face is rarely a problem; however, there are problems with supporting the tail entries (along the side of the panel where the shearer completes its cut). The tail entry is subject to severe ground pressures because of the superimposition of two major abutment stresses at that point. There is a side abutment pressure resulting from the previously mined panel and the face abutment from the active panel. This often results in so much deterioration in the tail entries that considerable additional support must be installed. To minimize this problem, the commonly used three-entry systems (with a double row of pillars on each side of the panel) are giving way to four-entry systems (with three rows of pillars on each side of the panel).

Shortwall Mining. This is a modified version of the longwall system where a continuous miner is used instead of a planer or shearer. Belt conveyors, shuttle cars or specially designed coal haulers replace the face conveyor. The panel is usually only 150-300 feet wide, hence the name of the mining method. After the entries to either side of the panel have been cut an interconnection is cut by a continuous miner and the roof support equipment is set in place. The continuous miner than cuts a 10 foot wide section across the face with the roof supports being advanced and extended over the miner as the cut is made. When the miner has completed the cut it backs out under the supports and then the supports are moved nearer to the face for the next cut.

This method is not commonly used in the U.S.; however, it has several advantages over continuous and longwall mining. Compared to continuous mining, shortwall mining offers better roof support, flow of air directed along the face to reduce dust and methane hazards, higher production rates, lower production costs, and higher recovery efficiencies. The advantages over longwall mining include greater flexibility in mining operations, less development needed, easier integration with continuous mining operations, lower capital costs, and not as affected by seam partings or rolling. This mining method cannot achieve the production rates or lower production costs of longwall mining and therefore would only be used when seam or roof conditions

are not favorable for longwall operations or when the producer cannot afford the additional capital costs.

Surface Mining

Over the past 30 years, there has been a dramatic increase in the degree of surface mining. With the introduction of giant excavating equipment around 1960 surface mining became cheaper, easier and more productive than underground mining. The two main types of surface mining are strip and auger mining. Strip mining is the most commonly used method and includes area and contour mining. Area mining is used in flat terrain and contour in hilly or mountainous terrain. Auger mining is used only when coal outcrops on slopes to steep for contour mining or in conjunction with contour mining after the stripping ratio becomes uneconomical.

The basic steps are the same for area and contour mining; however, the equipment needs differ. The steps are surface preparation, overburden blasting (if necessary) and removal, coal extraction and reclamation. Surface preparation includes the construction of access roads and maintenance and personnel facilities as well as vegetation and topsoil removal. The removal of vegetation is usually done by bulldozers. If the topsoil is not to be removed and stockpiled and the vegetation is sparse it may be removed with the overburden. When topsoil is removed and stockpiled separately, bulldozers, scrapers and loaders are used. The overburden is removed next, either directly or by blasting with ANFO (ammonium nitrate and fuel oil) and stockpiled as spoils. Tractors, shovels, draglines or bucket-wheel excavators are used to expose the coal seam. A description of this equipment follows:

- Tractors may be used in small mines or in conjunction with more specialized equipment in larger mines, particularly to clean the coal seam surface. Their principal advantages are maneuverability, ability to negotiate steep grades and capability to dig and transport their own loads. They are used for clearing, preparing benches, leveling spoil piles and constructing access and haulage roads.

- Large diesel or electrically powered stripping shovels can be used for scooping up fragmented overburden or coal. They are often designed for a particular mine application and may have bucket capacities of up to 180 yds^3 and a reach of 200 feet. In large surface mines they are used in conjunction with a dragline to load coal. Although shovels are better diggers than draglines, in terms of cost and digging hard materials, they can only dig above grade and are more costly at the larger bucket capacities.

- Electrically powered draglines are used for below grade stripping of overburden. Draglines are commonly used because of their long reach, versatility and lower cost at larger bucket capacities. They have bucket capacities up to 250 yds^3 and boom lengths of 300 feet.

- Bucket-wheel excavators are also used for stripping of overburden, although less frequently because of their higher costs, lower maneuverability and ineffectiveness with harder overburden materials. The bucket-wheel may be more than 50 feet in diameter and have a boom length of 400 feet. Stripped overburden materials are dumped on a conveyor

belt which carries these materials to the in-mine transportation system. They are effective for digging above grade and may be used in conjunction with draglines or stripping shovels.

The exposed coal seam is extracted (after blasting if necessary) with a coal digging machine or shovel and loaded into giant trucks (200 tons) for transport to a preparation plant. The mined out areas are then reclaimed by backfilling the spoils, either from other cuts (using draglines) or from stockpiles (using bulldozers). Following grading and compaction, topsoil may be hauled and spread over the backfill. This area is then seeded and fertilized.

Area Mining. This method is used when the topography is flat and the coal seam is parallel to the surface. Open pits are developed in a series of long narrow strips, as shown in Figure 4. A trench is initially cut across the end

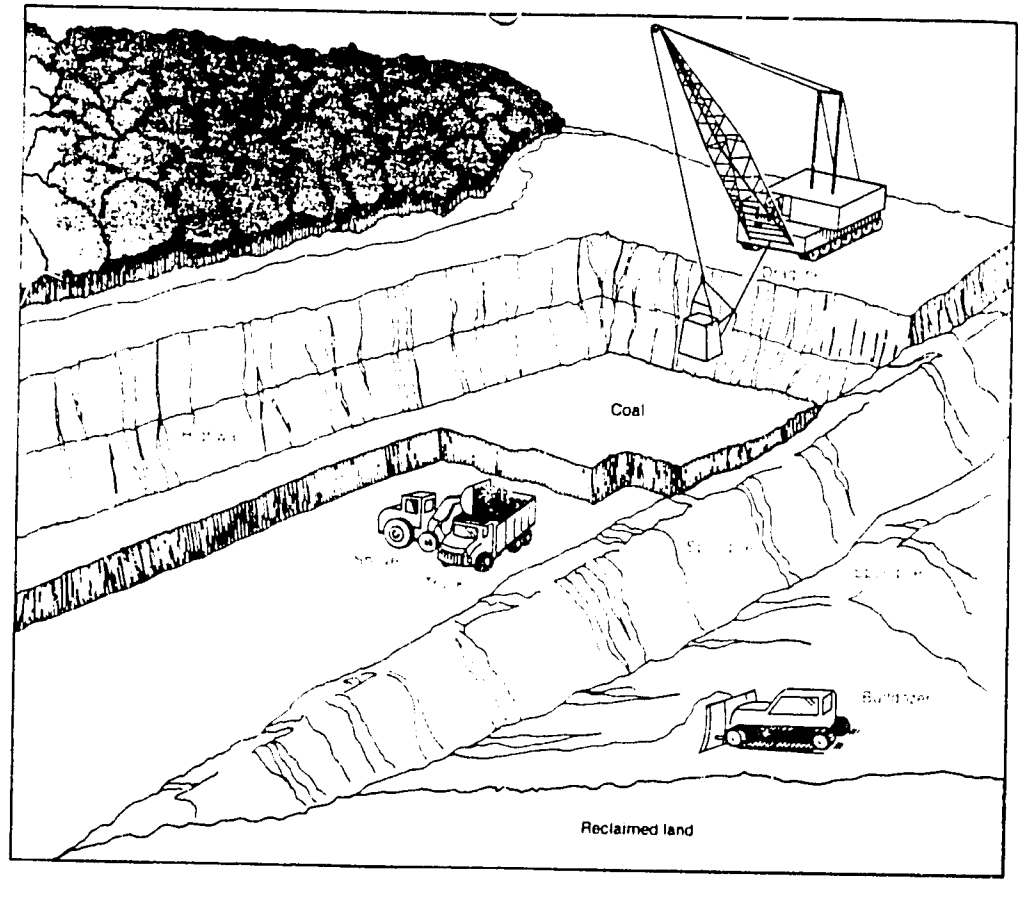


FIGURE 4 Area mining and associated reclamation.
(Source: U.S. Congress, OTA, 1979)

of the strip using an excavator or dragline. The top soil is removed and stored for reclamation and the underlying overburden is piled along side the cut on the side away from the mining areas. The pile forces a ridge called a

spoil bank. Once the coal seam is exposed a loading shovel loads the coal (which may have to be blasted first) in large haulage trucks. The excavator or dragline moves along the strip in advance of the coal loading activities. The dragline uses the prepared overburden surface as a workbench, while the excavator uses the exposed coal seam as a workbench. When the coal has been removed from one strip, the excavator or dragline is moved to the next strip to dig a new trench parallel to the first. The removed overburden is deposited in the mined out cut. The cycle is repeated until the mine boundaries are reached. A variation in area mining is open pit mining. A large rectangular area, perhaps 1000 by 2000 feet, is prepared. The overburden is then removed and stockpiled. After this initial cut, the overburden from subsequent cuts is stored in mined out areas of the pit. This type of mining is used for very thick seams.

Contour Strip Mining. This method is used when a horizontal or gently sloping coal seam outcrops on the side of a hill or mountain. Typically the overburden is removed by starting at the coal outcrop and excavating along its surface into the hill. Following initial excavating operations, the cut is extended along the hillside creating a bench (at coal seam level), an upslope highwall and a downslope spoil pile (Figure 5). After the coal is exposed and removed from the first cut, a second cut is made into the hill.

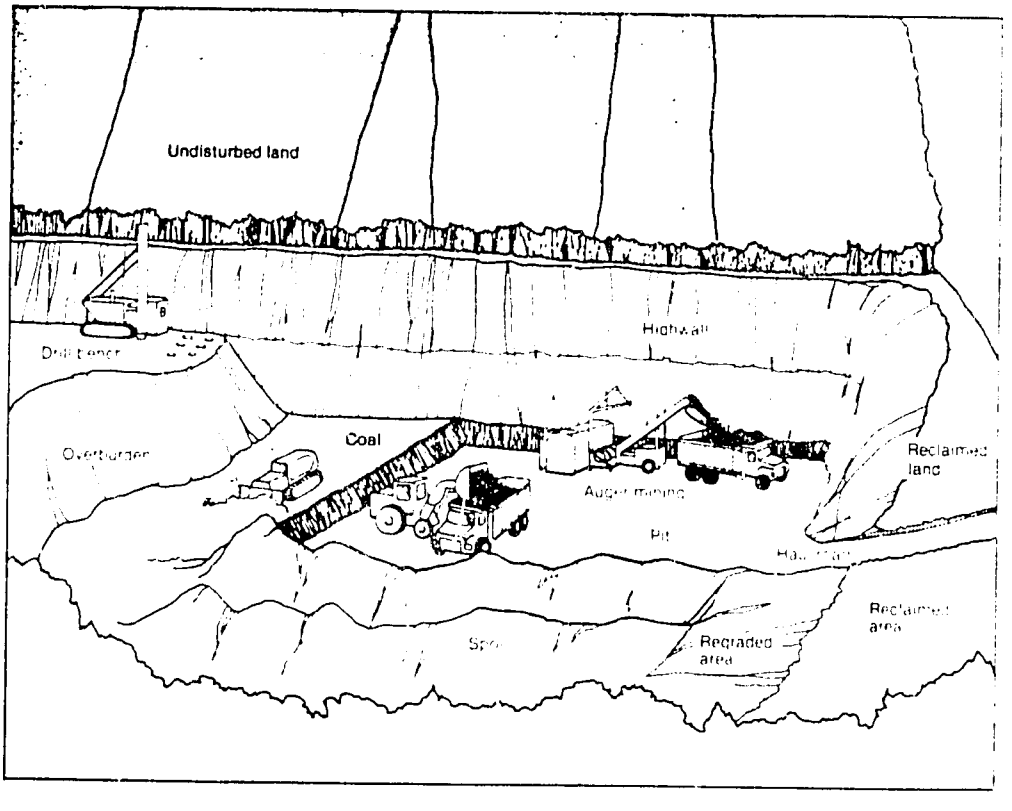


FIGURE 5. Contour and auger mining.
(Source: U.S. Congress, OTA, 1979)

The spoils from this are deposited in the first cut. This continues until the stripping ratio (overburden to coal seams thickness) becomes uneconomical.

29

Either draglines or shovels will be used for these excavations; however, their capacities will be much smaller than for area mining because of the difficult terrain and shorter life span of this type of mine.

There are several variations on contour mining and these include box-cut, block-cut, head-of-hollow and mountain-top removal methods. In the box-cut method, the initial cut is excavated where the final highwall will be and the spoils are deposited downslope. This type of mining creates an upslope and a downslope highwall. As the coal is extracted, the spoils covering the second cut are used to back fill the mined out area. This minimizes the amount of spoil cast downslope. The block-cut is similar to conventional contour mining, except that a minimum amount of overburden is placed downslope. Following this initial cut and subsequent coal removal, overburden materials from the next cut are hauled back to the mined out area. Head-of-hollow method is used when there is a shallow valley between two adjacent hills with outcroppings. The overburden from above each coal seam is used to fill in the valley. Mountain-top removal is utilized when the coal seam is located near the top of a mountain. In this case the entire mountain top is excavated, the coal removed and the spoils returned to the mined-out area for reshaping.

Auger Mining. Large diameter drills are used to bore horizontally into an exposed coal seam. This method is used when coal outcrops on extremely steep slopes or in conjunction with contour mining. Extremely steep slopes may limit contour mining activities and auger mining can cut an additional 150-200 feet into the coal seam after the highwall becomes to high for further contour mining. Recovery efficiencies are typically 45-50 percent; however, they can be higher if the seam is level and has no partings. Minimal overburden removal is required for auger mining. The bloom (exposed coal in outcropping) is removed and a work bench wide enough for the auger and haulage equipment is prepared. After the coal has been removed by drilling a series of closely spaced holes, the area is backfilled and reclaimed. Gas (methane) pockets are common in this type of mining and extreme caution must be exercised.

Reclamation

Both underground and surface mining activities cause physical disturbances to the land and curtail their natural productivity. These effects are the result of the construction and maintenance of facilities, mine development activities, overburden stripping, coal cleaning and waste treatment and disposal. In the past, little was done to minimize these effects; however, current mining operations are required to reclaim the disturbed areas back to some reasonable level of productivity. This is particularly important for surface mining, since large areas of land are affected.

The quantities of materials stockpiled on the surface during underground mining are generally minor and are derived from mine development (portal excavation) and coal cleaning. The wastes from the cleaned coal represent the major contribution to these stockpiles. Reclamation of these stockpile areas can be accomplished by (1) removing the materials from the site for disposal in an approved landfill and seeding the affected area, (2) leveling and covering the stockpiles with a thick layer of topsoil and then seeding, and (3) moving the materials into the mine and seeding. This last method can also help minimize land subsidence so common to underground mining.

Surface mining operations can affect hundreds or thousands of acres of land. Large areas of land may be removed from productivity during stripping operations. Fortunately, this loss in productivity is only temporary if proper reclamation practices are utilized. These practices include initial removal of the topsoil and separate stockpiling. Once an area has been mined out, backfilling, restoration of the surface topography, replacement of topsoil, seeding and fertilizing should be done as soon as possible. Reclamation is easiest for area mining and the most difficult for contour mining. Area mining methods typically backfill mined-out area when excavating the next cut; therefore, only grading and reshaping are needed. Because of the flatter terrain, erosion control measures (such as, terracing and diversion ditches) are minimal. Contour mining, on the other hand, usually requires more backfilling, considerable reshaping activities and greater erosion control.

ECONOMIC CONSIDERATIONS

Coal production costs, on a per ton basis, vary considerably depending on the particular mining method. For a particular mining method, costs will also change based on equipment, seam depth, seam thickness and overburden characteristics. As a general rule, costs will increase as seam depth increases and decrease as seam thickness increases. Unstable or consolidated overburdens also increase production costs. All these factors have an impact on the amount of capital investment needed to develop a mine for coal production. Other considerations being equal, higher capital investments are required for machinery-oriented (capital-intensive) methods; however, these higher initial costs are offset by higher production rates, lower labor costs and lower production costs per ton of coal. Lower capital investments are needed for labor-oriented (labor-intensive) methods; however, these lower initial costs are offset by lower production rates, higher labor costs and higher production costs. When selecting a mining method, given adequate capital and technical feasibility, the coal producer will generally select capital-intensive methods since they provide the best return on investment. If sufficient capital is not available or technical feasibility prevents the use of more capital-intensive methods, an appropriate balance between capital-intensity and labor-intensity will be necessary. Jacobs and Bliss (USAID, 1983) have demonstrated that such a balance is particularly important in lesser developed countries. Although a coal producer would tend to select capital-intensive methods to maximize the return on investment, such methods contribute less to the country's economy. Foreign exchange considerations, a large pool of available unskilled workers and lower labor costs favor labor-intensive methods from a national perspective. The governments in these countries must, therefore, provide appropriate mechanisms (i.e., tax credits) to ensure reasonable rates of return on investments with more labor-intensive methods.

Production costs, under normal mining conditions, will be significantly less for surface mining methods. A comparison of selected cost components and related parameters for area and continuous mining in Table 11, clearly demonstrates the order of magnitude of these differences. Factors contributing to the cheaper production costs for surface-mined coal are lower capital investments, lower labor costs, thicker seams, shallower seams, higher production rates and economies of scale. Surface-mined coal can be extracted at higher rates with about one-third the work force primarily because of the

31

extensive use of large capacity equipment and the relatively easy access to the coal. Equipment capacities for underground mining are lower because of more confined working conditions, access to coal is more restricted due to roof supporting and safety requirements, and a larger work force is required for maintenance, development and production activities. Therefore, when mining conditions are suitable, seam depth less than 200 feet or stripping ratio less than 15:1, surface mining methods are the obvious choice from a cost perspective. As the market value of coal increases or when roof conditions make underground mining too costly, surface mining at greater depths or stripping ratios are economical.

TABLE 11. COMPARATIVE SURFACE (AREA) AND UNDERGROUND (CONTINUOUS) MINING COSTS AND COST-RELATED DATA FOR DIFFERENT ANNUAL PRODUCTION LEVELS, AS OF 1978.

	SURFACE MINING[a]			UNDERGROUND MINING[b]	
Annual Production(10^6tons)	3.0	5.0	4.0	1.2	2.4
COSTS					
Capital Investment					
Total (10^6 dollars)	47.83	101.32	67.17	55.95	86.92
Dollars/ton	15.94	20.26	16.79	47.10	36.58
Dollars/10^6 Btu's	1.06	1.35	0.80	1.88	1.46
Annual Operating					
Total (Dollars/ton)	5.37	6.23	7.17	16.73	15.27
Total (Dollars/10^6 Btu's)	0.36	0.42	0.34	0.67	0.61
Labor Only (Dollars/ton)[c]	1.36	1.18	1.40	7.75	7.12
COST-RELATED					
Production (Tons/manshift)[d]	107	124	104	19	21
Work Force Size	121	175	160	284	510
Coal Seam Depth (feet)	60	50	120	800	800
Coal Seam Thickness (feet)	20	10	30	6	6
Stripping Ratio	3:1	5:1	4:1	150:1	150:1
Coal Rank	Lignite		Subbituminous	Bituminous	

[a] Data derived from Department of Energy Report No. FE/EES-79/6, 1979.
[b] Data derived from Department of Energy Report No. FE/EES-79/1, 1978
[c] Includes payroll overhead and various union benefits.
[d] Annual Production / Work Force Size x number of working days.

Surface Mining Cost Factors

All things being equal, production costs increase for the three major mining methods in the following order: auger, area and contour. Table 12 shows the

36

relative capital investment and operating costs for each of these methods. Despite auger mining's limited application, because of low recovery efficiencies and inability to extract more than 150-200 feet into a seam, it utilizes the least amount of equipment, excavates the least amount of overburden and requires the lowest amount of reclamation; therefore, capital investments and operating costs are the lowest. Although area and contour mining both have higher equipment, excavation and reclamation requirements,

TABLE 12. RELATIVE COMPARISONS OF COSTS FOR VARIOUS SURFACE MINING METHODS.

COSTS	MINING METHODS		
	AUGER	AREA	CONTOUR
Capital Investment			
Total	Lowest	Lower	Highest
Dollars/ton	Lowest	Lower	Highest
Annual Operating			
Dollars/ton	Lowest	Lower	Highest
Labor Only	Lowest	Lower	Highest
Reclamation			
Dollars/ton	Lowest	Lower	Highest

differences in equipment size, overburden characteristics, stripping ratios (seam depth/seam thickness)and complexity of reclamation practices account for the differences in production costs. Because area mines are located in flat open terrain, overburden is less difficult to excavate, stripping ratios remain reasonably constant and reclamation (leveling and grading) is fairly simple. These conditions favor larger mining operations and the use of more cost-effective giant excavation equipment. The resulting economies of scale and cheaper reclamation costs result in lower production costs. The overburden is more difficult to remove in mountainous or hilly terrain, stripping ratios increase rapidly and reclamation is more difficult and complex (contouring, terracing, diversion ditches). These conditions limit the size of the mining operation and use of giant excavation equipment. The more limited application of economies of scale and greater reclamation costs result in higher production costs.

Underground Mining Cost Factors

Production costs per ton of coal go from highest to lowest for the five underground mining technologies in the following order: hand, conventional, continuous, shortwall and longwall. The relative capital investments and annual operating costs for each of these methods is shown in Table 13. Labor, roof control, recovery efficiency, machinery maintenance, ventilation and mine

development are all important cost factors. The more capital-intensive methods, such as shortwall and longwall mining, are able to minimize labor, roof control, mine development, ventilation and machinery maintenance costs by concentrating the mining efforts at a single large face. At the same time they are able to maximize production rates, working time at the face and recovery efficiences, thereby keeping production costs lower. Longwall and shortwall mining methods are not cost-effective, however, when roof conditions prevent proper caving, seams are not contiguous or have partings, or seam thickness is variable. Also, at depths greater than 1000 feet, shortwall or longwall mining may be the only options because of high safety and roof supporting cost.

TABLE 13. RELATIVE COMPARISONS OF COSTS FOR VARIOUS UNDERGROUND MINING METHODS.

COSTS	MINING METHODS				
	HAND	CONVENTIONAL	CONTINUOUS	SHORTWALL	LONGWALL
Capital Investment					
Total	Lowest	>----------	---------->		Highest
Dollars/ton	Highest	<----------	---------->		Lowest
Annual Operating					
Dollars/ton	Highest	<----------	----------<		Lowest
Labor Only	Highest	<----------	----------<		Lowest
Development					
Dollars/ton	Highest	<----------	----------<		Lowest

The more labor-intensive room and pillar methods, such as hand, conventional and continuous mining have higher labor, roof control, mine development, ventilation and machinery maintenance cost because several smaller faces are being worked simultaneously. At the same time, recovery efficiencies, production rates and working time at the face are low, thereby keeping production costs high. Inspite of the higher production costs, these methods are still appropriate when seams are not contiguous or contain partings, seam thickness is variable or roofing conditions do not permit proper caving. Of the three room and pillar methods, continuous mining has the lowest production costs, because it can achieve higher production rates with a smaller face crew. Hand mining is rarely done in the U.S. and conventional mining is rapidly being replaced by continuous miners. They are still more cost-effective in shallower mines when roof conditions are poor, since the continuous miner must stop mining during roof bolting operations. Also, hand and conventional mining methods are not as affected by machine maintenance and malfunctions, provide a higher quality of coal and have greater flexibility in mining operations. These can be important factors to mining cost analyses.

ENVIRONMENTAL CONSIDERATIONS

The major environment considerations are acid-mine drainage, leaching and runoff from spoils and coal waste piles, erosion of mined areas, elimination or alteration of habitats as a result of stripping and stockpiling activities, and land subsidence. Table 14 provides a quantitative comparison of these impacts for underground and surface mining activities as well as ways to minimize these impacts (mitigation) Noise and air pollution do occur but are considered to be of minor significance. For underground mining, dust and methane levels are major concerns in terms of the health and safety of the mine personnel.

TABLE 14. QUANTITATIVE COMPARISONS OF IMPACT SOURCES FROM UNDERGROUND AND SURFACE MINING ACTIVITIES AND METHODS OF MITIGATION.[a]

IMPACT SOURCE	MINING		MITIGATION
	UNDERGROUND	SURFACE[b]	
Waste Disposal			
Tons/year	3.6×10^4	$1.5\text{-}3.0 \times 10^6$	Reclamation
Acres/year	< 1	27-55	
Water Use			
Gallons/year	1.0×10^7	Minimal, Road Dusting Only	Collection, and Treatment
Erosion			
Tons/year	5	165-10,350	Reclamation
Land Disturbance[c]			
Acres/year	45	120-2,100	Reclamation
Acid Drainage			
Tons/year	17,250	2,100	Collection & Neutralization

[a] Based on a production level of 1,000,000 tons/year.
[b] Lower values for waste disposal and land disturbance are based on thicker seams and lower values for erosion and acid drainage on lower rainfall.
[c] For underground mining this is due to subsidence.

Underground Mining

Acid drainage, water use and land subsidence are the major underground mining impacts.. Water is used at the face to help minimize dust during mining operations in order to minimize health and safety impacts to the face crews. Too much dust in the air can lead to dust explosions or increased lung diseases (Black Lung). The resultant coal-water mixture becomes acidic because of the presence of sulfur and various trace elements within the coal. If this water is not collected and treated, it will eventually find its way into ground and surface waters. This can cause deterioration of drinking water quality or alter the pH of surface waters sufficiently to make them less suitable for the more sensitive aquatic biota. Typically, this water is collected and treated to remove solids and to neutralize the acid, thereby minimizing any adverse impacts to ground and surface waters.

Land subsidence impacts are much more difficult to control because they occur over a longer period of time. The problem is more critical with the room and pillar mining method. Typically, the pillars are left intact to support the increased weight of the overburden as a result of coal extraction. In time these pillars can give way and the roof between the pillars can collapse. The affected overburden will either gradually or suddenly subside after an unknown period of time. This can create safety hazards to people residing over these areas or make the land unusable for farming, etc. Once the land subsides, there is little that can be done other than trying to fill it in. The problem can be minimized through controlled caving (longwall and shortwall mining), by mining a lower percentage of the coal, and reclaiming mining wastes stored on the surface to support critical areas.

The major impacts to the health and safety of the miners are related to dust and methane liberation. Extraction of coal from the face creates considerable fine dust and, in some cases, liberates methane gases trapped in the seam, particularly with current continuous mining equipment. Because of their flammable and explosive nature, they have to be carefully controlled to protect the miners. Additionally, the fine coal dust is easily respired by the miners and with prolonged exposure, this can cause considerable damage to the lung tissue. The levels of dust are controlled by spraying the face with water during extraction and dusting the surfaces of mined-out areas with a non-flammable powder, i.e., lime. Ventilation is also used to dilute dust and methane gases, particularly at the face. Another method of controlling dust and methane levels is to minimize the number of working faces so that ventilation is more easily directed through the working areas. Modern continuous mining methods operate on this principle.

Surface Mining

The major impacts associated with surface mining are the large areas of disrupted surface area and erosion. As shown in Table 14, in excess of 2000 acres per million tons of mined coal can be removed from productivity. The thinner the seam, the more land that will be impacted, since larger areas will have to be mined to extract a given quantity of coal. This can either permanently or temporarily eliminate aquatic and terrestrial habitats,or preclude former land uses. The biota associated with these habitats are either destroyed or displaced to nearby habitats. Areas that are valuable agriculturally, environmentally or recreationally will require more reclamation work since overburden materials may have to segregated, surface waters rerouted and original vegetation restored. In most cases, proper reclamation procedures will minimize permanent losses; however, the original level or type of productivity may not be achieved. Areas that originally have a low productivity can actually be more productive after mining if reclamation is carried out properly.

More subtle effects include erosion and the resultant runoff into surface waters. Surface preparation, excavation and stockpiling of overburden all expose large quantities of loose materials. Without a cover of rooted vegetation to prevent erosion, runoff from these materials during and after rainfalls can transport considerable quantities of suspended and dissolved solids into local surface waters. These materials can reduce the natural productivity of these waters by reducing the light needed for photosynthesis, smothering bottom dwelling organisms, making feeding and breeding areas

unsuitable and damaging the breathing apparatus of organisms residing in the water column. Also increased levels of toxic chemicals can be introduced in the form of dissolved solids and these can have acute (death) or chronic (lower growth, reproduction, etc.) effects. Erosion will be of particular concern in areas where contour mining is used, because of the hilly or mountainous terrain, as well as areas of high precipitation. Fortunately, runoff can be controlled through compaction of the spoils areas and erosion control ditches. The runoff is usually collected in a settling pond to remove suspended and dissolved solids before discharge to local surface waters. This is only a temporary solution to the problem, however, and revegetating the areas as soon as possible is the best method for reducing runoff.

PREPARATION

PREPARATION

Most coal producers have a coal preparation plant as an integral part of the mine in order to size and upgrade the coal to the customers' requirements. Raw coal has varying quantities of clay, pyrite, rock and debris depending on the mining method or inherent properties. Hand and conventional mining are more selective and less non-combustibles from seam partings, the roof and bottom are introduced into the coal. The more productive machinery-oriented methods (continuous, longwall and surface), on the other hand, are less selective and introduce considerable quantities of non-combustibles to the coal. In addition to the materials from mining, some coals have inherently higher moisture, mineral and sulfur levels. Preparation plants are required to remove these increasing quantities of non-combustibles and reduce coal impurities.

The major users of coal are the electric utility and coke industries and their requirements determine the degree of coal preparation. Based on these requirements, most coal is at least reduced in size and screened. About 50 percent of the coal in the U.S. is washed to reduce ash, sulfur and refuse and upgrade the heating value. Figure 6 shows the results of a typical coal cleaning.

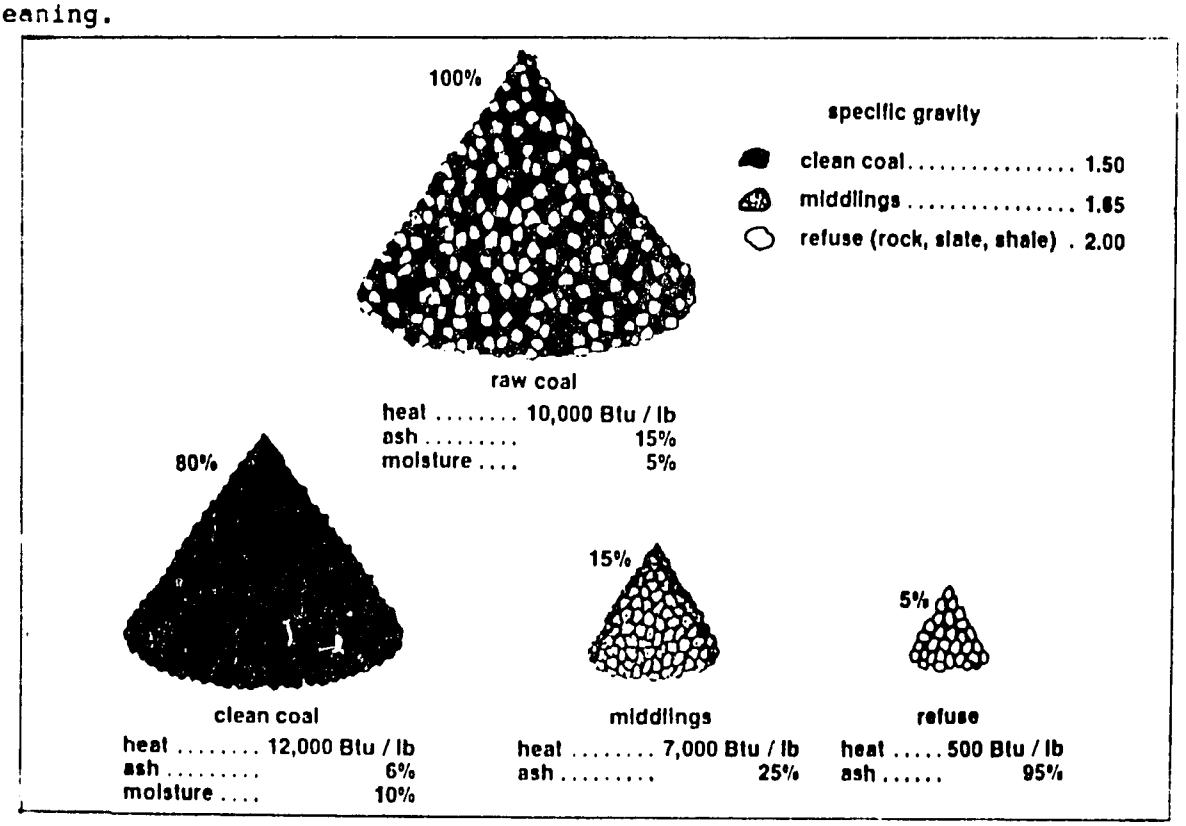


FIGURE 6. Typical Improvements in Raw Coal by Coal Preparation. (Source: Department of Energy, 1983)

Coal cleaning benefits the user in the following ways:

- Lower quantities of coal are required to meet Btu requirements as a result of the increased heating value.

29

- Less corrosion, fouling and slagging in boilers and furnaces due to lower ash content.

- Longer pulverizer life since less of the higher Btu coal must be pulverized to meet Btu requirements.

- Smaller quantities of ash to collect and handle.

- Ability to meet emission standards with less pollution abatement equipment.

- Better product uniformity (coke industry).

As the demand for coal continues to increase, these benefits will become more important and the amount and levels of preparation will increase.

TECHNOLOGIES

There are five levels of preparation used to meet the requirements of the steam and metallurgical coal markets. The important aspects of these five levels are summarized in Table 15. Each of these levels will include one or more of the following operations: size reduction, sizing, cleaning and dewatering and drying. The equipment used for the operations at each level of preparation is shown in Table 16. As the level of preparation increases, so does the number of operations and amount of equipment required. Level I is generally used for steam coals that have low ash and sulfur contents and involves size reduction to specified market sizes. Levels II-V wash

TABLE 15. COAL PREPARATION LEVELS AND CHARACTERISTICS,

CHARACTERISTICS	LEVELS				
	I	II	III	IV	V
Kind of Cleaning	Crushing Only	Coarse	Coarse, & Fine	Coarse, Fine & Ultrafine	All Sizes
Ash Removal	Minor	Fair to Good	Good	Good to Excellent	Excellent
Sulfur Removal	None	None to Fair	Fair	Fair to Good	Excellent
Yield Weight, percent	98-100	75-85	60-80	60-80	60-80
Recovery Btu, percent	100	90-95	80-90	80-90	85-95

Source: M. Laurila, Arthur D. Little Company, February 1983.

40

progressively smaller-sized coals based on the ash, sulfur, moisture and heating value specifications of the user. As a general rule, the level of preparation increases as specifications become more stringent or as the ash and sulfur contents of run-of-mine increase. Currently, Level III is the most commonly used for steam coal and Level IV primarily for metallurgical coal (Figure 7). Level V is still at the demonstration stage in the U.S.

TABLE 16. EQUIPMENT USED FOR FIVE LEVELS OF COAL PREPARATION.

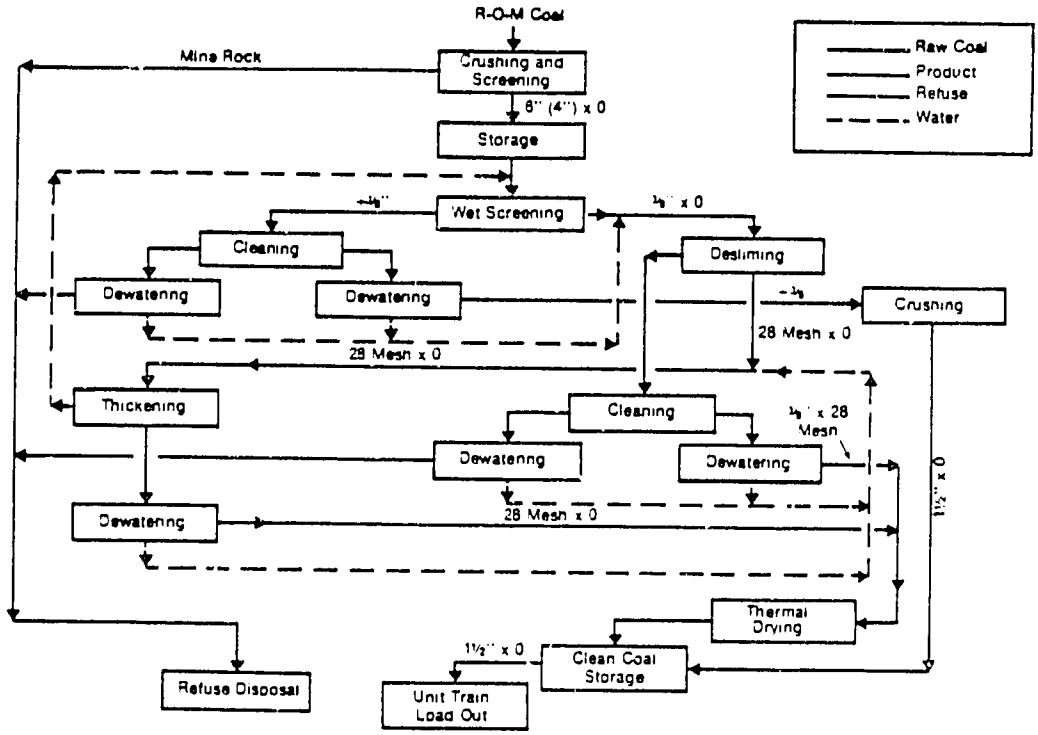
EQUIPMENT	LEVELS				
	I	II	III	IV	V
Size Reduction					
Scalping Screens	X	X	X	X	X
Rotary Breakers, Roll Crushers, Impact Crushers or Cage Mills	X	X	X	X	X
Sizing					
Vibrating Screens	X	X	X	X	X
Cleaning					
Baum Jigs or		X	X	X	X
Dense-Medium Vessels or		X	X	X	X
Batac Jigs, Hydrocyclones, or Concentrating Tables			X	X	X
Froth Flotation				X	
Multi-stage Flotation					X
Dewatering and Drying					
Screens or sieves		X	X	X	X
Centrifuges, Vacuum Filters, Filter Presses or Static Thickeners			X	X	X
Thermal Dryers				X	X

Size Reduction

This operation is used for all levels of preparation to reduce coal to market sizes and to liberate impurities, such as rock or pyrite particles, that are imbedded in or adhered to larger pieces of coal. As the coals are crushed to smaller sizes more impurities are liberated; however, the coal becomes more difficult to wash.

Size reduction is accomplished by rotary breakers, roll crushers, impact-type crushers or multiple roll crushers. Table 17 presents the important features of each type of size reducer. Rotary breakers can crush coal down to 1.5 inches and are typically used for coals with Hardgrove Indices greater than 55, low moisture, and low clay contamination. Coals not meeting these criteria can be crushed to 3-4 inches using roll crushers. When smaller sizes (down to about inch) are needed for run-of-mine coal, impact-type crushers

are used. Multiple roll crushers are usually used to crush cleaned coal or middlings (coals with specific gravities intermediate to the cleaned coal and refuse).



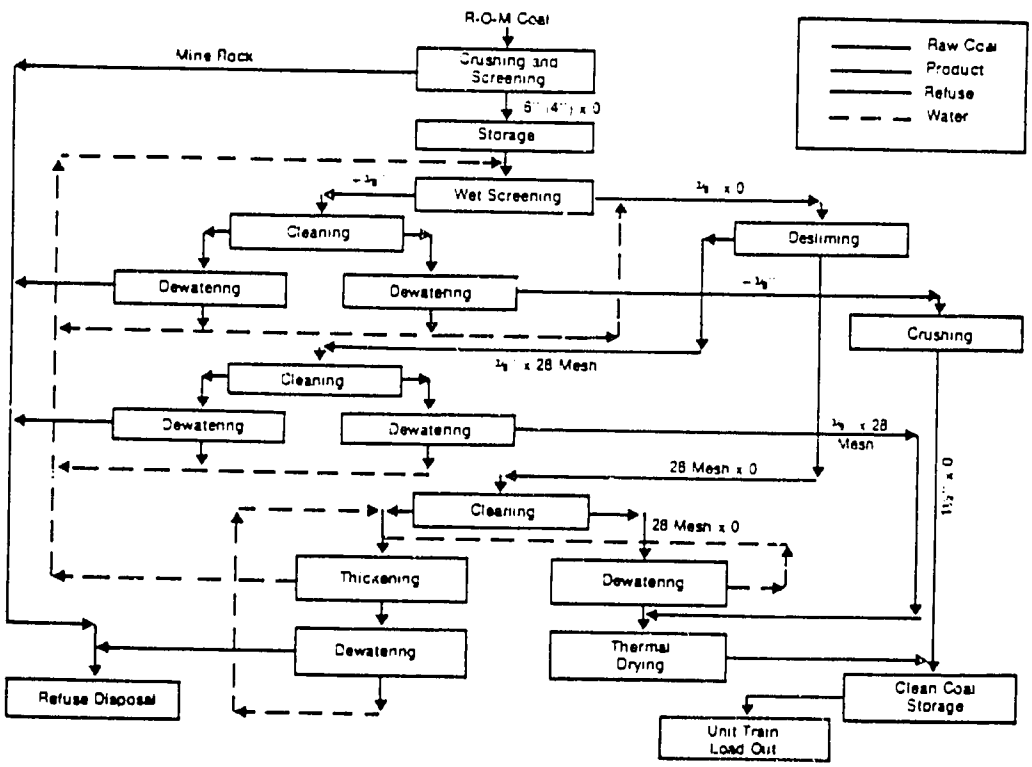


FIGURE 7. Flow Diagrams of Operations for Level III (A) and Level IV (B) Coal Preparation. (Source: World Coal, June 1978)

47

Sizing

Following size reduction, screens are used at all preparation levels to separate the coal into distinct size ranges for feeding washing units or transporting to markets. Sizing is important for effective coal cleaning because each type of washing unit is designed to perform optimally at specific size ranges. As the level of preparation increases the amount of screening also increases. Sharper size separations result in better performance of these units. The significant features of various sizing screens are shown in Table 18.

TABLE 17. SIGNIFICANT FEATURES OF PREPARATION EQUIPMENT USED FOR COAL SIZE REDUCTION.

REDUCTION UNIT	REDUCTION METHOD	FEED COAL	FINAL SIZE	ADVANTAGES & DISADVANTAGES
Rotary Breaker	Impact	Raw	< 6-8 inches	Low coal fines and carbon rejection. Soft, low moisture, low clay contamination coals only.
Roll Crusher	Compression & cleaving	Raw	< 6 inches	Low coal fines and both hard and soft coals. Low reduction in size ratio (6:1).
Impact-type Crusher	Impact	Raw	< 6 inches	High reduction in size ratio (30:1). Higher coal fines.
Multiple Roll Crusher	Compression & cleaving	Clean Middlings Raw	< 2 inches	Low fines and good size uniformity. Sensitive to moisture and feed sizes.

Cleaning (Washing)

Cleaning is done at Levels II-V with the amount and type of cleaning varying with coal size. As mentioned above the equipment used for cleaning will vary with coal size ranges. Coarse (0.25-6 inches) coal cleaning , Level II, is done by Baum Jigs or Dense-Medium Vessels (Figure 8). Batac Jigs, Dense-Medium Vessels, Dense-Medium Cyclones, and Concentrating Tables are used for fine (0.02-0.25 inches) coal washing, Level III (Figure 9). Single stage (Level IV) or Multi-stage (Level V) Froth Flotation is used for cleaning ultrafine (0.0-0.02 inches) coals (Figure 9). The significant features of these cleaning units are listed in Table 19.

Baum Jigs separate impurities from the coal on the basis of differences in specific gravity. Coal has specific gravities of 1.3-1.5, while the

43

impurities have values greater than 2.0. The Baum Jig stratifies the bed of raw coal in water by pulsation. The lighter coal particles move to the top and the heavier refuse settles to the bottom for collection and disposal.

Although it can clean a wide range of coal sizes it's most effective at 0.25-1 inches. These jigs are used more frequently than Dense-Medium Vessels because of their larger capacities and cheaper costs. Dense-Medium Vessels also operate by specific gravity differences; however, rather than using water as the separation medium, a suspension of magnetite and water is used. This suspension has a specific gravity between that of coal and the refuse and better separation can be obtained. A modification of the Baum Jig is the Batac Jig which is used for cleaning fine coals. The coal is stratified by

TABLE 18. SIGNIFICANT FEATURES OF SIZING SCREENS USED IN COAL PREPARATION.

SIZING SCREENS	PASS-THROUGH SIZES	FUNCTION
Scalping	< 6 inches	Removes small coal sizes before raw coal feed enters rotary breaker or roll crushers.
Raw Coal or Pre-Wet	< 0.25 or < 0.125 inches	Removes fine coal before coarse coal washing.
Desliming	< 0.02 inches	Removes ultrafine coal before fine coal washing.
Dewatering	< 0.005 inches	Removes free moisture from cleaned coal.

TABLE 19. SIGNIFICANT FEATURES OF WASHING UNITS USED TO PREPARE COAL.

WASHING UNIT	CAPACITY (tons/hr)	SIZE RANGE (inches)	SPECIFIC GRAVITIES	RELATIVE COSTS
Baum Jig	1000	0.25-6.0	>1.5-1.6	Inexpensive
Dense-Medium Vessel	800	0.25-6.0	1.3-1.9	Expensive
Dense-Medium Cyclone	100	0.02-0.25	1.3-1.9	Expensive
Concentrating Tables	10-15	0.0-0.38	> 1.5	Inexpensive
Froth Flotation Cells	-	0.0-0.02	-	Expensive

44

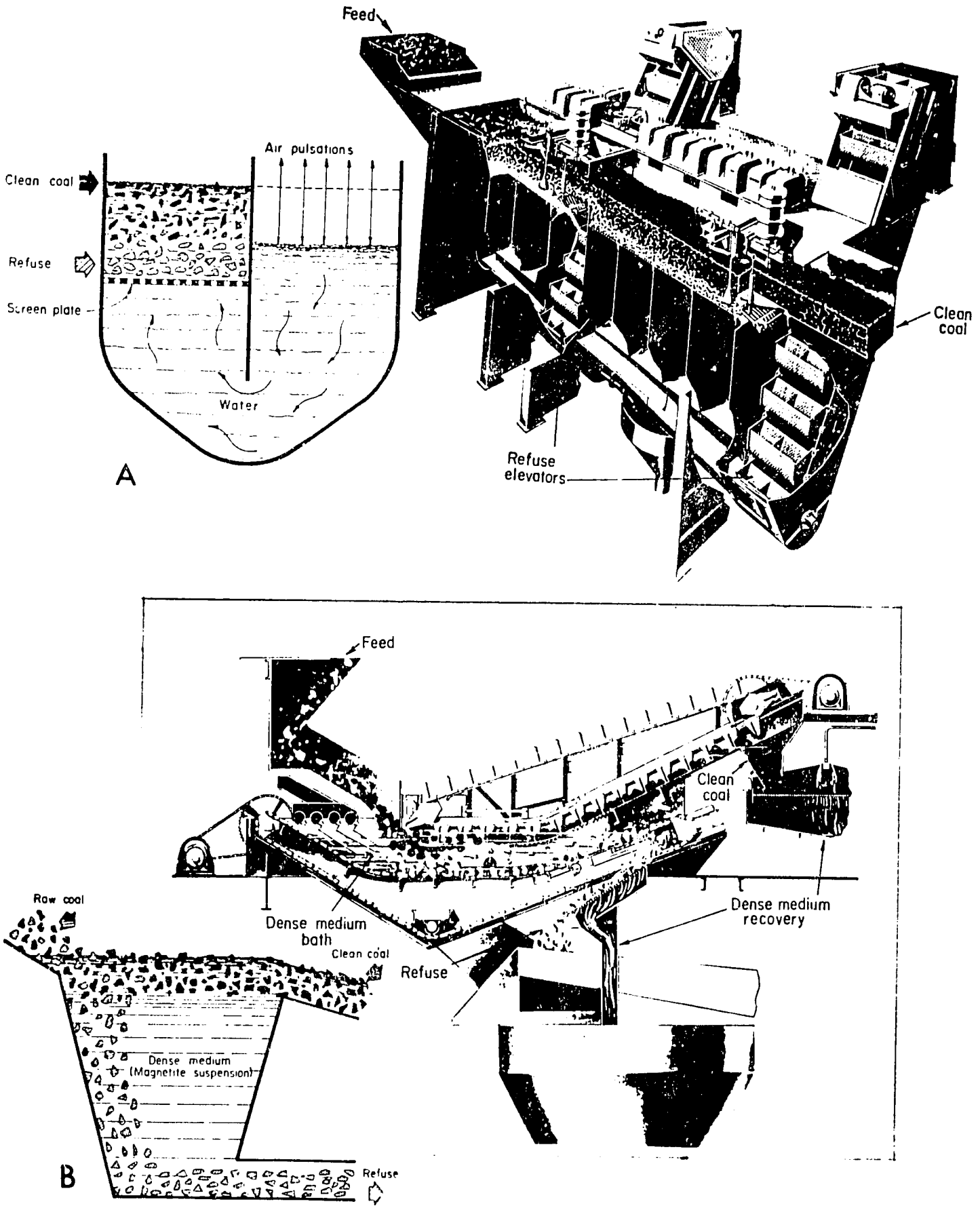


FIGURE 8. Coal cleaning equipment: A) Baum Jig; B) Dense-Medium Vessel. (Source: Department of Energy, 1983)

bubbling air directly through the coal-water-refuse mixture in this cleaning unit rather than using air pulsations on the water surface (Figure 8A).

Dense-Medium Cyclones clean coal by accelerating the dense-medium, coal and refuse by centrifugal force. The coal exits the cyclone from the top and the refuse from the bottom. Better separation of smaller-sized coals can be achieved with this method.

Concentrating Tables are tilted and ribbed and move back and forth in a horizontal direction. The lighter coal particles are carried to the bottom of the table, while the heavier refuse particles collect in the ribs and are carried to the end of the table. Fine coal can be cleaned inexpensively with this unit; however, the capacity is quite small and they are only effective on particles with specific gravities greater than 1.5.

Froth Flotation Cells utilize the differences in surface characteristics of coal and refuse to clean ultrafine coal. The coal-water mixture is conditioned with chemical reagents so that air bubbles will adhere only to the coal and float it to the top, while the refuse particles sink. Air is bubbled up through the slurry in the cell and clean coal is collected in the froth that forms at the top. This type of cleaning is very complex and expensive and is principally for metallurgical coals.

Dewatering and Drying

After the coal has been cleaned at Levels II-V, it is necessary to remove the free moisture by either mechanical or evaporative (thermal) separation. Screens, filters, centrifuges and static thickeners are used in dewatering operations. Water passes through the screens, filters and centrifuges, due to gravity, suction or centrifugal forces, respectively, leaving the coal behind. Static thickeners are large circular settling ponds with mechanical rakes that slowly revolve near the sloping bottom. The coal particles which settle out are pumped from the bottom and the water overflows at the top.

As the level of preparation increases more dewatering steps will be involved and different types of units will be used depending on the coal sizes and the desired degree of surface water removal. Screens can reduce moisture levels of the dewatered product to 20-60 percent for 0.01-0.25 inch particles, filters 20-40 percent for 0.0-0.05 inch particles, centrifuges 7.5-35 percent for 0.002-0.25 inch particles and static thickeners 60-80 percent for 0.0-0.02 inch particles. At the higher level of preparation the dewatered coal is dried in a fluidized-bed dryer. Using this rapid drying method, the moisture level of the dewatered coal can be reduced to 5 percent.

Following dewatering and/or drying the coal is conveyed to storage silos.

ECONOMIC CONSIDERATIONS

The major economic benefits of using cleaned coal are transportation, pulverizer, boiler and related equipment maintenance and ash disposal cost savings. These benefits are the result of the higher heating value and lower ash and sulfur content of these coals. The consumer has a specific annual Btu requirement that must be met and higher heating values mean less coal to meet

46

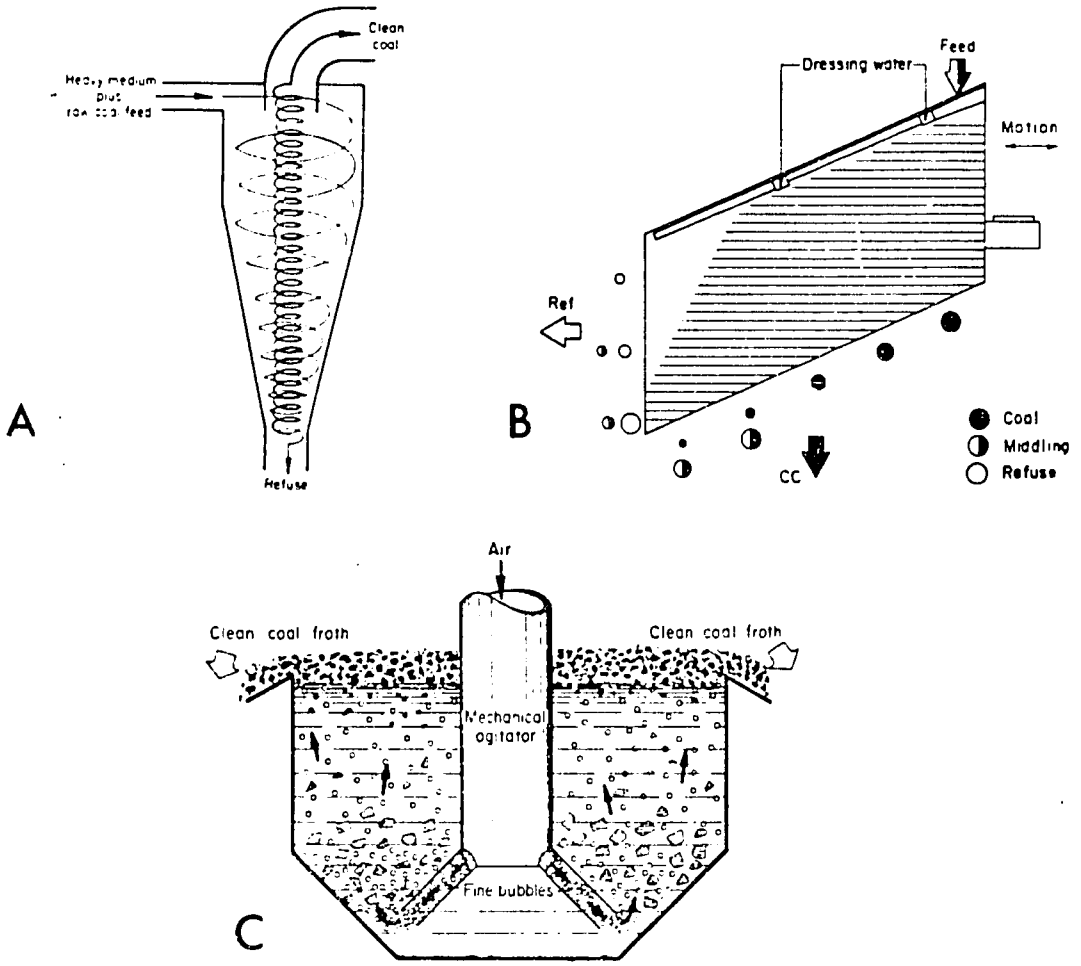


FIGURE 9. Coal cleaning equipment: A) Dense-Medium Cyclone; B) Concentrating Table; and C) Froth Flotation Cell (Source: Department of Energy, 1983).

this need. The higher heating value also reduces the amount of coal that must be pulverized prior to combustion. Ash can cause corrosion, fouling and slagging in the furnace or boiler: this reduces operating efficiency. The minerals in the coal that produce the ash can decrease its grindability. Additionally, the ash must be collected and disposed of properly to meet environmental standards. Therefore, reductions in ash can increase operating performance and reduce maintenance needs and ash collecting and handling requirements. Reduced sulfur levels may be required to meet emission standards and in some cases may eliminate the need for emission abatement equipment. As shown in Table 20, the resultant cost savings can be considerable.

Coal Preparation Costs

The cost savings derived from coal preparation are dependent on the level of preparation. Theoretically, as the level of preparation increases the benefits to the consumer should also increase. As shown in Table 21, these benefits come at significantly higher costs, however, and must be balanced against the savings in transportation,etc. In the above example where a low Btu coal was upgraded using Baum Jigs and Dense-Medium cleaning, savings of

41

TABLE 20. A COMPARISON OF THE AFFECT OF COAL CLEANING ON CAPITAL AND OPERATING COSTS (1982 dollars) OF A 500 MWe POWER PLANT.[a]

CATEGORY	CASE I	CASE II	CASE III
Coal Preparation Level	None	Baum Jig	Dense-Medium
Coal Needs (10^6 tons/year)	1.71	1.28	1.23
Coal Properties			
Percent Ash	28.3	10.6	8.2
Percent Sulfur	3.2	2.6	2.6
Heating Value (Btu/lb)	8,270	10,940	11,300
Costs (10^6 dollars)			
Capital Investment			
Direct Capital	384.4	367.4	365.4
Indirect Capital	248.8	237.2	235.9
Working Capital	11.1	9.8	9.6
Total Capital	644.3	614.4	610.9
Operating			
Variable Costs	68.2	58.0	57.2
Fixed Costs	152.0	145.0	144.1
Total Operating	220.2	203.0	201.3
Annual Cost Savings			
Total	Base	17.2	18.9
Dollars/ton	Base	13.4	15.4

[a] Source: M. Laurila, Arthur D. Little Co., February 1983.

$13.40-15.40 per ton of coal are projected even after the preparation costs are factored in. The preparation resulted in coal cost increases of approximately $6.50-7.70/ton. These costs are relatively inexpensive compared to the amount of heating value increase (32-37 percent) and ash reduction (62-71 percent) for Cases II and III. Preparation costs at higher levels would be considerably more expensive and with much smaller gains in heating value and ash reduction. The effect of increased cleaning (i.e., lower cleaning plant yields) on raw coal costs is demonstrated in (Figure 10).

As a result of these increases in preparation costs relative to incremental upgrading, most users of steam coal purchase coals cleaned at Levels II and III. When emission standards or specifications cannot be met with lower levels of preparation, economic considerations may be secondary to technological or environmental considerations. This is particularly true of metallurgical coals which must be cleaned more fully in order to achieve the properties critical for good coke formation. Steam coal users in areas where sulfur emissions are severely restricted may have no choice but to use coals cleaned at Level IV.

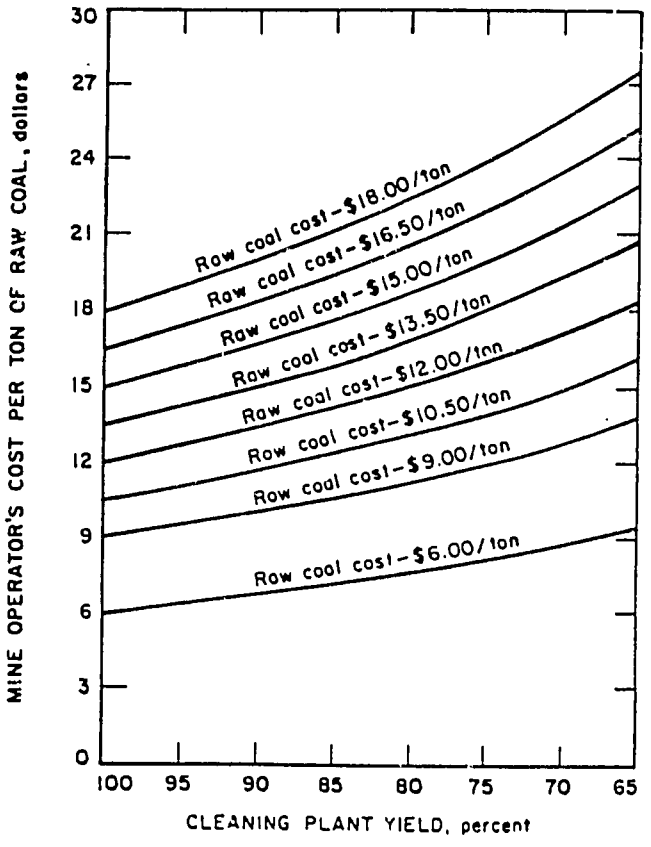


FIGURE 10. Incremental increases in coal cost with increasing level of coal cleaning (decreasing yield). (Source: M. Laurila, Arthur D. Little, Co., February 1983).

TABLE 21. COMPARATIVE COST (1982 dollars) DATA FOR THE FIVE LEVELS OF COAL PREPARATION.[a]

COST CATEGORIES	LEVELS				
	I[c]	II	III	IV	V
Capital Investment					
Total (10^6 dollars)	8-10	17	28	35	70
Dollars/Ton of Raw Coal[b]	0.30-0.32	0.56	0.84	1.16	2.32
Operating					
Dollars/Ton of Raw Coal	0.11-0.14	0.35	0.84	1.40	2.80
Total[d]					
Dollars/Ton of Raw Coal	0.41-0.46	0.91	1.68	2.56	5.12

[a] Source: World Coal, July 1978.
[b] 3,000,000 tons/year or 1,000 tons/hour.
[c] Lower values for rotary breakers, higher values for roll crushers.
[d] Add about $1.40/ton for thermal drying.

49

Cost Savings

The savings in transportation, ash disposal, and other operational costs are calculated on the basis of the higher heating values and reduced coal requirements and ash production. If a user consumes 3.75×10^{10} Btu's per year, 3.75×10^{6} tons of 10,000 Btu/lb run-of-mine coal would be required. If the coal is cleaned and the resultant heating value is 11,500 Btu's/lb, only 3.25×10^{6} tons are needed. Assuming a shipping cost of $0.01/ton mile and a travel distance of 500 miles, the savings on transportation costs would be (500,000 tons x 0.01 x 500) divided by 3.25×10^{6} or about $0.75/ton. Transportation savings can also be approximated using percent Btu increase to select an appropriate multiplier factor for shipping costs (Figure 11).

Similar calculations would be done to determine pulverizer savings based on the number of tons a pulverizer can grind before maintenance or replacement is needed. The savings in ash disposal would be determined by calculating the quantities of ash for the raw and cleaned coals, and calculating the respective costs of handling and disposing of these. Other savings such as furnace and boiler performance would be calculated on the basis of previous experience with coals of different heating value and ash contents and comparing raw coal and cleaned coal cost projections.

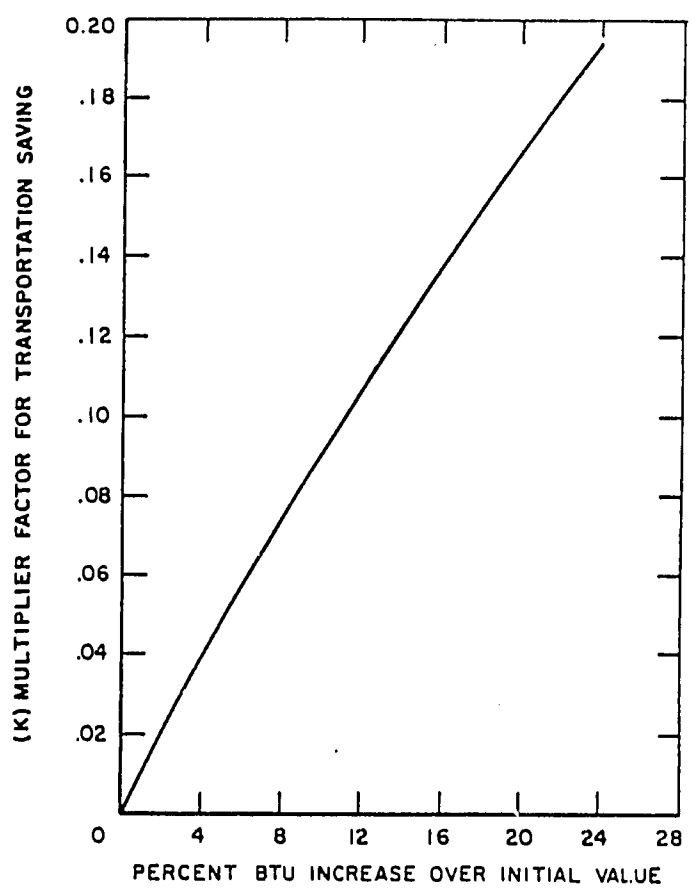


FIGURE 11. Savings in transportation costs with increasing level of coal cleaning (increasing Btu percentage). (Source: M. Laurila, Arthur D. Little Co., February 1983).

All the savings would be added together on a per ton basis and compared to the additional cost of cleaning the raw coal. This type of analysis would be done for more than one level of preparation in order to optimize performance and operating costs.

ENVIRONMENTAL CONSIDERATIONS

The primary environmental considerations for coal preparation are very similar to those for mining: land disturbance, water consumption, erosion, acid-drainage, discharges to surface waters and airborne particulates. The sources and magnitude of the impacts differ in most cases. While land disruption, runoff and acid drainage are major environmental considerations for mining, these are minimal compared to the magnitude of water consumption and use for coal preparation. The considerations are quantified for a representative coal preparation operation in Table 22.

Approximately 1500 gallons (about 6 tons) of water are required for each ton of coal that is cleaned. Fortunately about 80 percent of this is recycled, with the remaining water being discharged (about 15 percent) to surface waters or evaporated during thermal drying (5 percent). The discharged water may contain as much as 4-5 percent coal fines. These fines can cause mechanical and physiological damage to aquatic biota in the affected streams. The particles can smother bottom organisms and cause abrasions to breathing

TABLE 22. ENVIRONMENTAL IMPACTS OF A REPRESENTATIVE LEVEL III COAL PREPARATION PLANT. QUANTITIES ARE ON A PER MILLION TON RAW COAL BASIS.[a]

IMPACT SOURCE	QUANTITIES	LEVEL OF IMPACT
Water Use (Gallons/year)		
Total	1.3×10^9	Potentially serious
Recirculated	1.2×10^9	because of coal fines
Discharged	2.2×10^8	in discharge water.
Evaporation	5.1×10^7	Clarifiers may be needed.
Erosion and Runoff (Tons/year)		
Dissolved Solids	98	Minor, can be collected
Suspended Solids	190	in settling ponds.
Acid Drainage (Tons/year)	163	Minor, can be collected and neutralized.
Waste Disposal (Acres/year)	4.5	Minor, materials can be buried in the mine.
Airborne Particulates (tons/year)	210	Minor if precipitators used.

[a] Derived from EPA No. 68-01-0561, March 1975.

51

apparatuses. Additionally, these particles can alter the water quality (i.e., lower pH and increase concentrations of trace elements known to be toxic) sufficiently to cause death or, more likely, limit growth, reproduction and feeding activities. Effects at this level are generally limited to those surface waters having marginal water quality, low flows and poor mixing conditions. If at all possible these latter type of surface waters should be avoided, otherwise additional efforts may be necessary to reduce the quantity of coal fines prior to discharge.

Erosion, runoff and waste disposal are minor problems because of the smaller quantities of materials involved. The wastes contain particulates and toxic substances that can enter local surface and ground waters via runoff and leaching. Commonly used erosion control practices can substantially reduce these problems. Also, these wastes are often returned to the mine for disposal.

Thermal drying in fluidized beds generates considerable particulates because of the turbulent nature of the bed and small coal sizes. These particulates are discharged to the atmosphere at the rate of about 20 lb/ton of dried coal if precipitators are not used. When precipitators are used up to 90 percent removal is possible.

52

TRANSPORTATION

TRANSPORTATION

Coal from the mine or preparation plant can be transported to the end-user by one or more systems: barge, ship, train, pipeline, conveyor, or truck. The factors that influence system selection are geographical location of coal source and end-user, shipping distance, annual tonnage volume (throughput), volume of individual shipments and costs of competing systems. Because transportation costs can account for one-third to one-half of the delivered cost of coal, the end-user will want a system that optimizes cost, reliability, flexibility and efficiency.

TECHNOLOGIES

A transportation system is comprised of three functions, loading, hauling and unloading. The elements of loading and unloading include stockpiles, storage silos, reclaiming equipment, scales, conveyors, surge bins, loading chutes, loading tunnels/structures, electrical energy and labor. Unloading would differ in that it is custom built and interfaces with a second transport system in tandem such as a loading dock, pipeline terminal or process plant. Hauling involves the units such as barges, ships, trains, pipelines, conveyors and trucks and support equipment and traveling surfaces.

The unit sizes, optimum shipping distances and optimum annual tonnages for the major tansportation systems are presented in Table 23. In the U.S. over 74 percent of the coal is shipped by rail, 11 percent by water, 11 percent by highway and 4 percent by conveyor and pipeline.

TABLE 23. UNIT SIZES, OPTIMUM SHIPPING DISTANCES AND OPTIMUM ANNUAL TONNAGES FOR MAJOR TRANSPORTATION SYSTEMS.

TRANSPORTATION SYSTEM	UNIT SIZES	OPTIMUM DISTANCES	OPTIMUM ANNUAL TONNAGES
Ships	$15\text{-}200 \times 10^3$ DWT[a]	Unlimited	Unlimited
Barges	500-30,000 DWT	< 1000 miles	Unlimited
Trains	50-100 Tons	50-1500 miles	$0.25\text{-}30 \times 10^6$
Conveyor	36-72 inch Widths	< 25 miles	$2\text{-}10 \times 10^6$
Trucks			
Highway	15-20 Tons	15-50 miles	$< 2 \times 10^6$
Off Highway	60-200 Tons	< 5 miles	$< 5 \times 10^6$
Pipelines	12-48 inch Diameter	500-1500 miles	$5\text{-}30 \times 10^6$

[a] DWT - Dead Weight Tons

54

Trains

Transportation of coal by trains may be in the form of a single car, multiple car, or unit train shipment. Single hopper cars with a capacity of 100 tons are used primarily for shipments from small mines, or to small consumers, and are hauled in combination with other freight. The main disadvantage of single car movement of coal is its low efficiency in terms of manpower, equipment utilization, and turn around time. Multiple car shipments usually originate from mines of medium to large size or to medium size consumers. Several hopper cars are transported in combination with other freight. Better overall efficiencies are achieved but still less then unit train operations.

The unit train delivers coal to large consumers such as power plants and steel mills. More than 50 percent of the coal-fired power plants in the U.S. receive their coal by this means. A typical unit train consists of about 110 cars plus 3-5 locomotives, depending on grades and curves, with each car carrying 100 tons of coal. The two types of cars most commonly utilized are solid bottom gondolas and hopper cars. Standard locomotive size is 3000 horsepower. The unit train continually operates back and forth between the source of coal and the generating plant. Basically, the unit train has one origin, one destination and the car equipment remains as a unit and operates as a shuttle. Railroads use predetermined schedules for train loading, haulage volumes, mine departure, plant arrival, turnaround and mine return time to optimize operating conditions. Traveling speeds average about 50-60 miles per hour.

The unit train is used for long distance hauling when large throughputs are required and the terrain is not too steep. They have the lowest cost per ton-mile, high availability and operate continually. Car utilization is 5-6 times higher than other types of trains. The major drawbacks are the high capital cost, windage loss and inability to handle steep grades.

Loading and Unloading. The amount of time spent loading and unloading coal affects delivery times, costs and efficiency. Minimization of these times leads to more deliveries/unit time and better utilization of equipment which in turn help reduce costs. Loading and unloading systems for unit trains are much more elaborate and sophisticated then those for single or multiple car systems because of the smaller amounts of coal. Since most coal in the U.S is transported by unit trains for large consumers, and other transportation systems are typically used for smaller users, the following discussion will be limited to loading and unloading of unit trains.

Turnaround times for loading and unloading unit trains are typically 3-4 hours. Loading may be done on either single or parallel tracks, while unloading is done on single tracks. The movement of cars past the loading and unloading station may be controlled by the locomotive or various positioning devices that attach to the train and run parallel to the tracks. Loading of the cars will be by tripper conveyors or overhead chutes (flood loading). Unloading is by rotary dump or bottom-dump hopper cars. Rotary dumping (Figure 12) involves positioning one or two cars on a revolving platform, clamping the car in place and rotating the car 140-160 degrees, while still coupled, to dump the coal out the top of the car. The bottom-dump hopper cars move over undertrack pits or trestles and discharge the coal from the bottom through gates while moving (Figure 13).

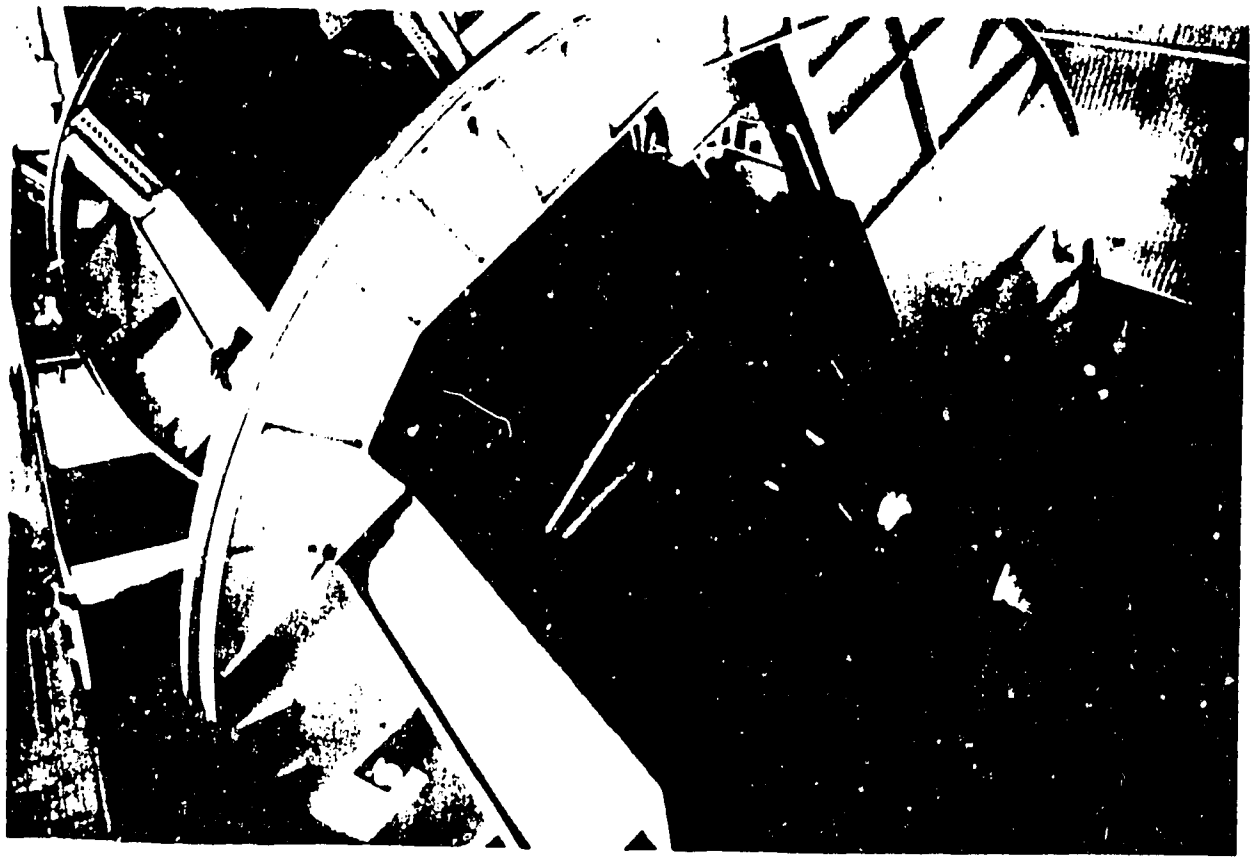


FIGURE 12. Rotary car dumper at beginning of rotation cycle.

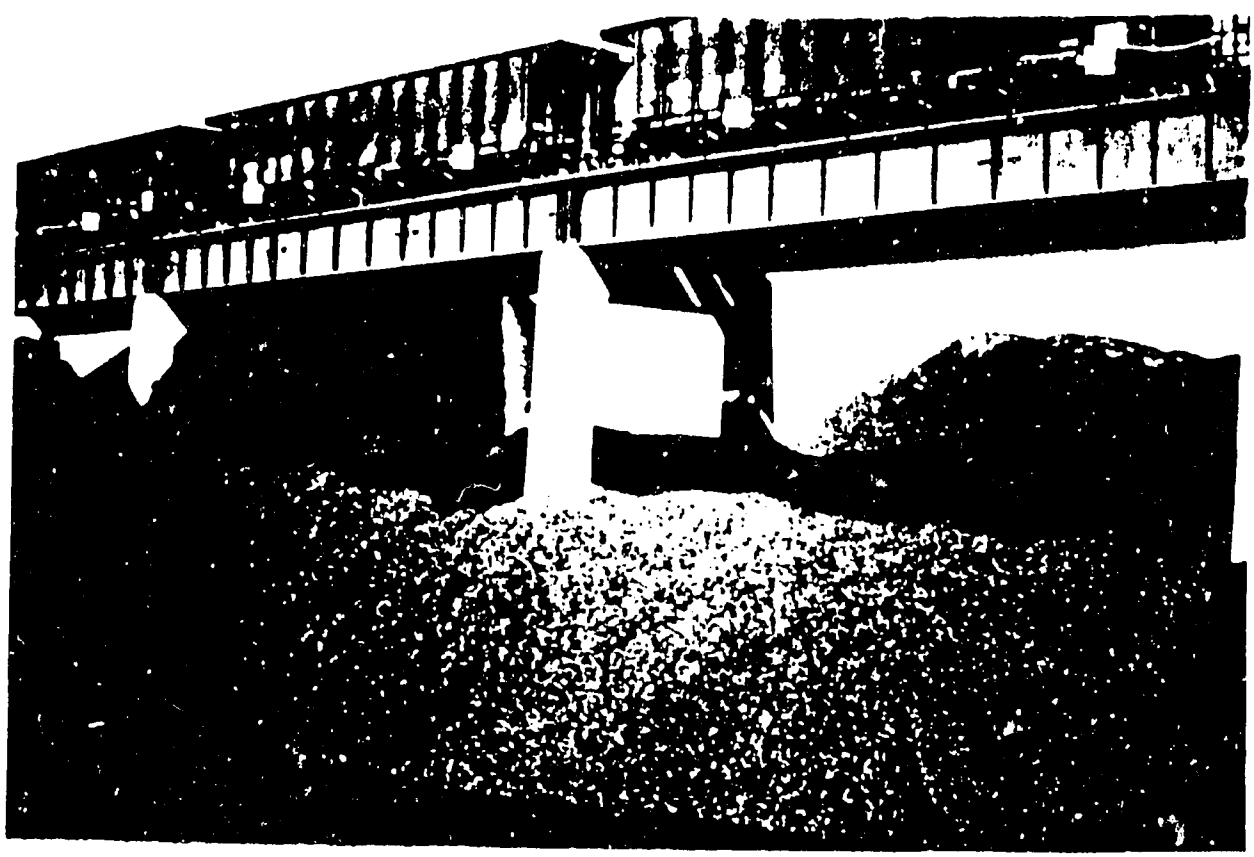


FIGURE 13. Trestle unloading of rapid-discharge hopper cars.

56

Bottom-dump hopper cars are effective in warm weather climates; however, they require special equipment, such as thaw houses, vibrators or shakers, in cold weather environments where coal may freeze. Under ideal conditions, a 110-car unit train can be unloaded in 40 minutes; however, when the coal is frozen the unloading time is 3-4 hours. Also, no below ground hopper is needed since the coal accumulates below the track in long narrow piles ready for reclaiming.

Rotary car dumpers can unload a car in about two minutes; therefore, a 110-car unit train normally requires about 3-4 hours for unloading. Despite this apparent disadvantage compared to bottom-dump systems, rotary dumping is more effective in cold environments.

Barges and Ships

Barges are used for hauling coal on inland waterways and ships on larger open water bodies such lakes, oceans and seas. Where feasible, barge transportation is perhaps the most practical, and is second only to ships in lowest cost per ton-mile. Several barges (usually 15) and a tow boat (from 3,000-10,000 horsepower) comprise a "tow". These "tows" may be combination and unit "tows". The open hopper barges vary in size from 900 to 1400 tons depending on channel depths, current velocities, and lock widths. When 15 barges are used, they are arranged 3 across and 5 long. Larger numbers (i.e., 25-30) of barges can be hauled on the larger rivers where there are no dams. The actual number will depend on safe handling at a given horsepower. Traveling speed averages 3-12 miles per hour.

The major limitation on quantity of coal that can be carried by barges is lock size. The smallest lock size will determine the maximum size of the barges. A major disadvantage of barges are their vulnerability to ice-jams, floods, and rough waters. Floods and rough waters can result in temporary shipping delays, while ice-jam related delays can last weeks or even months. Unlike ground based transportation, grades are not a problem since most loaded barges travel downstream.

Ships can vary from 60,000-200,000 DWT for ocean going vessels, to 15,000-60,000 DWT for large lakes and seas. They achieve the cheapest transportation costs of all hauling modes. A major disadvantage is their vulnerability to climatic conditions such as storms and ice-jams.

<u>Loading and Unloading.</u> Barges are loaded by tripper conveyors and pant-leg barge loaders and unloaded by clamshell bucket, continuous ladder (Figure 14), continuous bucket and rotary elevator belt. Loading rates vary from 3,000 to 5,700 tons/hour and unloading rates from 500 (clamshell buckets) to 5,000 (continuous ladder) tons/hour. A series of sheet piled cells are used to guide the barges and provide support for the loading or unloading facility. The barges moved back and forth under these facilities by wire ropes and winches located on the sheet piled cells. Barge positioners and shuttle barges may be used to facilitate barge movement.

High capacity (5,000 tons/hour or more) unloading facilities utilize a double continuous ladder to unload more rapidly and efficiently. The diggings heads are kept together for the first pass down the center of the barge. They are then extended to the width of the barge for the second pass. On the third and final pass the heads are together again to remove the remaining coal located

57

in the center of the barge. When unloading rates of 500-2,000 tons/hour are adequate the clamshell bucket unloader is effective.

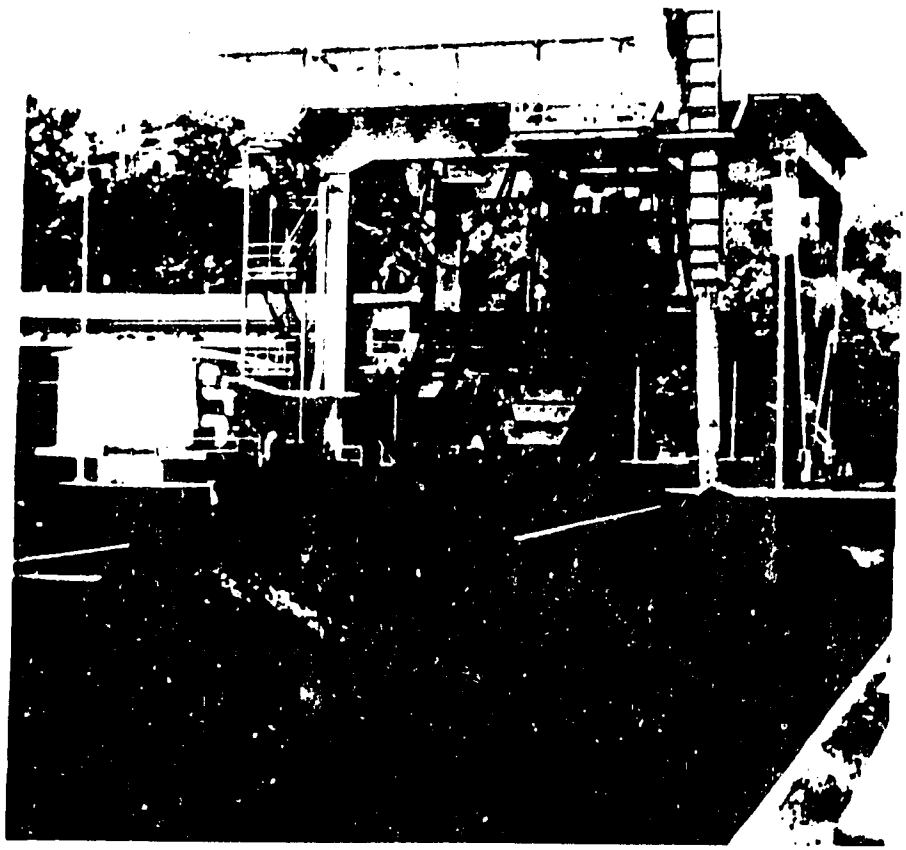


FIGURE 14. Continuous bucket ladder barge unloader.

In addition to the above methods of loading and unloading, ships may also be self-unloading (Figure 15). Internal conveyor systems located below the coal bring it from below deck and an on-deck conveyor deposits the coal onshore.

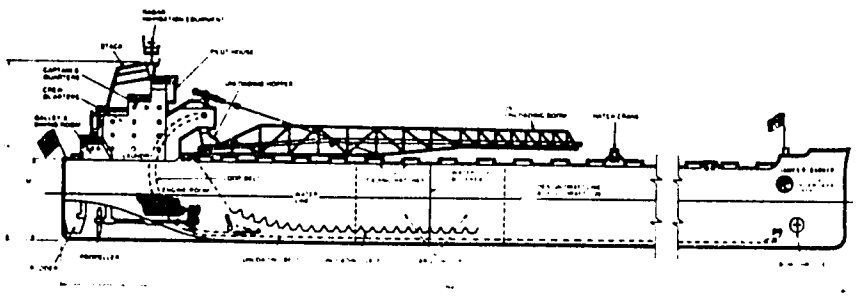


FIGURE 15. Self-unloading ship used on the Great Lakes.

Trucks

Trucks are typically used to transport coal from mining areas to preparation or storage areas, from the mine to adjacent power plants (mine-mouth plants) and to smaller power plants within 50 miles of the coal source. Off highway trucks are used for within mine transportation of coal at surface mines,

hauling to preparation plants, mine-mouth power plants, railroad sidings or waterway docks. Highway trucks are for offsite transportation to small end-users

Trucks are most effective for short,low tonnage hauls over moderate terrain (grades up to 20 percent). They can operate continuously, respond quickly to changing needs, and permit extensive product distribution. These attributes make trucks particularly suited to hauling coal to more efficient modes of transport, such as railroads, barges, pipelines, etc. The major disadvantages are the high costs/ton-mile, need for good road maintenance and dependence on weather and human elements.

Loading and Unloading. Loading and unloading operations for trucks are quite simple. Loading involves little more than driving under a chute for flood loading. Unloading may require dumping the coal directly on the active out-door storage pile or into a receiving hopper below grade.

Conveyors

Overland conveyor belts are used almost exclusively to transport coal from the mine to a mine-mouth power plant. A series of "flights" or straight conveyor runs are used to carry the coal distances of 8-10 miles. Each flight is an individual conveyor unit, with its own head and tail pulleys, belt take-up arrangement, motor, speed reducer and drive machinery. The full system is normally designed for automatic sequential start-up or shut-down from a central control unit. Local manual controls are located at transfer terminals.

These overland conveyors are most effective for short, high tonnage hauls over difficult terrain (grades up to 32 percent). They can operate continuously, require relatively little power and interfacing with existing facilities, have low labor needs, and are available about 90 percent of the time. The primary disadvantages are the high costs/ton-mile, complete system shutdown when conveyor belt breaks, and require additional equipment to spread the coal at the end of the conveyor system

Frequently, a combination of trucks and a conveyor system is used when both moderate and difficult terrains are involved, particularly at mine-mouth power plants. The trucks haul coal on the moderate grades and the conveyors over the difficult terrain. This helps reduce operating costs.

Pipelines

Coal transportation by water-based slurry pipelines involves three stages: coal preparation, slurry transmission and slurry dewatering at delivery point. The coal is first ground to a specified size with water being added during and after grinding until the slurry is 45-55 percent coal by weight. The slurry is then stored in mechanically agitated tanks to keep it in suspension. From the tanks, the slurry is pumped through the pipeline system by positive displacement reciprocating pumps located at intervals of 50-150 miles. Holding ponds may be constructed at various points along the way to hold the slurry if there is a system shut down. At the delivery terminal, the slurry is dewatered by natural settling, vacuum filtration, or centrifugation. Additional drying is often required before the slurry is used or transported

59

by another mode.

Slurry pipelines are most effective for long, high tonnage hauls when water is abundant and the coal has good dewatering characteristics. The major advantages of this transportation system are the low cost/ton-mile, continuous operations, low labor requirement, high availability and more direct routing. The main drawbacks are the high capital cost, the need for product dewatering and the ability to transport only one product (dedicated operation).

ECONOMIC CONSIDERATIONS

The selection of a transportation system is based primarily on economic considerations. Shipping distance and tonnage requirements contribute significantly to these considerations since they will determine the capital investment and operating costs associated with each system. Higher capital investments are warranted when shipping distances and tonnages are high because of lower operating costs. For short distance and low tonnage transport, the higher capital investments will take too long to recover and are only used when no other options exist. Transportation costs for each transportation system are presented in Table 24. In many cases a combination of transportation systems will be used (i.e., truck and barge, train and barge, etc.) and costs will vary accordingly.

Barges and Ships

For long, high tonnage hauls, this form of transportation is the cheapest. Capital costs are high for the tugs (about $4 million each) and barges (about $300 thousand each for 1500 DWT); however, labor costs are relatively low and there are no costs for supplying or maintaining right-of-ways. This mode of transportation is particularly cost-effective for users located on major rivers. This transportation system in combination with trucks or unit trains is still cost-effective for users located away from major waterways when direct unit train operations are not possible from the source of coal.

Trains

Unit trains are the cheapest form of overland transportation for long, high tonnage hauls. Capital costs are high for the unit train (about $7-8 million) and track (about $0.6-1.7 million/mile). Labor costs are also high; however, when the end-user is too far from a major waterway or transportation by train is more direct, this transportation system is usually the most cost-effective.

Pipelines

This transportation system is potentially competitve with unit trains. The capital costs are high (about $0.5-1.5 million/mile of pipeline) but the labor costs are very low. This system has not gained wide acceptance because of the lack of operating experience, high capital costs and the need for dewatering the coal before further shipment or use. More direct routing is possible with this mode of transport and this could make it more cost-effective then unit trains, particularly for distances greater than 100 miles.

TABLE 24 COSTS OF SHIPPING COAL BY DIFFERENT TRANSPORTATION SYSTEMS.

TRANSPORTATION SYSTEM	CENTS/TON-MILE	FACTOR ABOVE BASE
Large Ship (> 120,000 DWT)	0.06-0.12	Base (1)
Small Ship	0.20-0.80	5
Barge	0.40-0.80	7
Pipeline	0.50-1.10	9
Railroad		
Unit Train	0.60-1.40	11
Combination Train	1.80-2.80	25
Convayor	3.0-10.0	72
Truck	8.0-13.0	115

Source: W. Stevens, Bechtel, February 1983.

Coveyors

Coveyor transport of coal is expensive and is only justified for short, high tonnage hauls over difficult terrain. Overall capital costs are low; however, they are quite high on a per mile basis (about $2.4-3.1 million). This system is used almost exclusively for mine-mouth power plant operations.

Trucks

Capital costs are low for this system (about $80-100 thousand per 20 ton truck) but high labor costs, low availability and high fuel costs make this form of transportation expensive. Inspite of these high costs it is the cheapest mode for short, low tonnage hauls over moderate terrain. Trucking is particularly cost-effective for mine-mouth plant operations and as a means of transport between other transportation systems.

ENVIRONMENTAL CONSIDERATIONS

The primary environmental considerations are land and water use. Rights-of-way are required for roads, train tracks, slurry pipelines and conveyors. This alters or eliminates about 7-14 acres for every new mile of right-of-way. The magnitude of these impacts will depend on the importance of the land as ecological, agricultural or recreational resources. The use of existing rights-of-way or routing around sensitive areas can minimize these impacts.

Barges, ships and slurry pipelines impact water use. Barges and ships may loose up to 0.1 percent of the coal and discharge small amounts of pollutants to the waterways during operation. They also can stir up bottom sediments.

These effects can decrease water quality to a minor extent. Slurry pipelines utilize large quantities of water (2-2.5 x 10^8 gallons/million tons of coal). Although most of the water can be recovered during dewatering it may be several hundred miles from its point of origin. This will probably prohibit the use of this mode of transport in areas where water is limited. Also, the water from the dewatered coal will contain increased levels of potentially toxic substance and coal particles and will have to be treated before release into surface waters of marginal water quality or that are environmentally sensitive.

There will be some minor coal dust and diesel emissions from barges, ships, trains and trucks and dust from off-highway trucks.

60

CONVERSION

CONVERSION

Coal can be combusted directly or converted to gaseous (gasification) or liquid (liquefaction) fuels and then combusted. Currently conversion technologies are not competitive with naturally produced gaseous and liquid fuels. As the price of these fuels continue to rise, due to their limited supply, these conversion technologies will become price competitive and necessary to support industries built around gaseous and liquid fuels, particularly the transportation industry. These gasification and liquefaction technologies produce cleaner burning fuels that are conveniently stored and transported. Emission levels from combustion of these fuels are more acceptable from an environmental perspective as shown in Table 25.

TABLE 25. MAJOR EMISSION LEVELS FROM THE COMBUSTION OF COAL, GAS AND OIL.

EMISSIONS	COAL	GAS	OIL
Sulfur Dioxide	660-4390	0.6	830-920
Particulates	60-9440	5-15	140-720
Nitrogen Oxides	670-2440	80-700	130-760
Carbon Monoxide	44-88	17-20	40
Hydrocarbons	13-44	1-8	7

Source: Primer on National Gas and Methane, November 1979.

TECHNOLOGIES

Coal conversion to gaseous and liquid fuels is accomplished by addition of hydrogen and rejection of carbon as carbon dioxide. The differences between the various gasification and liquefaction technologies are based on the methods by which the Hydrogen/Carbon ratios in the feed materials are transformed to the desirable ratio in the fuel product. These different ratios are achieved by using different contacting mechanisms between reactants, operating temperatures and operating pressures.

Gasification

The basic reactants for gasifying coal include coal, steam and air (or oxygen). Coal supplies the needed carbon, steam the hydrogen and air the oxygen. The required heat for gasification is supplied directly by combustion of coal or externally. Direct heat is thermally more efficient and less complicated operationally than external heating. Gasification processes may burn mined and prepared coal (above-ground gasification) or coal in place (underground gasification).

Above-ground Gasification. There are three basic gasification process schemes (Figure 16), one for low Btu (150 Btu/standard cubic foot) gas and two for medium Btu (300-500 Btu/scf). The combustible gases produced by these process are carbon monoxide, hydrogen and methane. Methane has a heating value of about 1000 Btu's/cubic foot while the other two gases have about a third of this value. Principal noncombustible gases are carbon dioxide, hydrogen sulfide and nitrogen. Air is used as an oxidizing medium in the low Btu process, oxygen and oxygen plus external heat in the Synthesis and medium Btu gas processes.

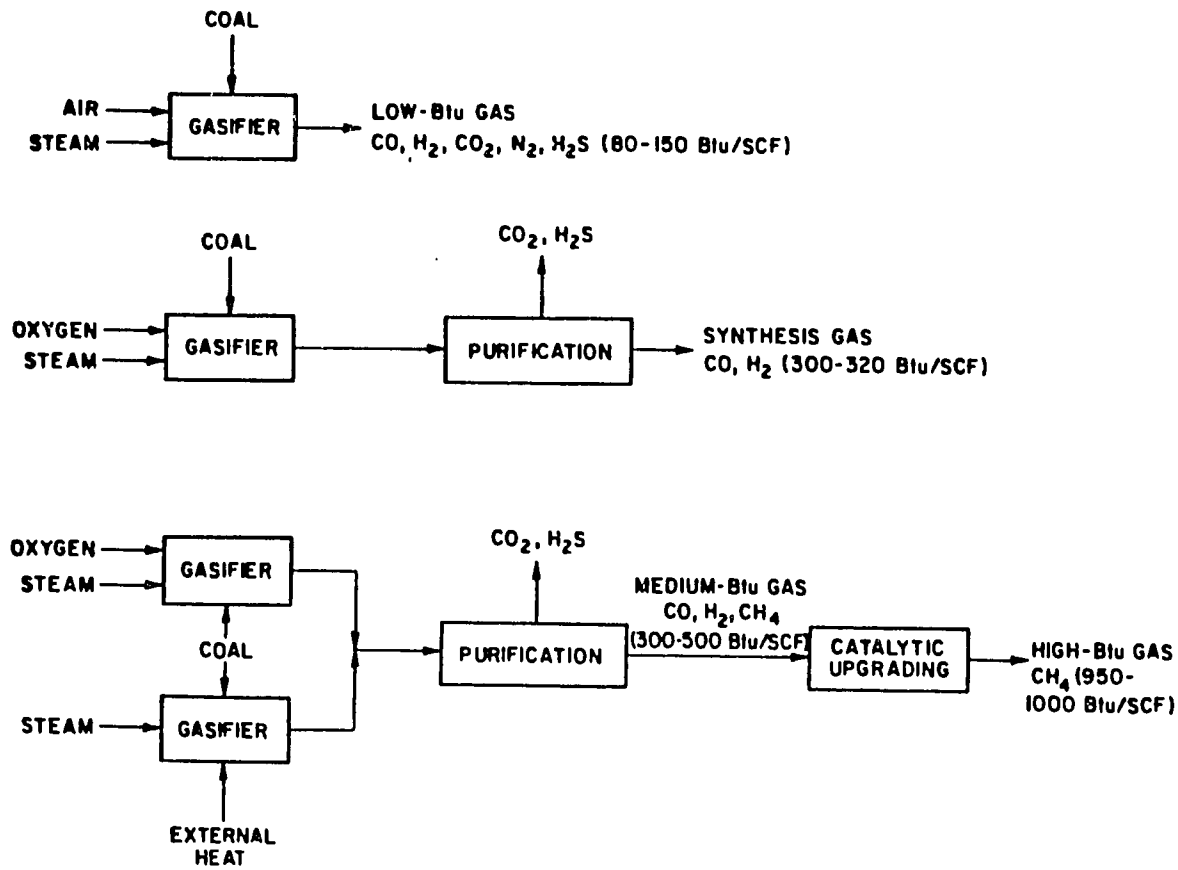


FIGURE 16. Simplified process schemes for coal gasification. (Source: S. Babu, IGT, February 1983)

Low Btu gases consist mainly of carbon monoxide, hydrogen, carbon dioxide and nitrogen. Because of their low heating values, they are not suitable for distribution and must be used onsite. Using oxygen instead of air eliminates the noncombustible nitrogen and produces a higher heating value synthesis gas composed of carbon monoxide and hydrogen. The use of oxygen plus external heat produces a medium Btu gas containing carbon monoxide, hydrogen and methane. The higher heating value of medium Btu gas makes it amenable to short distance distribution (<10 miles) and central processing plants to serve local industrial users are feasible. This latter gas can be catalytically upgraded to high Btu (1000 Btu/scf) gas. The high heating value makes high Btu gas suitable for long distance distribution. All the gases require some degree of purification (cleaning) or upgrading before they can be used. The most common applications for gases are presented in Table 26.

TABLE 26. APPLICATIONS OF COAL GASIFICATION PRODUCTS.

Low Btu Gas	Industrial Fuel Gas Reducing Gas for Ore Processing
Synthesis Gas	Fuel Cells Substitute for Liquid Fuels (such as methyl fuels and gasoline) Hydrogen Chemicals Fertilizers
Medium Btu Gas	Pipeline Industrial Fuel Gas (for boilers, kilns combined cycle power, fuel cells) Reducing Gas for Ore Processing Town Gas Synthesis Gas and High Btu Gas
High Btu Gas	Substitute Natural Gas for Domestic and Industrial Uses

The types and properties of coal-derived gases are a function of the design of each gasification process. The alternative processes will be a function of the reactor and bed type as well as operating pressures and temperatures. There are three types of reactor vessels: gasifiers, hydrogasifiers and devolitilizers. Gasifiers produce gas by reactions between coal and water at elevated temperatures. Methane is produced by reacting hydrogen and coal under pressure in hydrogasifiers. Devolitilizers decompose large coal molecules through reactions with hydrogen. The three bed types are fixed (or moving), fluidized and entrained. Grates are used to support coal, through which steam or hydrogen is passed, in fixed-bed systems. Fluidized-bed systems use fine coals that are suspended by gases passing through them. Finely sized coal is also used in entrained systems; however, the coal is transported to the reactor in steam or oxygen. The advantages and disadvantages of these bed types are summarized in Table 27. System design features of low-, medium- and high-Btu systems can be found in Table 28.

Underground Gasification. The previous processes require coal that has been mined and prepared for use. Gasification of underground coal seams is possible although more difficult because the reactions are controlled by the coal quality, direction of flow, shape of "reactors", heat loss and rate of "feed" imposed by underground conditions. Air and/or steam is forced underground to support the controlled combustion within the coal seam. There are two basic underground gasification processes, classified according to the method utilized to reach the coal seam: shaft and shaftless. Shaft systems require extensive underground mining in preparation for gasification and are used principally in Russia. Shaftless systems utilize drilled access openings to supply air, steam or oxygen and to collect produced gas and are under study in the U.S.

Before the coal can be combusted, the permeability of the seam must be enhanced between the inlet and outlet. This is done by directional drilling,

66

TABLE 27. ADVANTAGES AND DISADVANTAGES OF COAL GASIFICATION BED TYPES.

BED TYPE	ADVANTAGES	DISADVANTAGES
Fixed (Moving)	Excellent counter-current contact Facilitates thermal gradients Good control of residence times	Poor transfer rates Cannot handle fines Cannot handle agglomerating solids Complicated solids handling Produces unwanted byproducts Difficult to scale-up Low throughput
Fluidized	Easy to operate Excellent heat transfer Desirable for catalysis Suitable for gas-solid reactions Simple in Design Easy to scale-up	Cannot handle agglomerating solids Serious attrition of friable solids Back-mixed solids permit feed losses High pressure drop Difficult to maintain temperature gradients Design of gas distributors is critical Complex pressure balances in integrated operation
Entrained	Can handle agglomerating solids Precise control of residence time High solid conversions possible	Massive reactor dimensions Limited surge capacity Complicated reactor design Difficult to scale-up

Source: S. Babu, IGT, February 1983

countercurrent (reversing) combustion, electrolinking, hydrofracking and explosive fracturing. Directional drilling involves drilling holes in the coal seam. Countercurrent combustion burns a narrow channel between the inlet and outlet by establishing a narrow flame front moving in the opposite direction as the forced airflow. Electric current is used to carbonize coal in electrolinking. Water and chemical explosives are employed to fracture the coal in hydrofracking and explosive fracturing, respectively.

There are three underground coal gasification concepts under study in the U.S.: linked vertical well, longwall generator and packed-bed. The linked vertical well (Figure 17) employs countercurrent combustion to link two adjacent wells. High volumes of low pressure air are injected down the well that served as the production outlet during linking and the fire zone moves back toward the other well where the produced gases are collected. The reaction front expands vertically as it moves toward the production well. For

61

TABLE 28. SELECTED DESIGN FEATURES OF COAL GASIFICATION PROCESSES.

PROCESS	REACTOR TYPE	BED TYPE	PRESSURE (LBS/SQ IN)	HYDROGEN SOURCE	OXYGEN SOURCE	HEAT	PRETREATMENT	COAL INPUT
Low-Medium Btu								
Lurgi	Gasifier	Modified fixed	300-450	Steam	Air/ Oxygen	Direct Burning	Sizing	Noncaking, coarse
Koppers-Totzek	Gasifier	Entrained Suspension	Atmosph.	Steam	Oxygen	Direct Burning	Pulverizing	Caking or non-caking, < 0.003"
BuMines	Gasifier	Modified fixed	Atmosph.-300	Steam	Air	Direct Burning	Pulverizing	Caking or non-caking, coarse or fine
Westinghouse	Gasifier	Fluidized	200-300	Steam	Air	Direct & internal exothermic reactions	Pulverizing drying, integrated devolatiles/ desulfurizers	Caking or non-caking, < 0.003"
Ash Agglomerating	Gasifier	Fluidized		Steam	Air	Direct Burning	Pulverizing	Caking or non-caking, < 0.003"
High Btu								
Lurgi	Gasifier	Modified fixed	300-500	Steam	Oxygen	Direct Burning	Sizing	Noncaking, Coarse
HYGAS	Hydrogasifier	Fluidized	1,000	Hydrogen	Oxygen	Direct Burning	Sizing, slurry and heating	All fine coals
BI-Gas	Gasifier and Hydrogasifier	Entrained Flow	1,000	Steam	Oxygen	Direct Burning	None	Liquid to Rank A bitum., < 0.003"
Synthane	Gasifier or Devolatilizer	Fluidized	1,000	Steam	Oxygen	Direct Burning	Sizing, heat and volatilize	All fine coals
CO_2 Acceptor	Gasifier or Devolatilizer	Fluidized	150	Steam	Air	Direct and Indirect Burning	Sizing	Lignite of Sub-bituminous, 1/8"

Source: Energy Alternatives, University of Oklahoma, 1975.

a seam 30 feet thick, the front can advance 1-2 feet/day consuming all the coal over a distance of 40-50 feet wide. The product gas has a low Btu value because of high percentages of nitrogen (45-50) and carbon dioxide (10-15). The longwall generator process utilizes directional drilling to drill six inch boreholes on an incline to the coal seam and then horizontally through the seam for distances of up to 500 feet before being connected to the surface. Additional holes will be drilled at 100 foot intervals between the entry and exit boreholes. Several of these borehole systems will be drilled parallel to one another about 100 feet apart. Every other system will be used for gasification and systems in between will collect the gases as the reaction fronts expand laterally. This process also produces low Btu gas. The packed well concept employs explosive fracturing to prepare the coal seam for gasification. Gas-collecting wells are drilled to the bottom of the fractured coal zone. The holes drilled for fracturing are then used to inject oxygen and start a combustion zone on the surface of the fractured coal. After good combustion is established the injected oxygen is replaced by oxygen-water or oxygen-steam mixtures. This product gas has a medium Btu value and is easily upgraded to pipeline quality (high Btu).

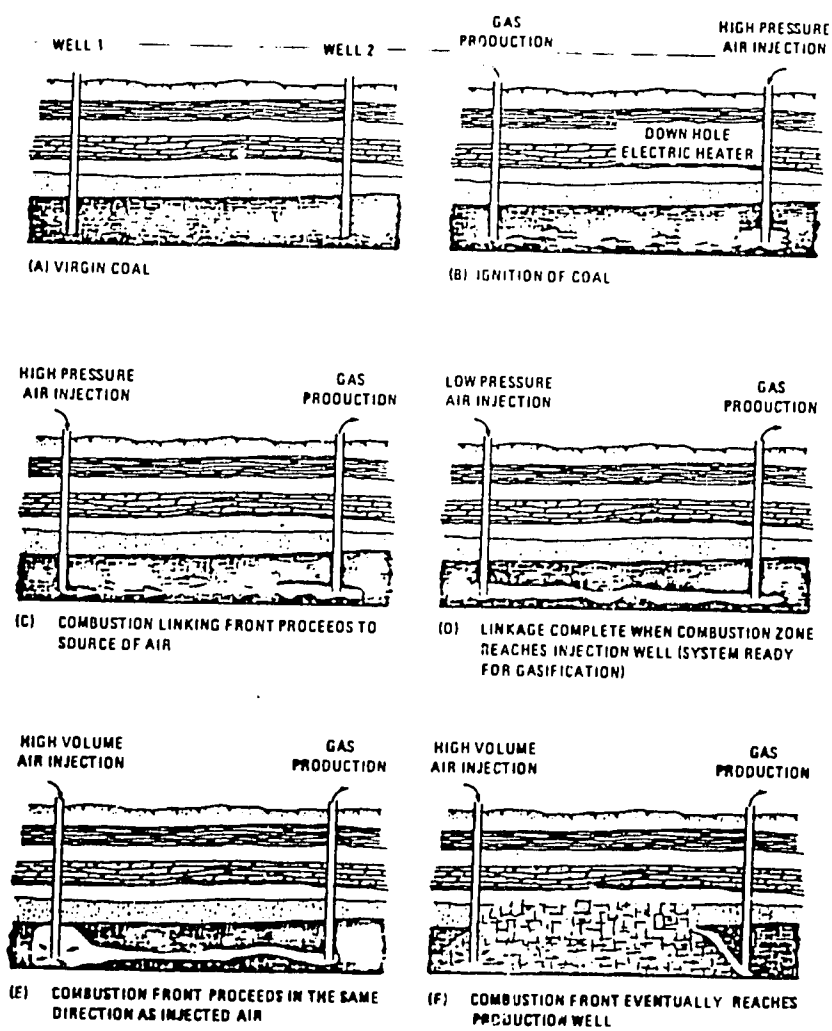


FIGURE 17. Schematic representation of Linked Vertical Well underground coal gasification. (Source; S. Babu, IGT, 1983)

The advantages and disadvantages of underground gasification are as follows;

Advantages	Disadvantages
Utilizes coal not economically mined.	Potentially unreliable due to underground conditions.
Minimizes health and safety problems.	Possible disruption of aquifers and pollution of groundwater.
Produces less surface disruption due to solid wastes.	Potential damage due to subsidence.
Consumes less water.	Low heating value gas
Generates less atmospheric pollution.	If oxygen injection not possible no synthetic natural gas.
Reduces capital investment and gas costs by about 25 percent	

Liquefaction

There are two types of liquefaction processes, indirect and direct. The indirect (synthesis) process utilizes synthesis gas, from hydrogasification, and catalytic conversion to produce methanol, gasoline, or other liquid fuels. Direct (degradation) liquefaction processes start with a coal slurry and produce various liquid fuels depending on whether hydrogenation, pyrolysis or solvent refining methods are employed in subsequent steps. Simplified liquefaction process schemes are shown in Figure 18 and system design features of various processes are presented in Table 29. The potential uses of coal-derived liquids as substitutes for petroleum-derived fuels is summarized in

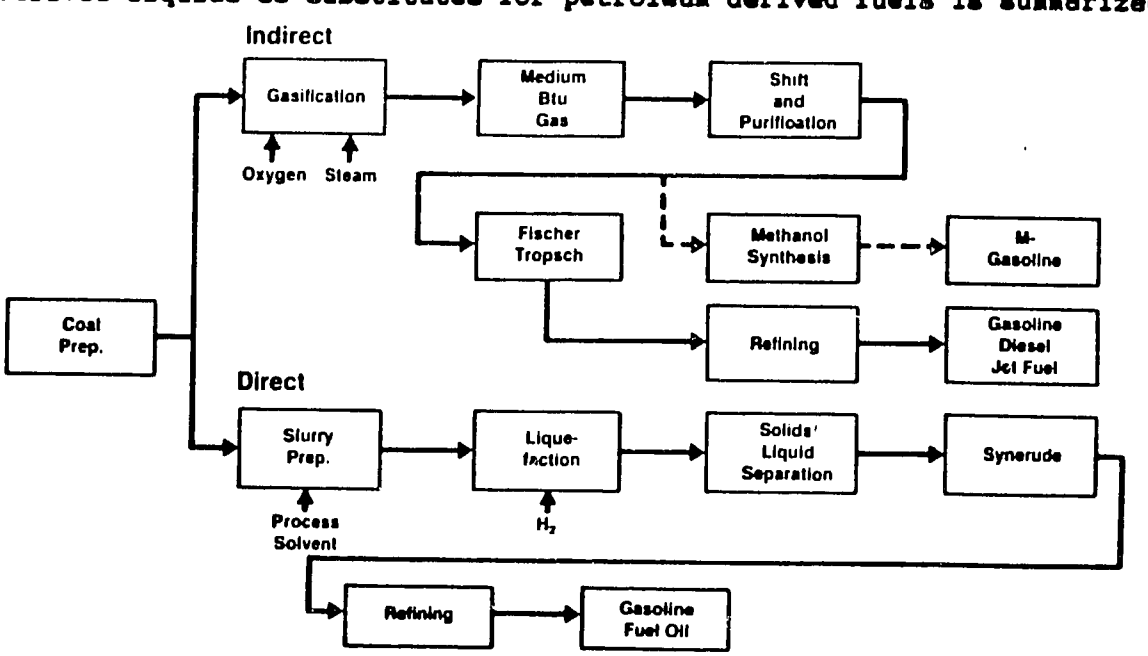


FIGURE 18. Simplified coal liquefaction process scheme. (Source: A. Talib, MITRE, March 1983)

70

Metal-based catalysts are used extensively and there is considerable recycling of gases and solids in liquefaction processes. The essential steps to both types of processes are (1) addition of hydrogen, (2) hydrocracking to lower molecular weight compounds, (3) removal of sulfur, oxygen and nitrogen as hydrogen sulfide, water and ammonia, and (4) separation of unconverted coal and ash from clean liquid fuels.

Indirect Liquefaction.

This process starts with a hydrogasification stage to produce synthesis gas. The synthesis gas is then purified to remove undesirable components, including potential catalyst poisons. A combination of blending with recycled gas and the "shift" reaction (steam is reacted with carbon monoxide in the presence of a nickel-based catalyst) are used to adjust the carbon monoxide/hydrogen ratio. The carbon dioxide that results from this adjustment is subsequently removed. The resultant product gas undergoes catalytic conversion (Fischer-Tropsch reaction) in the presence of iron-based catalysts to produce mainly paraffinic hydrocarbons. These can be refined and upgraded to produce gasoline, diesel fuel, jet fuel and pipeline gas. Methanol and high Btu gas can also be produced from the purified synthesis gas.

TABLE 29. SYSTEM DESIGN FEATURES FOR COAL LIQUEFACTION PROCESSES.

PROCESS	REACTOR TEMPERATURE (°F)	REACTOR PRESSURE (LBS/SQ. INCH)	COAL INPUT
Hydrogenation			
Synthoil	850	2,000-4,000	Pulverized, dried, caking or noncaking
H-Coal	850	3,000	Pulverized, dried, caking or noncaking
Solvent Refined Coal	800	1,000	Pulverized, dried, caking or noncaking
Consol Synthetic Fuel	800	1,000	Pulverized, dried, caking or noncaking
Pyrolysis			
COED	600-1600 in 4 reactors	6-10	Pulverized, dried, caking or noncaking
TOSCOAL	970	Atmospheric	Pulverized, dried, caking or noncaking
Catalytic Conversion			
Fischer-Tropsch	600-700	330-360	Depends on gasification process
Methanol (MTG)	680-780	320	Same as Previous

TABLE 30. POTENTIAL COAL-DERIVED LIQUID FUEL SUBSTITUTIONS FOR PETROLEUM-DERIVED FUELS.

PETROLEUM DERIVED FUEL	DIRECT SUBSTITUTION	INDIRECT SUBSTITUTION
Gasoline	Methanol Low-energy Value Gas	Methanol
Diesel	Low-energy Value Gas Fischer-Tropsch Liquids	Methanol
Distillate Oil	Low-energy Value Gas Medium-energy Value Gas Fischer-Tropsch Liquids	Solid Fuel
Residual Fuel Oil	Pyrolytic Oil Coal or Char-oil Slurry Low-energy Value Gas Medium-energy Value Gas	Solid Fuel
LPG	Low-energy Value Gas Medium-energy Value Gas Fischer-Tropsch Liquids	

The advantages and disadvantages of indirect liquefaction are as follows:

Advantages	Disadvantages
Ability to produce a wide variety of products selectively.	Thermal efficiency generally lower than for direct processes.
Already technically proven for large scale gasoline production.	Producing diesel fuels and kerosenes difficult with current technology.
More flexible gasifiers under development will provide greater independence from coal type.	Plant needs more equipment than for direct processes.
Less severe reaction conditions than for direct liquefaction	

Direct Liquefaction. Hydrogenation, pyrolysis and solvent refining are the three processes used to produce liquids from coal slurries. In hydrogenation, hydrogen gas or a hydrogen-rich solvent is mixed with the coal slurry in the presence of a catalyst within the reactor. This process breaks down the complex coal structures and produces a mixture of gases, liquids and solids that are separated as they leave the reactor. Fuel oil and syncrude are the principle products. Pyrolysis is used to break chemical bonds between clusters of coal molecules by applying heat in the absence of an oxidizing

agent. Char, syncrude and gases are the main products. Solvent refining is essentially pyrolysis in the presence of a solvent to obtain a liquified product. Coal dissolves in the solvent and captures additional hydrogen. A rapid reduction in pressure is used to drive off the solvent leaving solids, that are low in ash and sulfur, fuel oils and high Btu gas. An additional hydrogenation step converts the solids into liquid fuels.

The advantages of direct liquefaction include a higher thermal efficiency than indirect gasification, variable output of high octane gasoline and/or middle distillates and middle distillates suitable for jet fuel. The overriding disadvantage of this process is that it has not been demonstrated on a large scale.

ECONOMIC CONSIDERATIONS

Gases and liquids derived from coal are currently very expensive relative to current coal, natural gas and crude oil prices. As a result, these conversion technologies are expected to have limited application for the near future. Gasification, particularly low and medium Btu, has the best potential for penetrating the market because of it cheaper costs (Figure 19).

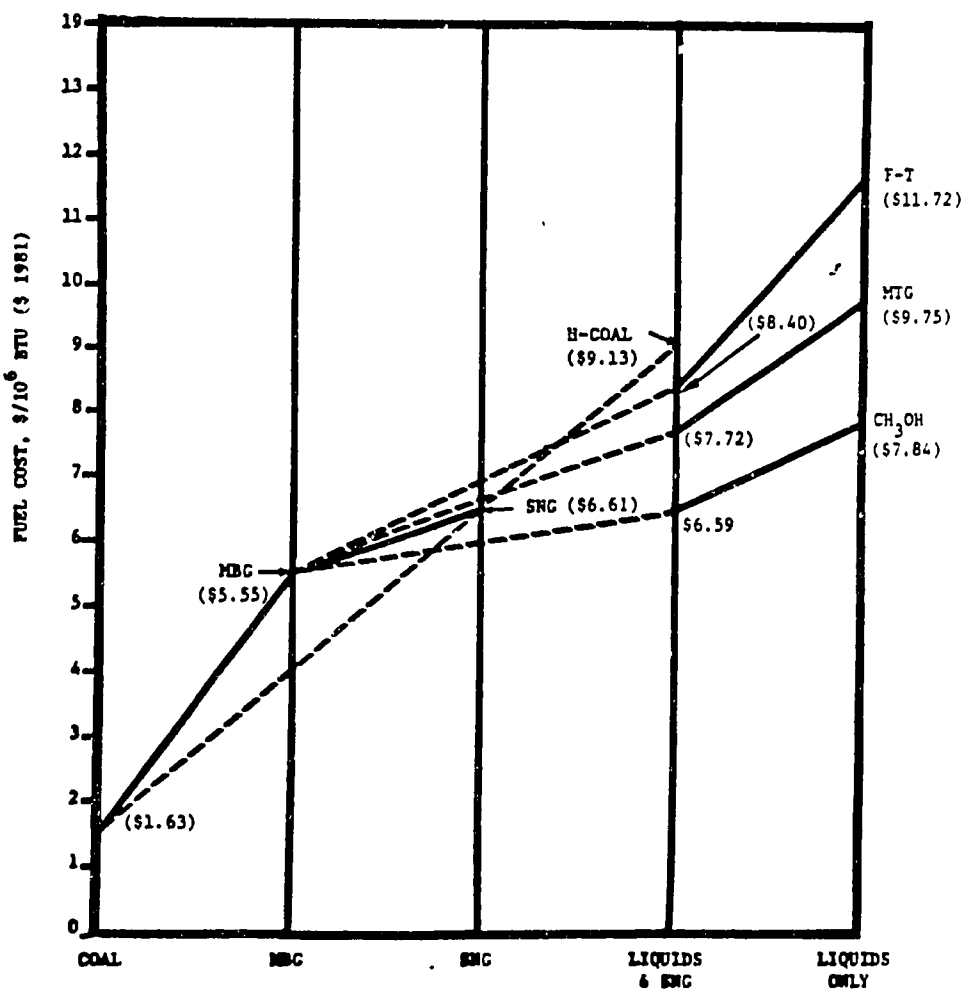


FIGURE 19. Comparative fuel cost for coal and coal-derived medium Btu gas (MBG), high Btu gas (SNG), and liquid fuels.

73

The high costs of coal-derived gaseous and liquid fuels are attributable to high coal and fixed costs. The proportion of fixed costs to total costs are much higher for liquefaction than gasification technologies because of the greater equipment requirements (Figure 20). Coal costs increase with the quality of fuel produced but less dramatically.

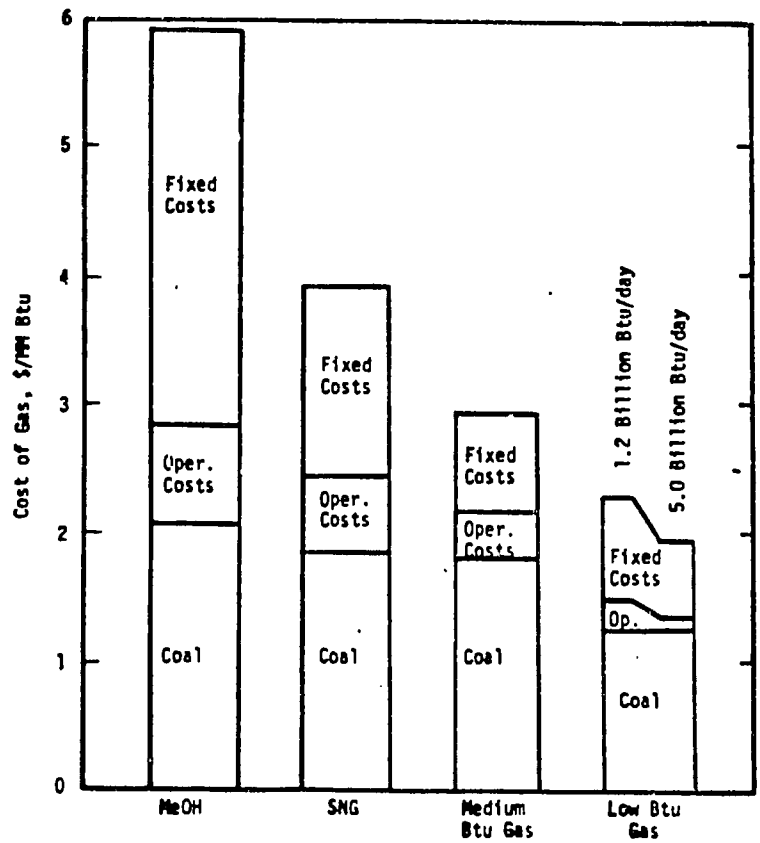


FIGURE 20. Fixed, operating and coal costs for coal-derived gaseous and liquids fuels. (Source: Amer. Nat. Gas Co., 1977).

Gasification

Capital investment costs vary with the type of gasifier bed, heating value of gas, production level and coal source. As shown in Table 31, fluidized-bed and entrained-beds require capital investments that are about 1.6 times higher than fixed-bed systems for a given level of production. Higher investments are needed for medium Btu facilites than for low Btu facilities up to a production level of 1.0×10^{11} Btu's/day for all bed types. At production levels greater than 1.0×10^{11} the investment costs are less for medium btu systems. Capital investment/10^6 Btu's decreases with increased production for all processes. These investment costs/10^6 Btu's reach minimal levels at production rates of 1.0×10^{11} for low Btu gas, 1.5×10^{11} for fluidized- and entrained-bed medium Btu systems and 2.0×10^{11} for fixed-bed medium Btu gas.

Capital investment and production cost for underground gasification systems are projected to be 25 and 15 percent lower than above ground systems, principally because gasifier equipment and mining are not required.

The estimated percentages of total capital investment required for the different above ground gasification plant elements are as follows:

Coal Handling and Preparation	4%
Gasification System	10%
Oxygen and Steam Plants	29%
Gas and Effluent Clean-up	37%
Shift and Methanation	9%
Balance	11%

TABLE 31. ESTIMATED CAPITAL INVESTMENTS ($ 1978) FOR LOW AND MEDIUM BTU COAL GASIFICATION SYSTEMS AT DIFFERENT PRODUCTION LEVELS.

PRODUCTION LEVEL (10^9 BTU'S/DAY)	FIXED-BED LBG	FIXED-BED MBG	FLUIDIZED-BED LBG	FLUIDIZED-BED MBG	ENTRAINED-BED MBG
Capital Investment (10^6 Dollars)					
2.5	8	-	-	-	-
5.0	13	-	-	-	-
10.0	24	60	-	-	-
25.0	57	94	104	119	-
50.0	102	132	164	174	174
100.0	189	191	300	303	303
150.0	321	281	456	441	441
200.0	401	340	618	601	601
Capital Investment (Dollars/10^6 Btu's)[a]					
2.5	9.7	-	-	-	-
5.0	7.9	-	-	-	-
10.0	7.3	18.2	-	-	-
25.0	6.9	11.4	12.6	14.4	-
50.0	6.2	8.0	9.9	10.5	10.5
100.0	5.7	5.8	9.1	9.2	9.2
150.0	6.5	5.7	9.2	8.9	8.9
200.0	6.1	5.2	9.4	9.1	9.1

Source: N. R. Baker, IGT, January 1979.
[a] Based on 330 production days per year.

Liquefaction

Economic comparisons of liquefaction processes are difficult because of the variety of possible products and the lack of large scale operating plants. Current estimates of capital investment and operating costs for three indirect and one direct representative process are presented in Table 32. Typically capital investments and operating costs will increase as the quality of liquid

fuel increases because of the additional equipment requirements and recycling of products. Increasing production levels will decrease the per unit liquid output costs as a result of economies of scale.

TABLE 32. CAPITAL INVESTMENT AND OPERATING COSTS FOR REPRESENTATIVE INDIRECT AND DIRECT LIQUEFACTION PROCESSES.

PROCESS	1981 COSTS IN 10^6 DOLLARS		
	CAPITAL INVESTMENT	ANNUAL OPERATING	ANNUAL COAL
Indirect Liquefaction			
Methanol (Mobil-M)	2,668	239	321[a]
Methanol to Gas (MTG)	3,190	286	321
Fischer-Tropsch	3,492	321	321
Direct Liquefaction			
H-Coal Syncrude	3,250	209	321

Source: A. Talib, MITRE, March, 1983.
[a] Coal input is 27,800 tons/day for all processes.

The estimated percentages of capital investment required for indirect liquefaction plant systems are as follows:

Gasifier	22%
Steam and Oxygen Production	29%
Gas Clean-up and Shift	21%
SNG Production	2%
LPG and Gasoline Production	16%
Balance	10%

ENVIRONMENTAL CONSIDERATIONS

Coal-derived fuels provide less environmental problems for the user; however, the process of producing these fuels generates emissions, liquid wastes and solid wastes. Land is also required for coal storage, waste disposal and facilities. These impact sources are summarized in Table 33 for gasification and liquefaction.

The emissions are due primarily to leakage from the gasifier and are relatively minor. The liquid wastes from condensation and purification steps are are potentially hazardous to biota because or the high levels of organic chemicals, such as phenols and polynuclear aromatic hydrocarbons. Before discharging to surface waters they need be treated by solvent extraction, biological oxidation or carbon adsorption methods to remove the organics. Fortunately most gasification and liquefaction plants are designed to either remove the organics and/or recycle the waste waters. Runoff from coal and

76

solid waste storage piles can decrease the water quality of local surface and groundwaters if appropriate control measures are not employed.

The solid wastes, primarily from the reactor vessels, include ash and slag that are not considered hazardous and spent catalysts, spent sorbents and biological sludges which may be hazardous. If these latter materials are to be stored onsite in impoundments they will have to be chemically fixed or the ponds will require impermeable liners to prevent groundwater contamination. The solids can be disposed of in an approved landfill, returned to the mine, or by deepwell injection to minimize impacts. This would also reduce the amount of impacted land.

TABLE 33. COAL GASIFICATION AND LIQUEFACTION IMPACT SOURCES.

Solids	Ash Slag Spent Catalysts Spent Sorbents Biological Sludge
Liquids	Phenols Aromatic Hydrocarbons Aromatic Amines Alkylated Benzenes Heavy Metals (As, Cd, Hg, Pb) Dissolved and Suspended Solids Biochemical Oxygen Demand
Emissions	Sulfur Dioxide Nitrogen Oxides Carbon Monoxide Hydrocarbons Particulates
Land	Facilities Coal Storage Pile Solid Waste Storage Pile

Source: Electric Power Research Instituto, EPRI AP-2245, 1982.

Quantitative comparisons of the impact sources for gasification and liquefaction are difficult since there is considerable variability within each process and limited experience with commercial scale facilities. However, for most of the sources identified in Table 33, experience with various demonstration units indicates a great deal of overlap in pollutant quantities and land requirements.

77

UTILIZATION

UTILIZATION

Coal and coal-derived fuels have many uses including electricity and power generation, primary metals production, cement production, transportation, substitutes for oil and gas in existing facilities and as a source of steam and power to various industries. Some of the specific application of these fuels are summarized in Table 34. In the paragraphs that follow the primary emphasis will be on utility applications since the majority of coal and coal-derived fuels will be used to generate electricity. Transportation applications of coal-derived fuels will not be discussed since it is unlikely that there will be much activity in this area for the near future.

TABLE 34. REPRESENTATIVE APPLICATIONS FOR COAL AND COAL-DERIVED FUELS.

PROJECTS \ APPLICATIONS	ELECTRICITY AND POWER GENERATION	LIQUID FUELS FOR TRANSPORTATION & INDUSTRIAL USES	CEMENT & OTHER CALCINATION OPERATIONS	OTHER INDUSTRIES
Combustion:				
• Coal-fired power and cogeneration plants	• Augment and expand existing utility power supply system	---	---	• Source of steam and power for: - Textile industry - Distilleries - Chemical plants
• Coal-oil mixture combustion	• Retrofit of existing oil-fired power plants	---	• Retrofit of existing oil-fired kilns	• Retrofit of existing oil-fired equipment
• Fluidized-bed combustion	• Use of high-sulfur low-quality coals in utility boilers	---	---	• Use of low-quality coals
Gasification:				
• Gasification retrofit	• Retrofit of existing oil-fired boilers	---	• Retrofit of existing oil-fired equipment	• Retrofit of existing oil-fired equipment
• Gasification and combined power cycle	• Improved coal-based power generation	---	---	---
• Gasification and chemical synthesis: - Methanol - Ammonia - M-Gasoline	• Methanol as fuel for advanced gas turbines	• Methanol for transportation fuel • Gasoline for transportation fuel	---	• Ammonia Fertilizer • Methanol as chemical intermediate
• Gasification and F.T. synthesis	---	• Gasoline and diesel fuels for transportation sector	---	• Feedstock for petrochemical industries
• Direct liquefaction	• Distillate fuels for utility boilers and turbines	• Gasoline and other transportation fuels	---	• Feedstock for chemical industry • LPG for domestic fuel consumption
• Carbonization/ pyrolysis	• Pelletized high energy density fuel • Pyrolytic for utility boilers	---	---	• Source of aromatics • Pelletized fuel for domestic consumption

Source: A. Talib, MITRE, March 1983.

TECHNOLOGIES-ELECTRICITY AND PROCESS STEAM

There are several steps involved in the utilization of coal after delivery to the consumer. For electricity, steam and cement production, these include handling and storage, pulverizing, combustion, cleaning of combustion gases, collection and disposal of waste materials. Blending, carbonization, quenching and drying, screening, and pig iron production are the major steps in steel production.

Handling and Storage

Once the coal has been unloaded, it is transported to the storage pile or directly to the plant via a system of belt conveyors (Figure 21). Coal not transported directly from the unloading facility to the bunkers or silos is delivered to the yard storage area for future reclaiming. There is typically an active (live) and a reserve (dead) pile in the storage area. The active pile usually has enough coal for 3-5 days of operation and the dead pile, 60-90 days of operation. Either outdoor (open) or covered storage systems may be utilized depending on the quantity and dust control requirements (Figure 22). Reclaiming, sampling and blending are common coal handling operations.

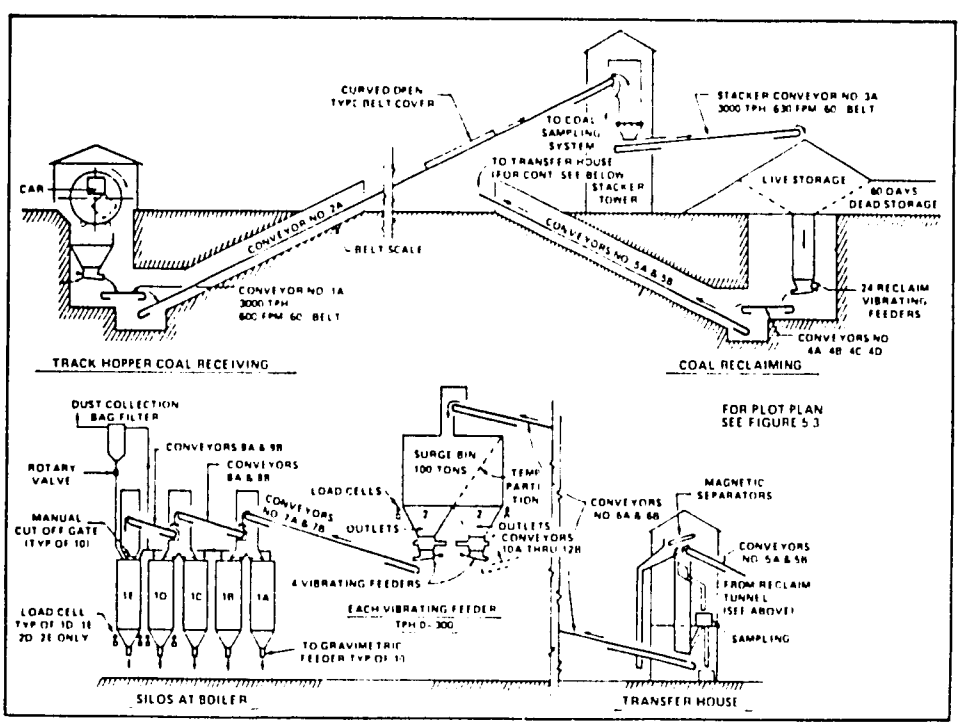


FIGURE 21. A representative coal handling and storage system. (Source: Electric Power Research Institute, EPRI PE-1865, May 1981)

Outdoor Storage. The selection of a proper site is an important consideration in constructing outdoor stockpiles. Loads of 3,500-4,000 lbs/square foot to the underlying soil require firm, level ground and subsoil of adequate bearing capacity.

80

Common active pile configurations are conical, kidney-shaped, and long straight piles or windrows. The configuration selected for any given facility will depend on the quantity of coal to be stored and the stacking equipment used.

Conical piles typically are built with a fixed cantilevered, stacker conveyor equipped with a telescopic chute to restrict dust. Kidney-shaped piles are built up with a pivoting stacker conveyor with either a fixed boom and telescopic chute, or an elevating boom that is raised as the pile height increases. Long straight piles are laid down with a variety of stacking equipment. Overhead conveyors, such as a belt conveyor with a traveling

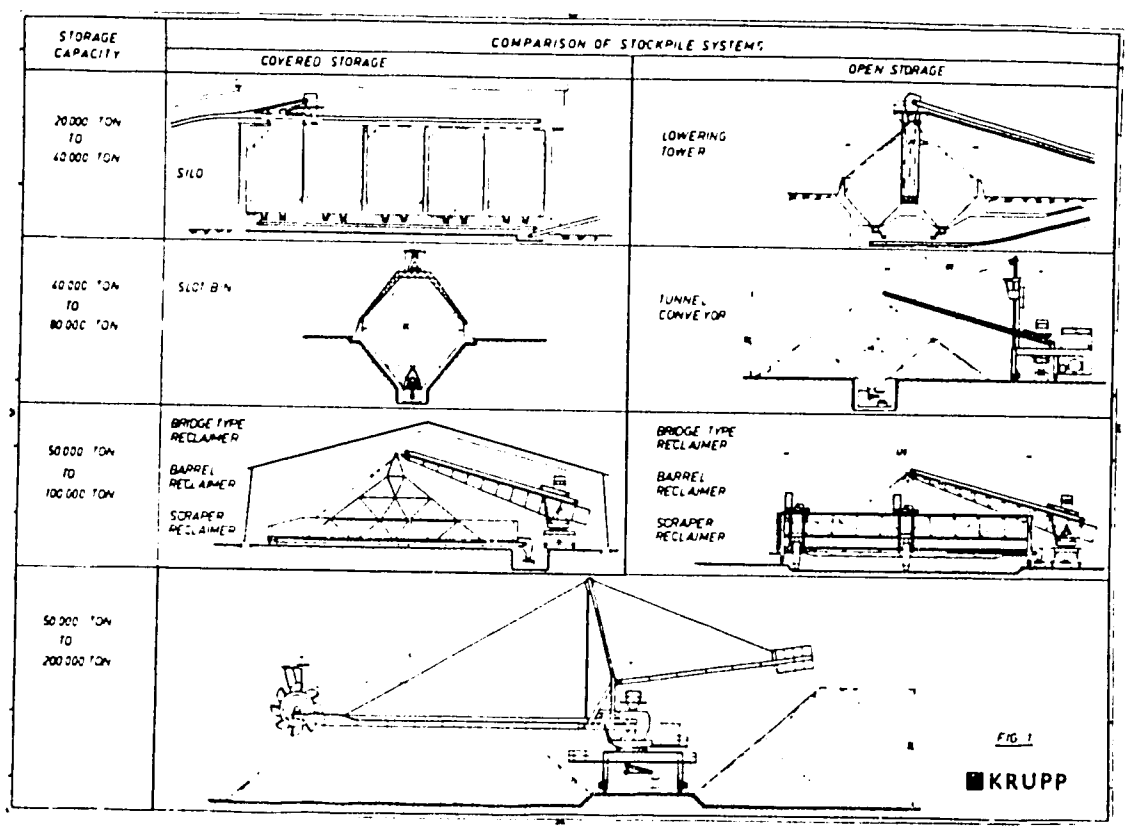


FIGURE 22. Types of outdoor and covered coal storage. (Source: Coal Handling and Storage Symposium, 1981.)

tripper, or a reversible shuttle conveyor may be employed. Often a traveling stacker that is fed by a yard belt conveyor with a traveling tripper is used. The traveling stacker boom may be fixed or movable (elevating or elevating and rotating). When large active piles are necessary, a rotating (slewing) boom stacker will allow two long, parallel coal piles, one on either side of the conveyor, to be laid down. Finally, the use of a combination traveling stacker and bucketwheel reclaimer with reversible boom conveyor belt, will permit the stacking of one or two parallel coal piles, or reclaiming from either pile to feed the in-plant storage bunkers or silos. The reserve pile is for long-term storage and must be constructed to minimize weathering and spontaneous combustion. Weathering is the oxidation of coal with prolonged exposure to air. This can result is a loss of 1-3 percent of the heating value and also alter firing characteristics. Weathering also

81

promotes slacking (reduction in size or crumbling), particularly near the pile surface and for low-rank coals. When oxidation of the coal occurs at a rapid rate, enough heat can be generated to cause spontaneous combustion. Spaces or channels in the pile must be restricted to eliminate or minimize this problem.

In laying down a reserve storage pile, coal is placed in layers 1-2 feet thick. Each layer is compacted by dozers, graders or spreaders to a density of 65-72 lbs/cubic foot to eliminate air spaces. The top of the pile is shaped in a crown-like manner, and made symmetrical to permit water runoff. The sides and top of the pile are covered with 12 inches of compacted fines, and then caped with 12 inches of sized lump coal to prevent erosion of the fines. After construction of the pile, it is checked on a daily basis for localized hot spots.

Covered Storage. Facilities for the enclosed storage of coal include the in-plant bunkers or silos, and active storage in silos and storage barns. The bunkers or silos are used to feed pulverizers or furnaces. Enclosed active storage is generally required when fugitive dust emissions and coal pile runoff must be controlled.

Bunkers are large capacity (e.g., 12-30 hour supply of coal), rectangular-shaped bins with multiple hopper-type outlets. These bunkers are rapidly being replaced with cylindrical steel silos with conical outlets because they present fewer problems with coal hang-up. In newer steam generating plants each pulverizer has its own silo. These individual silos provide true first-in, first-out withdrawal, thereby reducing the possibility of spontaneous combustion which exists when coal remains dormant for long periods of time--as is frequently the case with bunker storage.

High capacity silos for active storage are usually slip-formed, reinforced concrete cylinders, They have multiple conical outlets, cut-off gates and feeders arranged to discharge onto one or more reclaim belt conveyors leading to the in-plant bunkers or silos. Diameters of 70-80 feet and capacities of 10,000-15,000 tons per silo are typical. Banks of silos may be used when large quantities of coal must be enclosed. These are capital-intensive structures and when a bank of 4-5 silos are required the storage barn may be a more cost effective system.

A storage barn encloses a long, straight coal pile configuration. The barn is basically an inverted-V shaped building made of metal siding on a structural steel framework. Its sides parallel the natural angle of repose of the stored coal. The pile is laid down within the storage barn by an overhead conveyor with a traveling tripper, or a reversible shuttle conveyor. Reclaiming is by a belt conveyor in a concrete tunnel below the coal pile. The conveyor emerges from underground outside the barn and delivers the coal to a transfer station or directly to in-plant bunkers or silos.

Reclaiming. Coal reclaiming systems are broadly classified as below-grade and above-grade, depending on whether coal is removed from below or above the storage pile. The tunnel conveyor is the principal method for below-grade reclaiming and can be adapted to a wide variety of feed systems, including vibrating feeders, pile dischargers, rotary plow feeders and bulldozers.

Vibrating feeders and pile dischargers are fixed units mounted at the outlets

of feed hoppers installed at equally spaced openings through the conveyor tunnel roof. Rotary plow feeders are traversing feeders used in slot reclaiming systems. Slot reclaiming is another form of tunnel reclaiming and involves a single or double row of slots located along the sides of the tunnel roof. The floor of the pile is sloped downward to form a V-shaped bunker over the tunnel. The rotary plow feeder is a multi-arm rotor mounted on a 4-wheeled carriage that travels on rails supported by the framing of the receiving belt conveyor. The rotor has six arms, or plow blades that specially curved to reduce impact and increase efficiency. The rotary plow feeder provides effective, virtually continuous reclaiming.

The reserve pile is reclaimed by bulldozer and underground hopper system. These hoppers are covered with 6 inch x 6 inch steel grizzly or grillage to restrict the size of coal agglomerations. Vibrating feeders below the hoppers are used to regulate the flow of coal to the conveyor belt.

Above-ground reclaiming systems include the bucket wheel stacker (lower portion of Figure 22), bridge-mounted bucket wheel and drum reclaimers (Figure 23). The latter two reclaimers are use almost exclusively for coal bed-blending operations. The bucket wheel stacker-reclaimer is the principal above-ground reclaimer. This unit can stack coal, delivered by the ground yard conveyor and trailing tripper, or conveyor reclaimed coal to the in-plant storage. The components of this reclaimer are the stacking/reclaiming boom with reversible belt conveyor, the boom counterweight, the bucket wheel and the traveling rail gantry mechanism with track wheels. Reclaiming is done by the bucket wheel which is a series of buckets arranged around the periphery of the wheel, at a circumferential spacing of 8-10 feet. The buckets are scoop shaped with two open faces, one at the leading edge (radial) and the other where the bucket attaches to the wheel (tangential). Coal falls transversally from each bucket, as it reaches the highest point of rotation, into a chute-like cell built into the wheel body, and then downward onto the boom conveyor belt. Because uniform flows of coal are possible with proper operation, this reclaimer is classed among the continuous reclaiming systems.

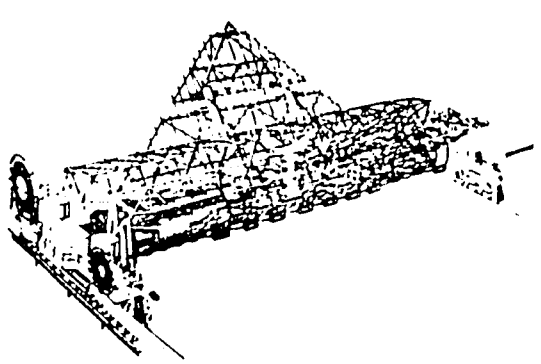


FIGURE 23. Drum reclaimer used for coal blending.
(Source: Coal Handling and Storage Symposium, 1981)

<u>Coal Sampling.</u> Many plants have sampling systems to analyze coal as it is received or as it is fired. The as-received sample analysis is commonly the

basis for payment as specified in the coal contract. The as-fired sample analysis is used to ascertain both boiler efficiency and verify that the coal meets environmental requirements. A typical sampling system consists of a primary, secondary and tertiary sample cutter, a sample crusher and a sample collector. Only a small portion of the coal sampled by the primary cutter is taken to the laboratory for analysis. The remaining coal is returned to the transporting conveyor by the sample reject system (a bucket elevator or redler type conveyor).

Coal Bed-Blending. Bed-blending is used to produce a homogenous mixture of different types of coal, with sulfur percentages and calorific values coinciding with design requirements. Usually two or more coals, such as low and high sulfur, are separately stacked out in individual layers or piles (one on top of another) of pre-determined quantity, to form long straight piles. Typical cross sections through these piles will consist of a series of chevron-shaped or windrow-shaped layers (Figure 24) containing all the coals laid down in the pile. The blending takes place as the coal is reclaimed by a bridge-mounted bucket wheel or barrel reclaimer. These reclaimers travel on rails moving from one end of the pile to the other, reclaiming from the face or cross section of the pile. The transverse movement of the bucket wheels, and the design and spacing of the scoops on the barrel reclaimer recover representative proportions of the various coals in the pile. The blended coal is then delivered to a cross-conveyor traveling with the reclaiming machine and discharged onto a collecting yard conveyor running parallel to the coal pile.

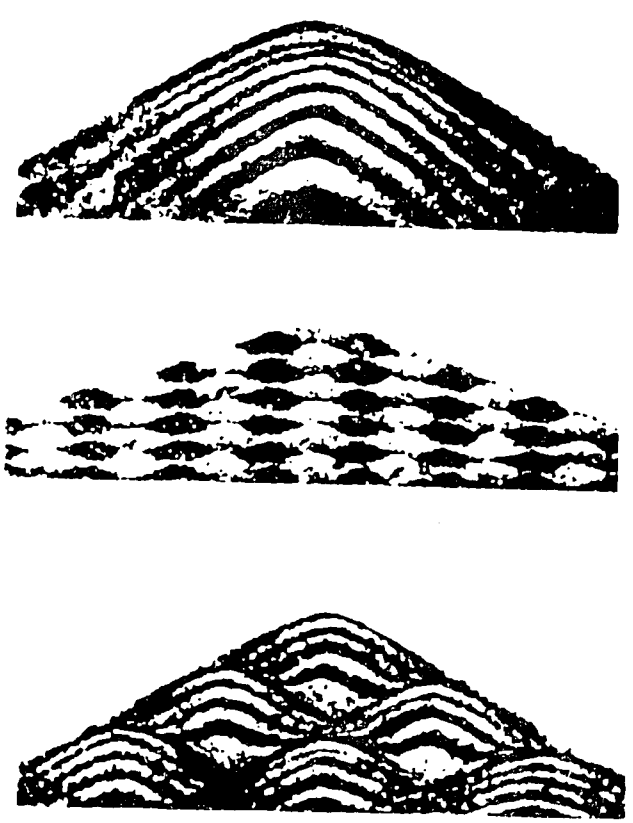


FIGURE 24. Coal bed-blending configurations.
(Source: Coal Handling and Storage Symposium, 1981)

Pulverizing

Once the coal has been delivered to a storage bunker or silo it may have to be pulverized before it can be fired. The use of pulverized coal has increased markedly over the past 30 years because of its better burning characteristics and associated reduced labor costs. Pulverized coal burns more like a gas and is, therefore, easier to light and control. Also, almost any kind of coal can be burned when pulverized.

Pulverized coal is used extensively to fire large furnaces for electricity and process steam generation and kilns used for cement production. The steps involved in pulverizing are coal feeding, grinding, drying, and delivery to furnace.

Coal feeding. There are two basic types of coal feeders, belt and overshot roll. The belt feeder is an endless belt running on two separate rollers, receiving coal at one end and discharging it at the other end. The rate of feed is controlled by the belt speed. This type of feeder is used for steam generation when combustion-control systems require individual coal metering to the burners. The overshot roll feeder is a multi-bladed rotor that turns about a fixed hollow cylindrical core. This core opens to a feeder discharge and is provided with heated air to assist in coal drying and minimize wet coal accumulations on surfaces. A hinged spring loaded leveling gate is mounted over the rotor to limit the discharge from the rotor pockets. Unlike the belt feeder this feeder can be integrally mounted on the side of the pulverizer. The rate of coal feed is controlled by the speed of the rotor. Both feeders are considered highly efficient volumetric feeding devices.

Grinding. The three principal ways of reducing the coal size (comminution) in preparation for burning are impact, attrition and crushing. Ball-tube, impact, attrition and ring-roll or ball-race mills are the four types of pulverizers and these use various combinations of these reduction methods. Table 35 summarizes some of the important features of each of the pulverizers.

A ball-tube mill is a large hollow, horizontal cylinder that is rotated on its axis. Its length is slightly less to somewhat greater than the diameter. Heavy cast, wear-resistant liners fit inside the cylindrical shell and this is filled to about one-half with forged steel or cast alloy balls varying 1-4 inches in diameter. Coal is fed into the cylinder through hollow trunnions, intermingling with the balls as it turns at 18-35 rpm. The continual cascading of the mixture during rotation pulverizes the coal by impact, attrition and crushing. Impact results from the balls falling on the coal, attrition from the particles sliding over one another and the liners, and crushing as the balls roll over each other and the liner. The larger coal particles are broken by impact and fine grinding is done by attrition and crushing. Hot air flow through the mill dries the coal and removes fines from the pulverizing zone. A classifier allows the fine particles to be carried to the furnace or storage, while oversize particles or rejects are returned to the grinding zone.

The impact mill has a series of hinged or fixed hammers revolving in a closed chamber lined with cast wear-resistant plates. Larger coal is reduced in size by the impact of the hammers and attrition of the coal particles as they slide over one another or the grinding surfaces produces the finer sizes. Heated

air flows through the mill to dry the coal.

TABLE 35. A COMPARISON OF SELECTED FEATURES OF THE FOUR MAJOR COAL PULVERIZER TYPES.

FEATURE	PULVERIZER TYPE BALL-TUBE	IMPACT	ATTRITION	RING-ROLL
Maintenance Needs	Low	High	High	Low
Power Consumption	High	High	High	Low
Sensitivity to Moisture	High	Low	Low	Low
Size	Large	Compact	Compact	Compact
Drying Ability	Fair	Good	Good	Good
Control of Coal Fines	Fair	Fair-Good[a]	Fair-Good[a]	Good
Capacity	High	Low	Low	High
Grinding Surface Wear	Low	High	High	Low
Capital Cost	High	Low	Low	Low

[a] Uniformity of fineness is good initially but decreases rapidly with wear on grinding surfaces.

Attrition mills contain pegs and lugs mounted on a high speed rotating disc in a chamber, the periphery of which is lined with wear-resistant plates and fixed rows of lugs. The rotating lugs mesh within the fixed lugs and both have wear-resistant alloy facings. This type of mill has characteristics similar to the impact mill.

Ring-roll and ball-race mills are the most commonly used pulverizers. They utilize rollers or balls rotating at medium speeds over a ring or a race to crush coal. Large particles may be reduced by impact between the crushing surfaces. In addition to crushing, attrition also produces finer particle sizes as the particles slide over one another. The roller diameters can vary in size from 20 to 50 percent of the ring diameter (up to 110 inches), and the ball diameter from 20 to 35 percent of the race diameter (up to 100 inches). The face width of the roller may represent 15-20 percent of the ring diameter. The roller may either be fixed with the ring rotating or vice versa; although the rotating ring is used most often. Pressure is maintained on the rollers or races by heavy springs, or pneumatic or hydraulic cylinders. Heated air is used to dry the coal and carry the fines away from the grinding zone.

76

Drying and Conveyance. Heated air passes through the different pulverizers to dry the coal and to entrain the coal fines for delivery to the furnace for firing or to a cyclone for storage. This heated air is either drawn through the pulverizer by suction using a fan (exhauster) located on the outlet side of the pulverizer or by pressure from forced air supplied by a fan located on the inlet side of the pulverizer. The source of this heated air is either from the combustion gases or primary air from the room or a preheated air duct or both. Combustion gases are generally used for direct-firing systems and primary air or vented pulverizer air for indirect and semi-direct systems. The coal from these latter two systems goes from the pulverizer to a cyclone to separate the coal from the heated air. In the semi-direct system the coal is then mixed with an independent source of heated primary air for transport to the burners. For indirect-firing, the coal is transported to a storage bin for later use. Preheated primary air is then used to deliver the coal from the storage bin to the burners.

Direct-firing systems commonly use furnaces operated under suction (balanced-draft) and the heated air will be transported through the pulverizer by suction. When pressurized furnaces are used, a pressurized exhauster will have to be used to convey heated air through the pulverizer and transport the entrained coal fines into the furnace.

Combustion

Combustion for electricity generation is and will continue to be the main use of coal. Process steam for industrial applications (e.g., chemicals) and cement production are also important uses. The production of electricity involves the conversion of chemical energy of coal into heat energy in a boiler. This heat energy converts water into steam and the heat energy of the steam is converted to mechanical energy by a turbine. Finally, the mechanical energy is changed to electrical energy by a generator (Figure 25). The production of process steam involves basically the same steps except that the steam is typically delivered to another user for various applications. Cement production utilizes coal as a heat source and the ash from the combusted coal aids in the formation of the "clinkers".

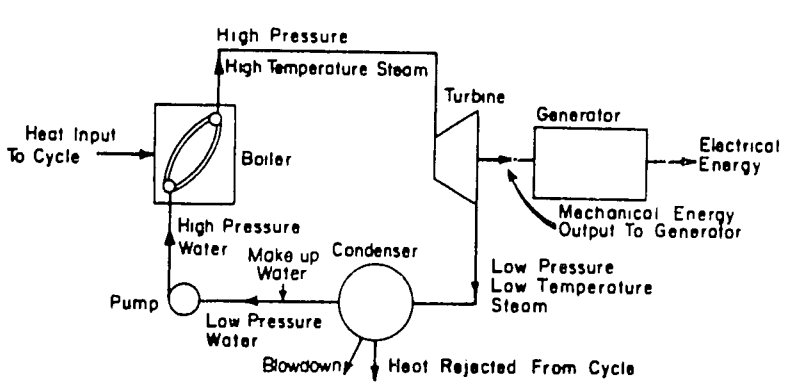


FIGURE 25. Simplified schematic for electricity generation processes. (Source: Energy Alternatives, 1975)

The production of electricity or process steam can result from three types of combustion systems: pulverized, fixed bed and fluidized bed. The pulverized

coal-fired boiler furnaces are the most commonly used and these may be horizontally, tangentially or vertically fired systems. Fixed bed (stoker) combustion systems are not in general use for electricity generation, but are used for industrial process steam production. The four major types are spreaders, underfeeders, vibrating grates and chain grates. Fluidized bed combustion systems are still at the demonstration stage and atmospheric and pressurized are the two main types.

The basic components of all these different firing system are the furnace, boiler, superheater, reheater, economizer, condenser and combustion gas clean-up and discharge (Figure 26). Combustion of the coal occurs in the furnace. The furnace has water walls (boiler) which absorb approximately 50 percent of the heat. The water within the tubes running through the furnace wall is partially converted to steam. This steam is transported to the superheater to raise its temperature above the saturated temperature level, through increased pressure. After the superheated steam has been used it is returned to a reheater to increase its temperature for reuse. Before returning to the boiler, the steam must be converted back to water and this is done by passing it through a condenser. The economizer circulates boiler feedwater through the flue gas to absorb additional heat thereby increasing boiler efficiency. After the combustion gas has been utilized for steam production and heating the boiler feedwater, flyash must be collected by filtering the gases through bag houses or electrostatic precipitators and/or sulfur dioxide removes by flue gas desulfurization.

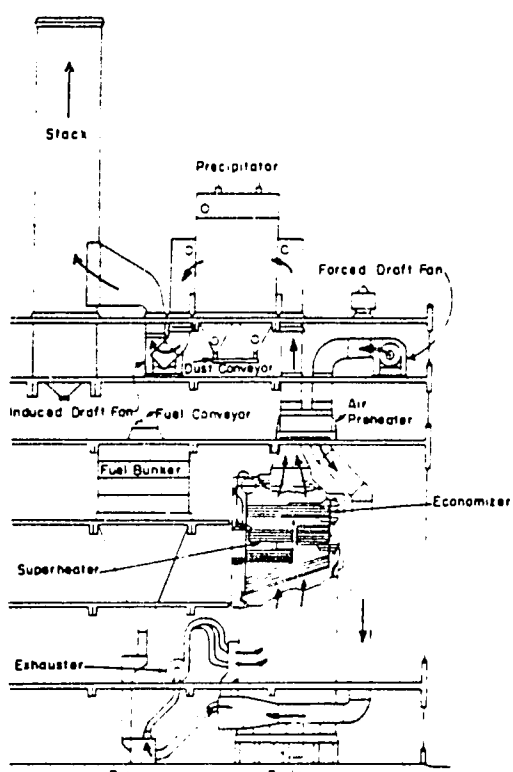


FIGURE 26. A typical pulverized coal furnace system. (Source: Energy Alternatives, 1975)

Pulverized Coal Firing. These combustion systems are highly efficient, producing about one kilowatt-hour for every pound of coal. This high efficiency is achieved by using mechanical turbulence to increase the contacts between molecules of the combustion reactants. This is done through multiple or single flame envelopes. Horizontally fired systems use the multiple envelop concept and tangentially fired systems the single envelop concept. Vertically fired furnaces combine features of both concepts.

Horizontal fired systems utilize rows of burners located on the front wall only or on both front and rear furnace walls. The pulverized coal is mixed with hot combustion air in individual burner registers and enters the combustion zone in a rotating manner. The rotation is the result of the coal and primary air be intoduced tangentially to the coal nozzle. The degree of resultant airswirl, coupled with the flow-shaping contour of the burner throat, establishes a recirculation pattern extending several throat diameters into the furnace. The hot products from the combusted coal are directed back toward the nozzle, by the opposing furnace wall or flames to provide the heat needed for stable combustion.

Tangentially fired systems have vertical rows of burners located in each corner of the furnace. The pulverized coal and combustion air are projected from the corners along a line tangential to a small circle, lying in a horizontal plane, at the center of the furnace. A great deal of mixing occurs where these streams meet, creating a rotative motion similar to that of a cyclone. This motion spreads the flame body out to fill the furnace area. The coal nozzles can be tilted up or down to burn different grades of coal, control furnace exit-gas temperatures for variations in load, and to compensate for the effects of ash deposits on furnace wall heat absorption.

Vertically fired systems are used to fire coals that cannot be ignited easily, such as those with moisture-and-ash-free volatile matter less than 13 percent. They require less supplementary fuel than the horizontal or tangential systems, but have more complex operating characteristics. The pulverized coal and combustion air is directed toward the floor of the furnace from burners located on arched furnace walls. A long, looping flame is produced in the lower furnace, with the hot gases discharging up the center of the furnace. This type of flame provides the long residence times needed for combustion of less volatile coals.

Fixed Bed (Stoker) Coal Firing. These firing systems were in use long before pulverized firing systems. They utilize much larger coal sizes (1-1 inches) and burn the coal on grates within the furnaces. Stokers are less effective than pulverized coal firing systems, requiring about 1.5 tons per kilowatt-hour. Because of this lower efficiency they are less cost-effective than the pulverized firing systems at high production (electricity or steam) levels. They are cost-effective for smaller production levels and are particularly suitable for industrial process steam generation.

Spreader stokers employ rotating impellers to distribute coal across a grate that moves toward the feeder. The finer coal particles are burned while suspended over the fuel bed, while the heavier particles are combusted on the bed which lies on the grate. As the grate carries the coal through the furnace it burns out and is discharged at the same end as the coal feeder. These stokers can produce 10,000-300,000 lbs. of steam/hour.

Underfeed stokers utilize rotary screws or pushers to feed a retort from below the fuel bed. As the coal rises into the bed the volatile gases are distilled and mixed with air. This mixture is combusted it moves upward through the bed igniting the coal. Combustion continues until the coal is burned out and the ashes are discharged over the top of the retort as a result of new coal being introduced from below the bed. These stokers can produce 5,000-50,000 lbs. of steam/hour for a single retort and 40,000-300,000 for multiple retort systems.

Vibrating grate stokers have stationary grates. The coal is moved forward along the grate by vibrating or reciprocating motions imparted to the grate. These grates are water-cooled to increase the heat transfer surface. A wider range of coal grades can utilized with this type of stoker than with spreader or underfeed stokers. Steam production ranges from 10,000 to 300,000 lbs. of steam/hour.

Chain grate stokers are similar to vibrating stokers except a grate consisting of bars joined together like a chain moves the coal forward. The coal is ignited by hot combustion gases located above the fuel bed. The ignition front moves downward through the bed leaving burning coke above. As the coke is carried forward, it is consumed leaving a bed of ash that is discharged at the far end of the grate.

Fluidized Bed Firing. Fluidized bed principles have been utilized for several decades in non-combustion reactions; however, it has only been in recent years that these principles have been applied to combustion reactions. A bed of inert materials (usually limestone) is kept in turbulent motion by bubbles created by air being forced into the bed from below. Coal is then added to this bed and burned under atmospheric or elevated (3 to 10 atmospheres) pressures.

The system is initially fired by an ignition system to bring bed temperatures up to a level that will sustain firing. The bed temperatures can then be controlled by submerged tube banks that absorb heat. Introduced coal mixes with the heated inert bed materials and is quickly heated and combusted by their churning actions. This highly turbulent condition and a high degree of surface area contact between particles permits more efficient combustion of the coal at lower temperatures (1550-1750°C) than conventional furnaces (> 2,000°F). Such conditions also allow the burning of lower grade coals. These lower temperatures reduce the formation of undesirable nitrogen oxides and minimize slagging by keeping the ash well below its softening temperature. Sulfur dioxide emissions are minimal with fluidized bed firing because they combine chemically with the inert bed material (limestone).

Inspite of these potential advantages of fluidized bed firing, the lack of experience with commercial size furnaces and the current costs of the technology have limited its application. In the U.S., it will be several years before there will be appreciable commercial utilization and this will primarily be industrial applications.

Cleaning of Combustion Gases

The use of coal from a resource and economic point of view, relative to natural gas and petroleum, has considerable benefits; however, because of its high ash and sulfur content there are considerable environmental costs.

Combustion of the coal in various firing systems creates large quantities of ash and in some cases sulfur dioxide. The ash that is entrained in the flue gases is small enough to be respirable and can create serious health impacts if control measures are not used. Sulfur dioxide may have some health implications; however, its primary impact is the formation of acid-rain. These two problem areas have to be controlled by the preparation or combustion process or by cleaning of the flue gases. Currently, most control measures are centered around the later approach.

Particulate Removal. The fly ash or particulates are removed from the flue gas by dry cyclone or wet scrubber collectors, fabric filters or electrostatic precipitators. The dry cyclone and wet scrubber collectors separate the fly ash from the flue gas by mechanical means. Dry cyclone collectors remove particulates by centrifugal, inertial, and gravitational forces developed in a vortex separator. The particulate laden gas is admitted either tangentially or axially over whirl vanes to create a high velocity in the cylindrical portion of the separator. This subjects the particulates to an outward centrifugal force. Near the bottom of the cylindrical section the direction of the gas is reversed and the resultant inertia and gravity cause the particulates to fall into a collection hopper. Efficiencies are high for particulates greater than 20 microns and drop of very rapidly as the size approaches 10 microns. In wet scrubber systems, ash is forcefully bought into contact with fine droplets of water. The ash particles adhere to these droplets and are carried down through a diffuser into a separator vessel. About 95 percent of the ash particles sizes greater than 0.5 microns are removed by this scrubbing method.

Fabric filters have been receiving more attention recently because of their efficiency in handling low sulfur coals which are being used more frequently in an attempt to meet emission standards. The fabric is formed into a vertically hung tube or sleeve closed at the top. Flue gases are drawn through these bags with the ash particles forming a loosely deposited cake on the inside. The flue gas must be turned off periodically to remove this ash buildup by agitation or air back flow. Woven glass fiber coated with graphite and fluorocarbon polymers provide the best service, but polyester, cotton and wool fabrics are also used. The main disadvantage of these fabric filters is the higher maintenance cost relative to electrostatic precipitators and higher operating energy requirements.

Approximately 90 percent of the fly ash collected at major power stations is by electrostatic precipitators. Ash particles passing through the precipitator become negatively charged and are attracted to positively charged plates. This charge is imparted by a high DC voltage wire. The ash particles are deposited on the positive plates and removed subsequently by physical means. Electrostatic precipitators work quite well with most coals, an efficiency of up to 99 percent; however, low sulfur coals interfere with the electrical field (high resistivity) in the precipitator reducing its capturing effectiveness. Larger positive plate or deliberate injection of sulfur trioxide are two means of countering the effect of these coals. In spite of this and other problems, electrostatic precipitators have performed more effectively and with fewer overall problems.

Sulfur Dioxide Removal. Sulfur dioxide gases are removed form the flue gases by flue gas desulfurization. There are wet or dry and throwaway or

91

regenerable processes. In the U.S., the wet, throwaway process is used most frequently. With this process the flue gases are scrubbed by lime or limestone slurries (Figures 27 and 28) which react with and absorb sulfur dioxide. The removal of SO_2 in this manner is 80-90 percent efficient.

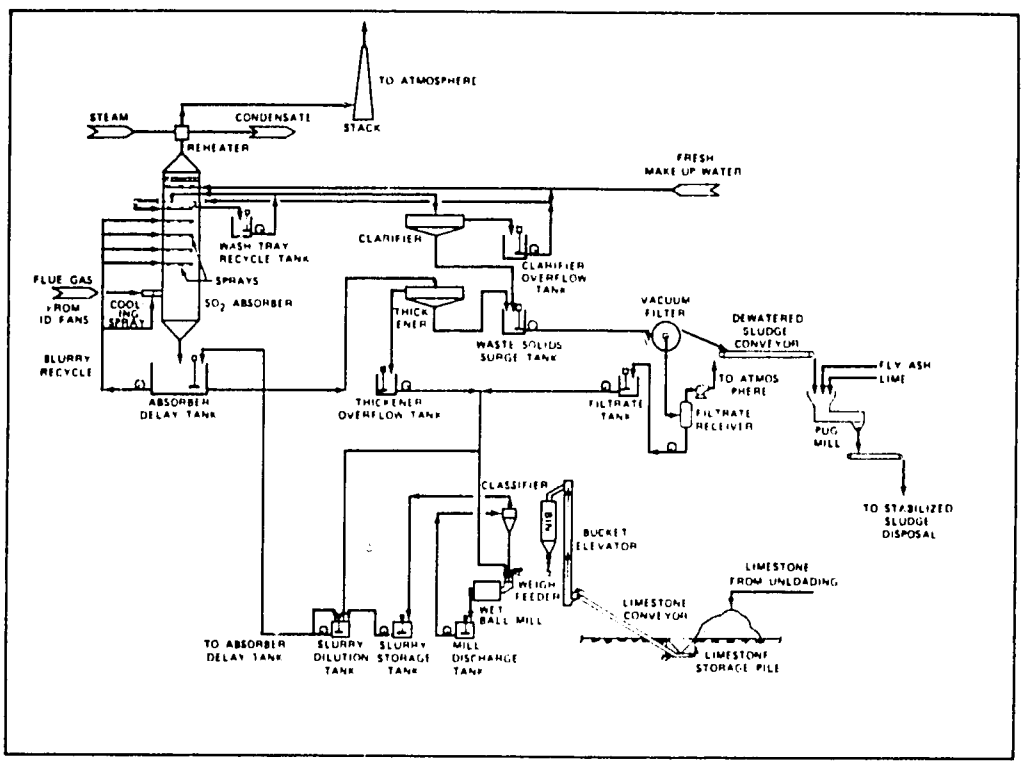


FIGURE 27. Flue gas desulfurization-Limestone process.
(Source: Electric Power Research Institute, EPRI PE 1865)

There are several major problems with flue gas desulfurization processes including high capital cost ($ 55-145/kilowatt-hour), high maintenance due to plugging of the scrubbers and large amounts of solid waste (scrubber sludge). Progress is being made on increasing the capture efficiency of the lime and limestone and developing better methods for regenerating the sorbent materials. Unfortunately these methods are not currently price competitive and more emphasis is being placed on using low sulfur coals or using higher levels of coal preparation to remove most of the sulfur.

Collection and Disposal of Wastes

Bottom ash, fly ash and scrubber sludge are produced in large quantities at electrical generating facilities and collection and disposal facilities are required. Bottom ash is collected from the bottom of the furnace and quenched in water impounded hoppers. The quenched ash is then reduced in size by a clinker grinder to facilitate transport by jet or centrifugal pumps to disposal areas.

Fly ash is collected in hoppers located below the fabric filter baghouse or precipitator and air heaters. Vacuum , pressure and/or conveyor systems are used to transport the fly ash to storage bins for offsite use. Water is often

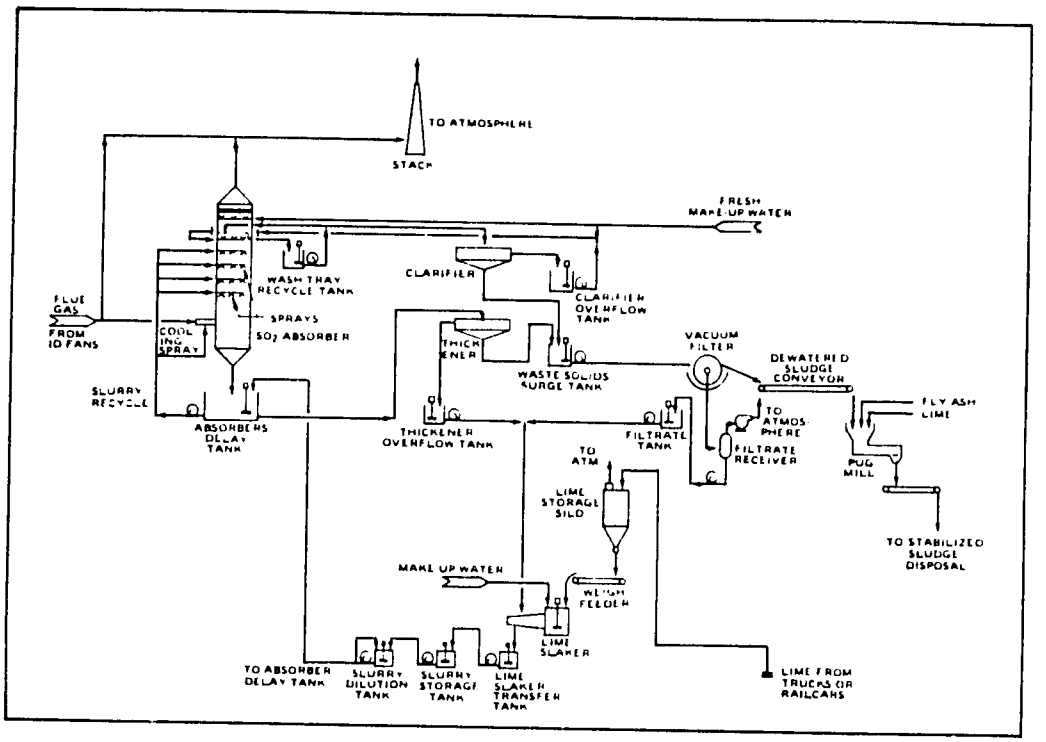


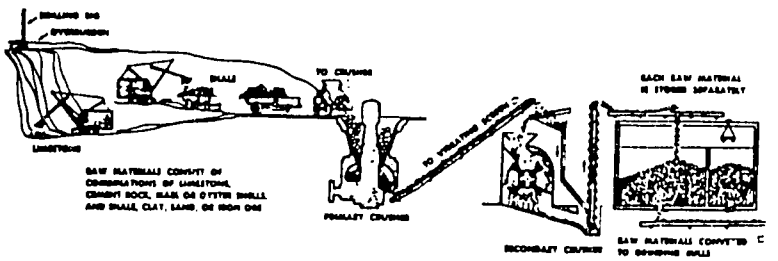
FIGURE 28. Flue gas desulfurization-Lime process.
(Source: Electric Power Research Institute, EPRI PE 1865, 1981)

mixed with the fly ash for transport to ash storage ponds or onsite disposal area. The ash storage ponds are generally used for scrubber sludge (spent lime or limestone) and bottom ash disposal.

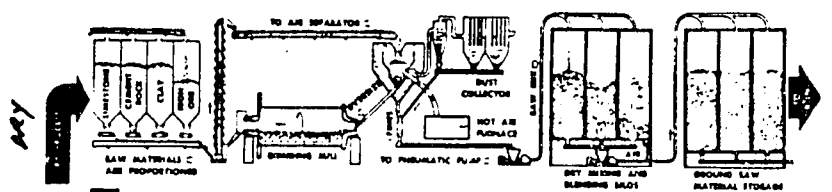
TECHNOLOGIES-CEMENT

Cement is produced by firing a mixture of limestone, cement rock or oyster shells with shale, clay, sand or iron ore. The firing takes place in a rotary kiln which produces "clinkers" that are ground with gypsum to produce the final product. Pulverized coal is the heat source for about 90 percent of the cement produced in the U.S. The steps involved in cement production are quarrying and crushing of raw materials, blending raw materials, pyroprocessing in a rotary kiln and grinding of the clinkers. These steps are depicted in Figure 29 for a typical plant producing 1100 tons of cement/day.

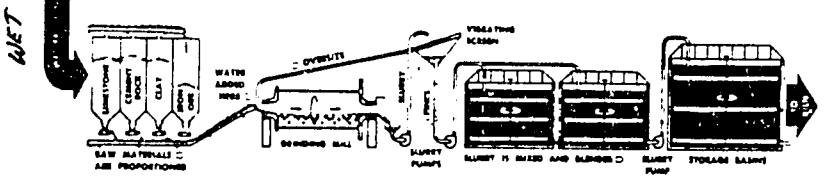
The required calcium oxide (about 65 percent) comes from limestone and the silica and alumina are derived from clay, shale or the overburden at the limestone quarry. If iron ore is not present in these materials, mill scale, pyrite cinders or iron ore can be added. Industrial products such as slag and fly ash contain carbonate free lime, silica and alumina and may also be used. These raw materials or industrial wastes are ground in primary and secondary crushers to a top size of 0.4-1.0 inches. For wet materials, kiln gases may be employed for drying during crushing. The ground materials are stored separately in bins and proportioned to a grinding mill for blending into a homogeneous fine powder. This fine powder can be stored dry (dry process) or made into a slurry (wet process) and then stored.



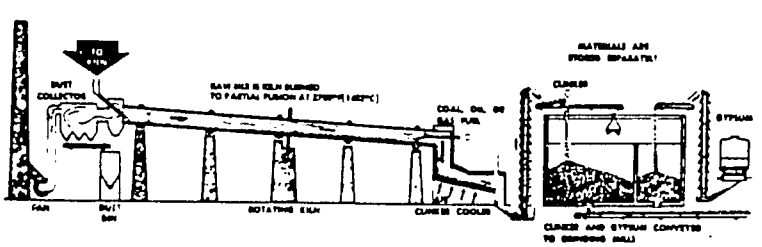
1 Stone is first reduced to 5-in [127 mm] size, then 3/4 in [19.05 mm] and stored



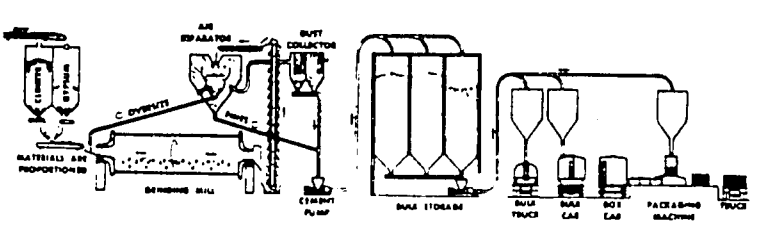
2 Raw materials are ground to powder and blended, or



2 Raw materials are ground, mixed with water to form slurry, and blended



3 Burning changes raw mix chemically into cement clinker



4 Clinker with gypsum added is ground into portland cement and shipped

FIGURE 29. How cement is produced.
(Source: C. Redman, ANL, March 1983)

In wet process kilns, the slurry is introduced into the feed end where it undergoes heating and drying. Chains are often used in the kiln to promote heat transfer and evaporation of the slurry fluids. The chains also break up the slurry into nodules that flow more readily down the kiln. After most of the moisture has been evaporated, the nodules move down the kiln, gradually heating to about 1010°F. Calcination and clinker formation occur as the nodules move toward the firing end of the kiln.

Kilns, suspension preheaters and precalciners may be used in the dry process. Conventional dry process kilns operate in basically the same manner as wet kilns; however, drying is not necessary. Additional refractory heat-recuperative devices, such as crosses, lifters and trefoils, may be utilized. Although the older dry process kilns were shorter, there is little difference in size between the newer wet and dry kilns. In suspension preheaters, the dry pulverized feed passes through a series of cyclones where it is separated and preheated several times. This partially calcines the feed which enters the kiln at 1470-1650°F. The kiln used in this method is much shorter and has an excellent heat exchange. These kilns are also very efficient (1334 Btu/lb. of clinker). Preheating can cause objectionably high alkali and sulfur in the clinker and kiln exit gases may have to be bypassed which reduces efficiency.

Precalciner systems permit the use of smaller kilns, since only clinkering is carried out in the kiln. Energy efficiency is about the same as the suspension preheater; however, there is little or no penalty associated with the bypass of kiln exit gases. In Japan, these kilns can produce up to 11,000 tons of clinker/day as compared with 3,270 tons/day for the largest long wet process kiln.

Following discharge to the clinker cooler, the clinkers are conveyed to storage or mixed with 4-6 percent gypsum and ground to a fine powder in a finish mill. The finished product is packaged or stored for shipping.

TECHNOLOGIES-STEEL PRODUCTION

The production of steel involves several steps including coal preparation, blending, carbonization, coke quenching, pig iron production and steel production. Coal preparation and blending technologies have been described earlier. Briefly, ash and sulfur levels must be very low and this requires Level IV preparation. Usually low and high volatile bituminous coals are blended together to achieve optimum coking coal characteristics. These blended coals are pulverized to 75-80 percent passing through 0.10 inch mesh. The prepared, blended coal is stored in larry cars above the carbonization ovens.

Carbonization

Carbonization is the distructive distillation of coal in the absence of air. The blended coal is fed into slot-type coke ovens (Figure 28) where it is exposed to temperatures of 1650-2190°F for 16-22 hours. The slot-type ovens alternate with flues that impart heat to the ovens. The oven chambers are about 46 feet long by 20 feet high and about 1.5 feet wide. Each chamber holds over 30 tons of coal and there can be up to 100 chambers per oven. The ovens operate continually over their lifetime (20-40 years). The volatile gases released from the coals during carbonization are drawn off and combusted in the flues to provide the needed heat. The flue temperatures may reach 2500°F and the chamber walls 2190°F.

The coals located next to the chamber walls undergo carbonization first. The coal particles initially melt, then fuse, devolatilize and solidify. The conducted heat causes a slow progression of these reactions toward the center

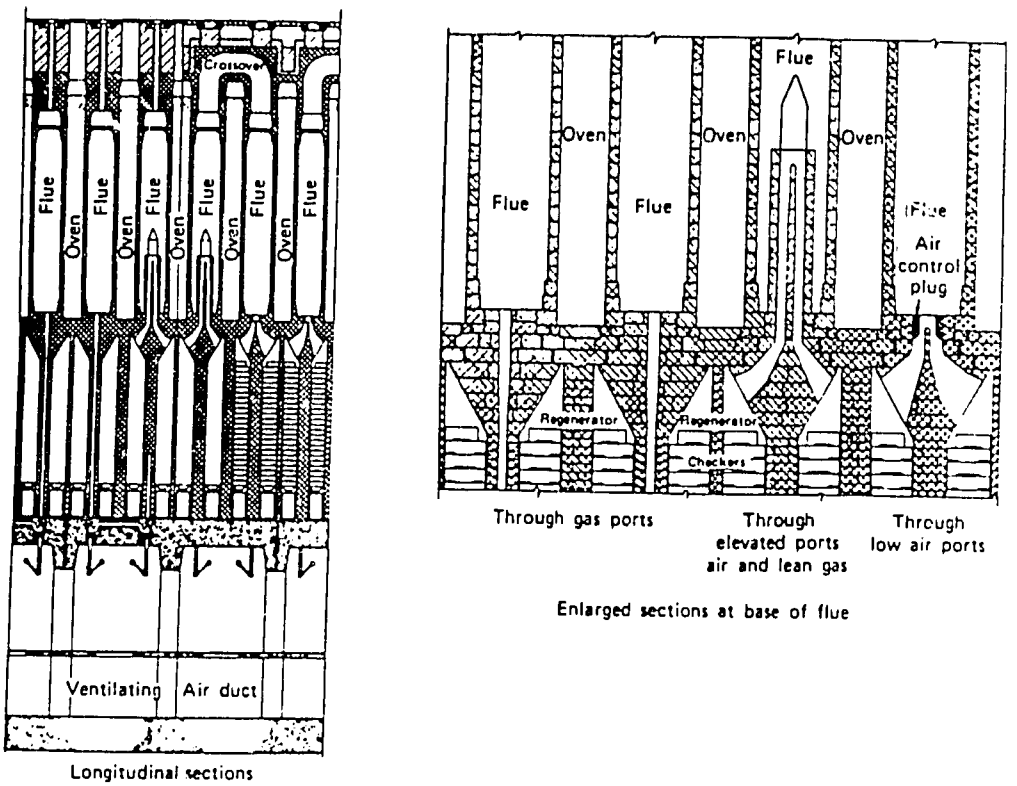


FIGURE 28. Slot-type coking ovens.
(Source: C. Redman, ANL, March 1983)

of the chamber. Once the coal has been converted to coke (essentially carbon plus ash) it is discharged from the chamber.

Quenching

The coke is discharged, by pusher rams, through the removable self-sealing doors located at the ends of the chambers. This "pushing" and the subsequent "charging" of the chamber is done by some predetermined time and spacing pattern. The coke is pushed into cars mounted on rails for transport to a quenching station. At the quenching station the coke is sprayed with about 260 gallons of water to cool it below its ignition temperature. The quenched coke is then spread on a brick wharf for further cooling. After cooling, the coke is screened to separate it into sizes suitable for blast furnace feed (~1 x 3 inches) and iron ore sintering and boiler firing (< 1 inch).

Pig Iron Production

Coke, iron bearing material, limestone and air are combined in blast furnaces (Figure 29) to produce pig iron. The blast furnace may have a hearth 46 feet in diameter and 197 feet in height, and a daily production rate of 10,000 tons. The materials are added from the top of the furnace, with the coke providing support for the iron-bearing materials and limestone. The pre-heated air from the bottom of the furnace burns the coke, providing the heat and reducing gases needed to convert the iron-bearing materials to a fluid state. These fluids flow to the bottom of the furnace where the pig iron is separated from the slag and transported via a ladle car to the steel making

furnace. Approximately 960 lbs of coke are required for each ton of pig iron produced.

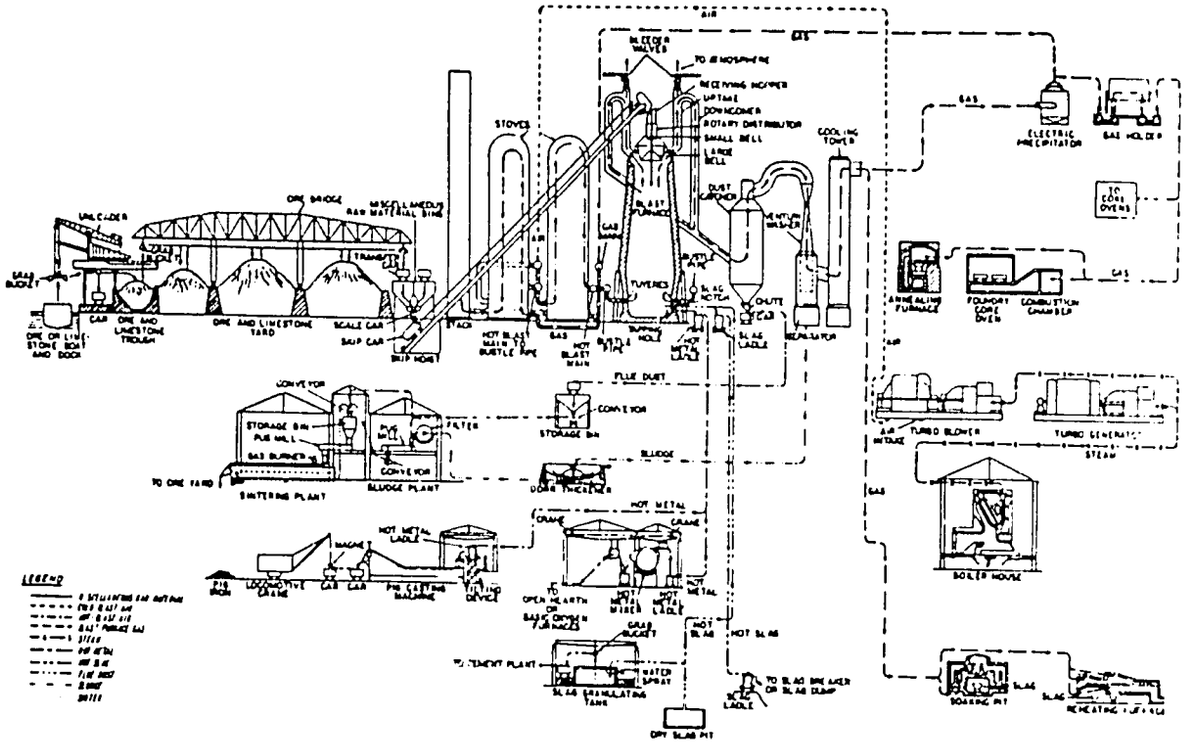


FIGURE 29. Blast furnace operations. (Source: C. Redman, ANL, March 1983.

Steel Production

The basic steps in producing steel are 1) the refinement of the molten pig iron, 2) charging the open-hearth furnace with limestone, iron ore and scrap, 3) heating this mixture, 4) adding the molten pig iron to the hearth mixture, and 5) oxidation of the molten materials to produce steel. The hearth (Figure 30) is a shallow rectangular basin that is heated by burning liquid or gaseous fuels. These hearths can produce 100-600 tons of steel in about 10 hours. The liquid steel is drained from the hearth into a steel ladle and then into molds from the nozzle at the base of the ladle.

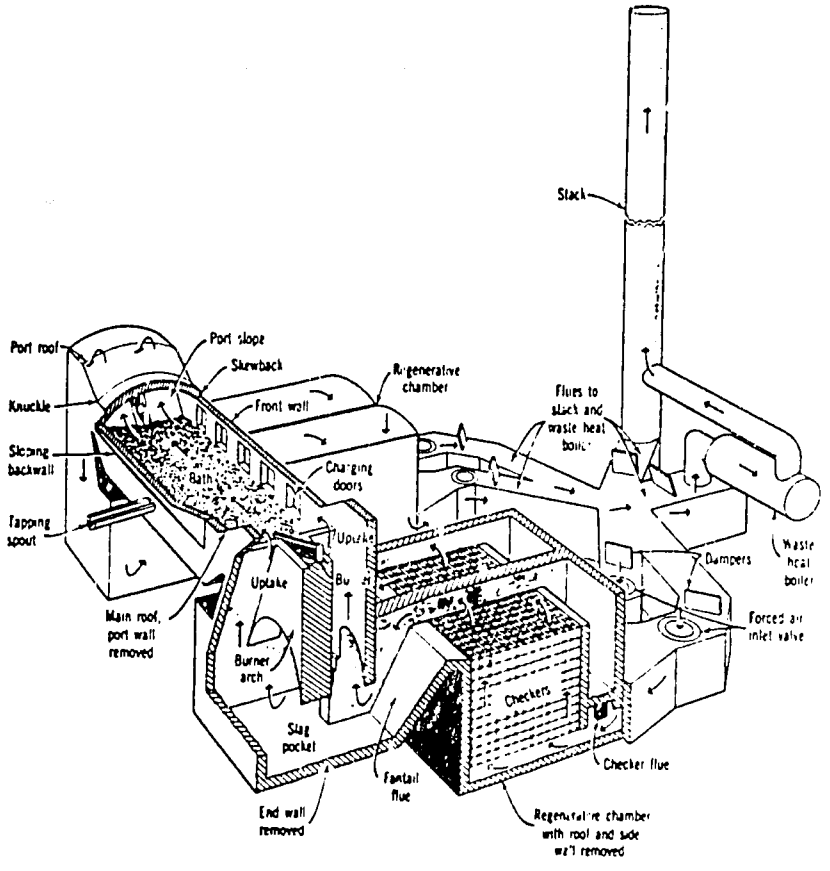


FIGURE 30. Open-hearth furnace for steel production. (Source: C. Redman, ANL, March 1983).

ECONOMIC CONSIDERATIONS

The production of steam for electricity generation is the major application of coal throughout the world. Capital investment, fuel and operating costs for producing this electricity are mainly a function of the type and size of coal-firing systems and coal rank and quality.

Current coal prices favor pulverized coal-firing systems and, therefore, they are the most commonly used. Stoker firing systems are too inefficient, at the larger steam production levels required for central electric generating stations, to be cost competitive with pulverized firing systems. Fluidized bed combustors and integrated gasification-combined cycle systems are attractive from a technological and environmental perspective; however, these technologies are currently under development and will not be available for commercial application until the 1990's. These two technologies are less sensitive to coal rank and quality and emit significantly less pollutants to the atmosphere than current pulverized firing systems. Comparative cost projections for these three systems in Table 36, indicate that inspite of lower coal costs and pollution abatement equipment costs, fluidized bed combustor and integrated gasification-combined cycle systems are more costly.

Detailed operating and coal and capital investment costs for 100 and 300 MWe pulverized coal-fired sytems are shown in Tables 37 and 38, repectively.

TABLE 36. COMPARATIVE COSTS FOR THREE TYPES OF COAL-FIRED POWER PLANTS[a].

COSTS	PULVERIZED FIRING	PRESSURIZED FLUIDIZED BED	INTEGRATED GASIFICATION
Total Capital	$ 5.0 x 10^8	$ 6.0 x 10^8	$ 5.5 x 10^8
Specific Capital ($/kWh)	995	1,130	1,150
Annual O&M, levelized	$ 2.7 x 10^7	$ 3.9 x 10^7	$ 3.1 x 10^7
Annual Coal, levelized	$ 6.6 x 10^7	$ 6.2 x 10^7	$ 5.9 x 10^7
Cost of Electricity (mills/kWh)	45.9	48.6	48.1

Source: Argonne National Laboratory, ANL/FE 83-9, 1983.
[a] Plants have a nominal rating of 500 MWe and use bituminous coal.

Economies of scale are obvious in these costs, since a tripling of output is achieved at roughly a doubling of costs. Direct capital, indirect capital, contingency and money costs represent about 49, 25, 10 and 26 percent of the total capital investment for each unit size. Equipment, labor and materials are approximately 52, 30 and 18 percent of direct capital costs for the 100 MWe unit and 54, 30 and 16 percent for the 300 MWe unit. Fuel costs represent about 38 and 56 percent of the annual expenses for the 100 and 300 MWe units, respectively, and account for over 74 percent of the increased annual expenses for the 300 MWe unit.

TABLE 37. ANNUAL OPERATING AND FUEL COSTS FOR TYPICAL 100 AND 300 MWe POWER PLANT UNITS UTILIZING BITUMINOUS COAL.

COST CATEGORY	MILLIONS OF 1983 DOLLARS 100 MWe	300 MWe
Operating and Maintenance Costs		
Labor	6.0	8.2
Maintenance Materials	2.2	3.0
Supplies and Expenses	3.0	3.8
Limestone	0.4	1.1
Waste Disposal	0.4	1.1
Total Operating Costs	12.0	17.2
Coal Costs	7.4	22.1
Total Operating and Coal Costs	19.4	39.3

Source: E. Fox, Oak Ridge National Laboratory, March 1983.

TABLE 38. DETAILED CAPITAL INVESTMENT COSTS FOR 100 AND 300 MWe POWER PLANTS FIRED WITH PULVERIZED COAL.

COST CATEGORIES	MILLIONS OF 1983 DOLLARS 100 MWe	300 MWe
Direct Capital Costs		
Land and Land Rights	5.0	5.0
Structures and Improvements	23.7	44.0
Boiler Plant	77.8	151.1
Turbine Plant	26.7	61.1
Electric Plant	18.9	33.0
Heat Rejection System	3.7	10.4
Miscellaneous Plant	9.8	12.9
Total Direct Costs	165.6	317.5
Indirect Capital Costs		
Construction Services	14.4	28.0
Home Office Engineering	9.8	18.4
Field Office Engineering	6.7	14.5
Owner's Cost	19.0	37.6
Total Indirect Costs	49.9	98.5
Contingency	31.7	61.8
Money Costs	89.0	171.0
TOTAL CAPITAL INVESTMENT	336.2	548.8

Source: E. Fox, Oak Ridge National Laboratory, March 1983.

Flue gas desulfurization and precipitator systems are generally required to control SO_2 and particulate emissions, particularly in larger urban areas. As indicated in Table 39, these systems can account for as much as 24 percent of the direct capital costs. Therefore, substantial savings in plant costs are possible if the units can be sited in areas not requiring emission abatement equipment.

Table 40 contains data showing the relationship between coal rank and quality and steam generator and desulfurization costs. These data are from 15 operating 1000 MWe plants in the U.S. Steam generator and desulfurization costs decrease significantly with increased heating value and decreased sulfur content. A steam generator designed for lignite can cost over $ 24 million more than one designed for bituminous coal. Desulfurization costs, on the other hand, typically increase $ 13-14 million for each additional percentage point of sulfur over one percent. Therefore, considerable cost savings can be achieved by using coal with a high heating value and a low sulfur content. Unfortunately, naturally occuring coals that satisfy these requirements are

101

TABLE 39. CAPITAL COSTS FOR EMISSION CONTROL EQUIPMENT FOR TYPICAL 100 AND 300 MWe POWER PLANT UNITS UTILIZING BITUMINOUS HIGH SULFUR COAL.

EQUIPMENT/MATERIALS	MILLIONS OF 1983 DOLLARS 100 MWe	300 MWe
Scrubber	19.3	37.5
Precipitator	5.7	11.3
Lime Feed	5.3	10.5
Waste Disposal	8.6	16.5
Total Costs	38.9	75.8
Percent of Total Direct Capital Costs	23.5	23.9

Source: E. Fox, Oak Ridge National Laboratory, March 1983.

rare and coal cleaning is generally required to either increase the heating value or decrease the sulfur.

TABLE 40. EFFECTS OF COAL RANK AND QUALITY ON STEAM GENERATOR AND FLUE GAS DESULFURIZATION COSTS[a].

HEATING VALUE (Btu/lb) Average	Range	STEAM GENERATOR COSTS (10^6 Dollars) Average	Range
6,230	5,790-6,670	131.9	129.3-134.5
7,955	7,400-8,250	118.7	114.4-134.5
9,515	8,570-9,450	110.4	107.0-121.4
10,490	9,860-11,510	107.4	107.2-107.9
11,905	11,680-12,130	106.8	106.3-107.2
SULFUR CONTENT (percent) Average	**Range**	**DESULFURIZATION COSTS (10^6 Dollars) Average**	**Range**
0.5	0.2-1.0	82.3	73.7-91.0
1.0	0.5-1.3	84.1	77.4-91.0
2.5	1.0-3.4	106.8	91.0-118.9
3.5	3.4-4.0	119.6	117.2-124.1
5.5	4.0-6.9	146.6	124.1-169.1

Source: Electric Power Research Institute, EPRI-PE 1865, 1981.

ENVIRONMENTAL CONSIDERATIONS

Major impacts to land, water and air result from the utilization of coal, particularly large coal-fired electrical generating stations. The impacts can result in land use conflicts, groundwater and surface water contamination, surface water quality deterioration, reduced biological productivity, acid-rain and increased incidence of lung diseases or illnesses.

Land

As shown in Table 41, significant amounts of land are required for station facilities, coal storage, ash and sludge disposal and heat dispersal. If ash and sludge are not removed from the site periodically for offsite burial or use, as much as 66-168 acres of land would be needed over a 30 year plant lifetime. All the site property is essentially removed from other productive uses (e.g., agricultural and recreational) for as long as the plant operates. Animals residing in the area prior to the station are either destroyed or displaced to contiguous habitats. Generally, the alteration of land use patterns by a given power plant is not a major problem unless agricultural or recreational acreage is limited or protected biological species are involved.

The storage of ash and sludge onsite can be a problem if soils are quite permeable. High concentrations of toxic metals (e.g., cadmium, mercury, lead, selenium, etc.) are often associated with this material and in permeable soils these can reach groundwaters and local surface waters. This can create health hazards or deterioration in surface water quality if proper mitigative measures, such as the use of lining materials (e.g., bentonite and plastic), are not employed. When human drinking water supplies or surface waters with important fishery resources are likely to be adversely affected, the storage ponds should be lined or the ash and sludge moved to more suitable disposal areas (e.g., mined out areas and landfills).

Water

Large quantities of water are also required to dissipate the heat from the steam, after it passes through the turbines. Usually, this is done by once-through cooling in areas where water is abundant and of good quality. When water is limited or of poor quality, closed-cycle cooling is employed. Once-through cooling consumes no water, while water is lost by evaporation in closed-cycle systems. The heat and biocides (used to keep the walls of the condenser free from slime) discharged to surface waters can result in some localized impacts if water flow is limited and mixing poor. Careful attention to discharge design and location can avoid most serious problems.

Entrainment of eggs and larvae of fishery species through the condenser typically results in 100 percent mortality in closed-cycle systems and 80-90 percent in open-cycle systems. Therefore, care should be taken not to locate the intake structure in areas of high biological productivity (e.g., breeding, feeding and nursery areas). Impingment of young-of-the-year, of important fishery species, on the intake water screens is a common occurrence. In

TABLE 41. ENVIRONMENTAL IMPACT SOURCE LEVELS FOR 100, 300 AND 500 MWe COAL-FIRED POWER PLANTS.[a]

IMPACT SOURCE	100 MWe	300 MWe	500 MWe
Land Requirements (acres)			
Station (fixed)	72.5	131.5	183.0
Coal Storage (fixed)	3.6	5.2	7.0
Ash Disposal (annual)	1.1	1.9	2.8
Sludge Disposal (annual)	1.1	1.9	2.8
Waste Heat Dispersal			
Cooling Towers (fixed)	2.8	7.6	11.6
Cooling Ponds (fixed)	100-200	300-600	500-1000
Annual Water Requirements (tons)			
Closed Cycle Cooling	1.0×10^6	3.0×10^6	5.0×10^6
Open Cycle Cooling	8.2×10^7	2.4×10^8	4.1×10^8
Waste Disposal			
With Recycle	2,100	6,400	11,000
Without Recycle	16,000	47,000	78,000
Annual Air Emissions (tons)			
Sulfur Dioxide			
With Scrubbers	1,600	5,000	8,200
Without Scrubbers	11,000	33,000	55,000
Particulates			
With Precipitator	75	225	375
Without Precipitator	15,000	45,000	75,000
Annual Heat Rejection (Btu's)			
Surface Waters	2.4×10^{12}	8.3×10^{12}	1.2×10^{13}
Atmosphere	0.5×10^{12}	1.7×10^{12}	2.6×10^{13}

Source: U.S Department of Interior, FWS/OBS-78/29, 1978.

[a] Bituminous coal with heating value of 11,400 Btu's/lb, sulfur content of 3.5 percent and ash content of 10 percent.

addition to causing serious impacts to the fishery, this can result in station shutdown to remove fish or shellfish from the screens. Again these potential problems can be minimized if the intake structure is not located in biologically productive areas.

Air

Sulfur dioxide, nitrogen oxides, carbon dioxide and particulates (fly ash) are discharged to the atmosphere from the power plant stack. Sulfur dioxide and nitrogen oxides can combine with precipitation to form acid-rain. This acid-rain can decrease the productivity of affected crops or forests by destroying

plant tissues. In a few cases, this type of rain has been known to reduce the pH in small lakes to levels unsuitable to biological life. Because these oxides are transported great distances, the impacts are often several miles away from the plant and may actually occur in other states or countries. Acid-rain is usually only a problem were air quality has deteriorated significantly; however, it is advisable to use low sulfur coal or flue gas desulfurization to minimize these impacts.

Carbon dioxide may contribute somewhat to acid-rain; however, its affect on atmospheric heat is more important. As carbon dioxide levels increase with greater reliance on fossil fuels, less of the Earth's surface heat may escape the atmosphere and this could cause a gradual increase in temperature. If the ocean is not able to buffer this additional carbon dioxide, it is possible that the resultant climatic changes could significantly affect regional crop production and coastal water levels. There is little that can be done at any given power station to mitigate the carbon dioxide production. If there should be a potential for serious effects, the use of fossil fuels, in general, will have to be limited.

Particulates are of particular concern because of potential human health impacts. These particulates are small enough to be respirable and can cause physical damage to lung tissues with prolonged exposure. This is especially true for humans with chronic respiratory ailments (e.g., pulmonary emphysema). In addition to causing physical damage to lung tissues, toxic metals adhere to the surface of the particulates and are readily absorbed from the lung tissues into the bloodstream. These toxic substances can concentrate in various tissues and organs, possibly causing deterioration or cancer. Therefore, it is important that precipitators be used in areas of high population density and/or poor air quality.

105

PART III

BIBLIOGRAPHY

BIBLIOGRAPHY

GENERAL

International Energy Agency. 1983. Coal: Environmental Issues and Remedies. Organisation for Economic Co-operations and Development. Paris, France.

International Energy Agency. 1982. World Energy Outlook. Organisation for Economic Co-operation and Development. Paris, France.

Meyers, R.A. 1981. Coal Handbook Marcel Dekker, Inc., New York, New York.

Oxley, J.H., et al. 1981. "Getting Back to Coal: Some Problems, Options and Opportunities: Overview, Switching to Coal, Coal Cleaning and Fluidized-Bed Combustion". Review Number 3. Battelle Memorial Institute, Columbus, Ohio.

Zimmerman, M.B. 1981. The U.S. Coal Industry: The Economics of Policy Choice. MIT Press, Cambridge, Massachusetts.

Considine, D.M. 1980. Energy Technology Handbook. McGraw-Hill Ryerson, Ltd., Ontario, Canada.

Green, A.E.S. 1980. Coal Burning Issues. University Presses of Florida, Gainesville, Florida.

Tatsch, J.H. 1980. "Coal Deposits: Origin, evolution and Present Characteristics". Tatsch Associates, Sudbury, Massachusetts.

Wilson, C.L. 1980. Coal: Bridge to the Future: World Coal Study. Ballinger Publishing Company, Cambridge, Massachusetts.

Berkowitz, N. 1979. An Introduction to Coal Technology. Academic Press, New York, New York.

Murdoch, S.H. 1979. "Demographic and Community Service Impacts of Coal Utilization in Rural Areas: An Examination of the Case of Fayette County, Texas". Technical Report Number 79-1. Agricultural Experimental Station, Texas A&M University, College Station, Texas.

Office of Technology Assessment. 1979. "The Direct Use of Coal: Prospects and Problems of Production and Combustion". U.S. Congress. U.S. Government Printing Office, Washington, DC.

Karr, C. 1978. Analystical Methods for Coal and Coal Products. Volumes 1-3. Academic Press, New York, New York.

Krutilla, J.V., et al. 1978. Economic and Fiscal Impacts of Coal Development: Northern Great Plains. Johns Hopkins Univ. Press, Baltimore, Maryland. University of Oklahoma Science and Public Policy Program. 1975. "Energy Alternatives: A Comparative Analysis". U.S. Government Printing Office, Washington, DC.

EXPLORATION

Argall, G.O. 1981. Coal Exploration: Proceedings of the Third International Coal Exploration Symposium. Volume 3. Miller Freeman Publications, Inc., San Francisco, California.

Argall, G.O. 1979. Coal Exploration: Proceedings of the Second International Coal Exploration Symposium. Volume 2. Miller Freeman Publications, Inc., San Francisco, California.

Muir, W.L. 1976. Coal Exploration: Proceedings of the First International Coal Exploration Symposium. Volume 1. Miller Freeman Publications, Inc., San Francisco, California.

MINING

International Energy Agency. 1983. Coal and Environmental Costs and Costing Methods. Organisation of Economic Co-operation and Development, Paris, France.

Fung, R. 1982. "Surface Coal Mining Technology: Engineering and Environmental Aspects". Noyes Data Corp., Park Ridge, New Jersey.

Church, H.K. 1981. Excavation Handbook. McGraw-Hill, Inc., New York, New York.

National Research Council. 1981. Surface Mining: Soil, Coal and Society. National Academy Press, Washington, DC.

Coal Age. 1980. Operating Handbook for Underground Mining. Volume II. McGraw-Hill, Inc., New York, New York.

Chironis, N.P. 1980. Training Manual for Miners: Underground Mining. Volume 1. McGraw-Hill, Inc., New York, New York.

Chironis, N.P. 1980. Training Manual for Miners: Surface Mining. Volume 2. McGraw-Hill, Inc., New York, New York.

Stout, K.S. 1980. Mining: Methods and Equipment. McGraw-Hill, Inc., New York, New York.

Berkshire, L.H. 1979. "Basic Estimated Capital Investment and Operating Costs for Subbituminous and Lignite Strip Mines". Report Number FE/EES-79/6. U.S. Department of Energy, Morgantown, West Virginia.

Rowe, J.E. 1979. Coal Surface Mining Impacts of Reclamation. Westview Press, Boulder, Colorado.

Schmidt, R.A. 1979. Coal in America: An Encyclopedia of Reserves, Production and Use. McGraw-Hill, Inc., New York, New York.

Coal Age. 1978. Operating Handbook of Surface Mining. McGraw-Hill, Inc., ıw York, New York.

Duda, J.R. 1978. "Basic Estimated Capital Investment and Operating Costs for Underground Bituminous Coal Mines Utilizing a Continuous Mining System". Report Number FE/EES-79/1. U.S. Department of Energy, Morgantown, West Virginia.

Coal Age. 1977. Operating Handbook for Underground Mining. McGraw-Hill, Inc., New York, New York.

Duda, J.R. and E.L. Hemingway. 1976. "Basic Estimated Capital Investment and Operating Costs for Underground Bituminous Coal Mines Developed for Longwall Mining". Report Number IC 8720. U.S. Department of Energy, Morgantown, West Virginia.

Howley, M.E. 1976. Coal: Social, Economic and Environmental Aspects. Academic Press, New York, New York.

PREPARATION

Moyers, J.C. 1983. "Coal Preparation Plant Automation". Noyes Data Corp., Park Ridge, New Jersey.

Tsai, S.C. 1982. Fundamentals of Coal Beneficiation and Utilization. Elsevier Scientific Publishing Company, New York, New York.

Killmeyer, R.P and R.E. Hucko. 1980. "Coal Preparation". U.S. Department of Energy, Pittsburgh, Pennsylvania.

PEDCo Environmental, Inc. 1980. "Cost Benefits Associated with the Use of Physically Cleaned Coal". Report Number EPA-600/7-80-105. Environmental Protection Agency, Research Triangle Park, North Carolina.

Coal Age. 1979. Operating Handbook of Coal Preparation. Volume III. McGraw-Hill, Inc., New York, New York.

Eliot, R.C. 1978. "Coal Desulfurization Prior to Combustion". Noyes Data Corp., Park Ridge, New Jersey.

TRANSPORTATION

Leeper, J.H. and M.E. Tomassoni. 1982. Coal Exports and Port Development: A Technical Memorandum of the Office of Technology Assessment. Cornell Maritime Press, Centreville, Maryland.

Manalytics, Inc. 1979. "Cost Models for Coal Transportation by Common Carrier". Report Number EPRI EA 695. Electric Power Research Institute, Palo Alto, California.

National Research Council, 1979. Critical Issues in Coal Transportation Systems. National Academy Press, Washington, DC.

101

Baumel, C.P., et al. 1978. "Economics of Alternative Coal Transportation and Distribution Systems in Iowa". Agricultural and Home Economics Experiment Station, Iowa State University, Ames, Iowa.

Szabo, M.E. 1978. "Environmental Assessment of Coal Transportation". U.S. Environmental Research Laboratory, Cincinnati, Ohio.

Hood, R. and T.G. White. 1977. "Coal Transportation Study, Final Report". Report Number COO/2970-1. Department of Energy, Washington, DC.

Campbell, T.C. and S. Katell. 1975. "Long Distance Coal Transport: Unit Trains or Slurry Pipelines". Report Number IC 8690. Bureau of Mines, Washington, DC.

CONVERSION

Krantz, W.B. and R.D. Gunn. 1983. Underground Gasification: The State of the Art. Volume 79. American Institute of Chemical Engineering, New York, New York.

International Energy Agency. 1982. Coal Liquefaction: A Technology Review. Organisation for Economic Co-operation and Development, Paris, France.

Braunstein, H.M., et al. 1981. Environmental, Health and Control Aspects of Coal Conversion: An Information Overview. Volumes 1 and 2. Ann Arbor Science Publications, Ann Arbor, Michigan.

Nowacki, P. 1981. "Coal Gasification Processes". Noyes Data Corp., Park Ridge, New Jersey.

Whitehurst, D.D., et al. 1980. Coal Liquefaction: The Chemistry and Technology of Thermal Processes. Academic Press, New York, New York.

Kasem, A. 1979. Technology and Economics of Three Clean Fuels from Coal. Marcel Dekker, Inc., New York, New York.

Nowacki, P. 1979. "Coal Liquefaction Processes". Noyes Data Corp., Park Ridge, New Jersey.

Wen, C.Y., et al. 1979. Coal Conversion Technology. Addison-Wesley Publishing Company, Reading, Massachusetts.

Predicasts, Inc. 1978. "Coal Gasification and Liquefaction". Predicasts, Inc., Cleveland, Ohio.

International Energy Agency. 1977. Potential Environmental Impacts from the Production of Synthetic Fuels from Coal. Organisation for Economic Co-operation and Development, Paris, France.

Lamb, G.H. 1977. "Underground Coal Gasification". Noyes Data Corp., Park Ridge, New Jersey.

110

UTILIZATION

Shannon, R.H. 1983. Handbook of Coal-Based Electric Power Generation: The Technology, Utilization, Application and Economics of Coal for Generating Electric Power. Noyes Data Corp., Park Ridge, New Jersey.

Argonne National Laboratory and Bechtel Group, Inc. 1983. "Design of Advanced Fossil Fuel Systems (DAFFS): A Study of Three Developing Technologies for Coal-Fired, Base-Loaded Electric Power Generation". Report Number ANL/FE 83-9. Argonne National Laboratory, Argonne, Illinois.

Chadwick, M.J. and N. Lindemann. 1982. Environmental Implications of Expanded Coal Utilization. Pergamon Press, Inc., Elmsford, New York.

International Energy Agency. 1982. The Use of Coal in Industry. Organisation for Economic Co-operation and Development, Paris, France.

Lord, N.W., et al. 1982. Coal-Oil Mixture Technology. Ann Arbor Science Publishers, Ann Arbor, Michigan.

Bechtel Power Corporation. 1981. "Coal-Fired Power Plant Capital Cost Estimates". Report Number EPRI PE 1865, TPS 78-810. Electric Power Research Institute, Palo Alto, California.

Elliot, M.A. 1981. The Chemistry of Coal Utilization. Supplementary Volume 2. Wiley Interscience, New York, New York.

Grainger, L. and J. Gibson. 1981. Coal Utilisation: Technology, Economics and Policy. Halsted Press, Division of John Wiley and Sons, Inc., New York, New York.

Singer, J.G. 1981. Combustion: Fossil Power Systems. Combustion-Engineering, Inc., Windsor, Connecticut.

Singh, J. and A. Deepah. 1980. Environmental and Climatic Impact of Coal Utilization. Academic Press, New York, New York.

Soholt, L.F., et al. 1980. "Handling of Combustion and Emission Abatement Wastes from Coal-Fired Power Plants: Implications for Fish and Wildlife Resources". Report Number FWS/OBS-80/33. U.S. Department of Interior, Washington, DC.

Wilson, R. 1980. Health Effects of Fossil Fuel Burning: Assessment and Mitigation. Ballinger Publishing Company, Cambridge, Massachusetts.

Dvorak, A.J., et al. 1978. "Impacts of Coal-Fired Power Plants on Fish, Wildlife and Their Habitats". Report Number FWS/OBS-78/29. U.S. Department of Interior, Washington, DC.

Babcock and Wilcox. 1978. Steam: Its Generation and Use. Babcock and Wilcox, New York, New York.

Yaverbaum, L. 1977. "Fluidized Bed Combustion of Coal and Waste Materials". Noyes Data Corp., Park Ridge, New Jersey.

EQUIPMENT

Chironis, N.P., et al. 1982. Coal Age: Equipment Guide. McGraw-Hill, Inc., New York, New York.

Coal Age: Buyer's Guide. McGraw-Hill, Inc., New York, New York. 1981.

112

PART IV

WORK SESSIONS

Mining
Preparation
Transportation
Plant Applications

MINING WORK SESSION

General Instructions

As a team, you are to consider, discuss, and determine the following items:

1. The type of mining operation to be established.

2. Production considerations, such as equipment required and its availability, energy requirements and its availability, work force areas needed for waste and spoil piles, movement of materials and personnel, water-related problems, societal factors, etc.

3. Regulation, such as government policies and permits, inspections.

4. Schedule for devvelopment of the mining operation and its expected lifetime.

5. Provision for worker safety, such as ventilation, support of roof, dust control, and fire prevention and control.

6. Environmental factors, such as temporary storage of material removed from the mine, effects of weather (for example, erosion, silting of streams, leaching of acids from waste piles), effects of blasting, and reclamation of the land.

In your evaluation, you may assume reasonable values for any parameters required as a basis for a decision. However, you should be able to justify and explain your choices in follow-on discussions with members of the teams assigned to other scenarios in the working sessions for mining. Be aware that there are no predetermined or unique solutions for the scenarios presented.

Scenario Number 1

You are to describe the design, development, and operation of a coal mine to produce 1,500 tonnes of coal per day for use in an electrical power plant. The mine and plant are located in your country, so assume vegetation, crops, roads, weather conditions, etc., typical of that area.

An appropriate coal deposit is located 10 km from the boundary of a moderate-size town. It is accessible by secondary roads. At present, the land is being used for forestry and the terrain is hilly with good surface drainage of water to nearby streams. An adequate work force and supply of electrical power are available in the nearby town.

The coal deposit consists of a three-meter thick seam, one kilometer wide and five kilometers in length. The seam is exposed and is tilted downward at an angle of five degrees. The coal is lignite.

The overburden contains no rock. Because of this, there is a serious potential for cave-ins and it is estimated that subsidence will occur at the rate of approximately three cm per year. There are no toxic or explosive gases in the seam. Disruption of the current forestry operation should be minimized.

Scenario Number 2

A supply of 300 tonnes of coal per day is required to support a metallurgical operation. An appropriate deposit of coal is available in a mountainous region in a rural area of your country. At present, the land is unused although it supports vegetation. Drainage is rapid. Any residual material resulting from the mining operation should be treated so that there is no significant environmental damage due; for example, to run-off from the spoil piles.

The overburden consists of dirt and fractured rock. The probability of sudden shifting of the material above t e seaam is considred moderate. Preliminary borings have indicated trapped ga. es, principally hydrogen sulfide and methane.

The deposit is located approximately 150 meters underground, but its lateral extent is unknown and, hence, must be determined. Initial probings have indicated a variable thickness of the deposit ranging from two to six meters. The rank is bituminous.

Scenario Number 3

One hundred tonnes of coal per day are required for a kiln operation (for example, brick production). An available deposit is located underneath a swamp in a remote rural area having dirt roads. At present, the swamp is being used for an aquaculture operation and is in a moderately flat region. Assume this area is in your country and at certain times of the year, there is a serious flooding problem.

The deposit is approximately 15 meters below the surface and has an extent of approximately 2.5 square kilometers. The average seam thickness is one meter and the deposit consists of peat. The overburden is clay.

There are relatively few people in the vicinity and the supply of electric power is very limited. No abnormal health or safety factors are associated with this particular coal deposit. The mining operation should be confined to a small area because of extensive aquaculture in the area. Any soil or spoil piles should not be allowed to change the acidity of the adjacent waters.

Scenario Number 4

A cement plant located near a moderate-size town in your country requires 50 tonnes of coal per day. Coal is available very near to the town in an area of flat land now used for agricultural activities. Drainage to nearby streams and adjacent navigable waterways is good.

The coal is subbituminous and it is located at slight to moderate (up to 30 meters) depths below the suraco. It exists in a number of isolated pockets, having an average area of 3,000 square meters. The thickness of the deposit is very large, ranging from 6 to 15 meters. At the surface, the overburden is well-drained, high quality soil, changing gradually to a mixture of earth and gravel with increasing depth. Adequate facilities and workforce are available in the nearby town. Because the land is being used currently for agriculture, the amount of land removed from productivity at any time must be minimized and

it must be restored promptly to its original use after each pocket of coal is removed.

PREPARATION WORK SESSION

General Instructions

The following hypothetical situation has been constructed to aid you in applying the topics to which you have been introduced during the preparation lectures.

You should understand that there is no one "correct" answer; instead your group should approach the "problem" using the combined knowledge of all members of your group. Your task is to suggest a practical "answer" based upon the experience and knowledge of your group--you can use course materials, library books, and lecture notes.

Based upon the information supplied in your scenario, you are to discuss the following topics:

(1) Decide what "preparation" is needed to meet the selected end-use.

(2) Select preparation processes or techniques to achieve this level of preparation.

(3) Determine the "requirements" to produce this level of preparation (i.e., labor force, power, types of equipment, and typical plant design).

(4) What "problems" will be encountered (and to what degree) in establishing the level of preparation (e.g., economic, operational, health and safety, environmental, and local practices/conditions)?

(5) What types of "mitigation" would you suggest to avoid or reduce the "problems" mentioned in item (4) above?

The end-product of your group working together will be a short written paper on how you would suggest a solution to the "situation" posed to you. The paper containing your solution to the "situation" should be prepared so it can be shared with the whole class during an open discussion session.

Scenario Number 1

Your company has been asked to pulverize coal in a manner acceptable for electric generation. You are requested to remove one-half of the sulfur. The sulfur content of the coal is 5 percent of which 1/3 is pyrite and 2/3 is chemically bound. The following list is a description of your coal:

MOISTURE	----	5%
ASH	----	8%
SULFUR	----	5%
BTU/LB	----	11,900

Scenario Number 2

Your company has been asked to prepare coal for a kiln operation where drying is required. Removal of rock fragments will be necessary since the coal consists of 70% coal and 30% rock. Do whatever you feel is necessary to prepare the coal. The following is a description of the coal you will be working with:

MOISTURE	----	52.4%
ASH	----	23.2%
SULFUR	----	0.5%
BTU/LB	----	4,600

Scenario Number 3

Your coal firm has been asked to prepare coal for a smelting operation. One of your problems is to remove rock fragments, since the coal is 80% coal and 20% rock. A description of your coal is as follows:

MOISTURE	----	13.2%
ASH	----	20.4%
SULFUR	----	0.72%
BTU/LB	----	9,200

Scenario Number 4

Your company has decided to replace the oil it has been using in its steam generation plant with coal. The sulfur fraction in your coal is pyrite; thus you will need to remove a large fraction of the pyrite sulfur. The coal should be prepared for use in your existing combustor. A description of the coal you plan to use is as follows:

MOISTURE	----	43.8%
ASH	----	4.4%
SULFUR	----	1.4%
BTU/LB	----	5,960

TRANSPORTATION WORK SESSION

General Instructions

Each team will be given a description (scenario) of a transportation problem to be evaluated. The type and quantity of coal to be handled, the location of the mine, the location of the end-use facility, and the terrain between the mine and the facility will be included in the problem description. Each team is to determine the mode of transportation, evaluate the requirements (equipment, facilities, labor, power, etc.), identify the particular problems (e.g., economic, operational, environmental, safety, etc.) that are likely to arise and identify possible means of mitigating these problems. You are encouraged to supplement the course material with your own experiences in addressing these problems.

Scenario Number 1

You are to supply 1500 tonnes of lignite coal per day to an electric power plant. This coal is to be provided from a single mine that is located on an island approximately 300 km from the power plant. The mine is located in hilly, forested terrain approximately 10 km from the coast. There are no existing transportation facilities between the mine and the coast or between the mine and a small seaport about 50 km away. The power plant is located on the coast about 20 km from a large coastal city. This city has port facilities but there are no coal-terminal facilities.

Scenario Number 2

You are to supply 300 tonnes of bituminous coal per day to a metallurgical facility located in a large city 200 km from the mine. The mine is located in a rural, mountainous area with no existing modes of transportation nearby. It is 20 km from the coast but there are no dock facilities in the vicinity. The city in which the metallurgical facility is located is on the coast and has dock facilities for loading and unloading vessels but no coal terminals are in existence. About 300 km of coastline separate the city and the mine. The terrain between them varies from mountains to small hills.

Scenario Number 3

You are to supply 100 tonnes of peat per day to a number of kilns located in an industrial part of a large city. The peat mine is in a coastal swamp. The city is about 100 km inland and is located along a navigable river. A water route between the mine and the city would be about 300 km long. A land route would be about 150 km long and would pass through moderately hilly terrain. There are no modes of land transportation in the immediate vicinity of the mine but a road is about 20 km away and a railroad is about 40 km away.

Scenario Number 4

You are to determine the facilities needed to handle large quantities of coal that are brought in by ship, by rail, and by truck. The coal must be screened and crushed. Some blending is required but not all coal is to be blended. The coal is to be shipped out by rail and truck to an electric power plant and to several industrial users.

PLANT APPLICATION WORK SESSION

General Instructions

In these work sessions you are to apply the principles given in the lectures and in the earlier work sessions. Each team will be given a generalized description of a plant application for coal use. Given this information, you are to determine the input requirements for this facility (fuel, water, labor, etc.) and to generally describe its physical requirements (e.g., fuel supply system, waste handling, land requirements, etc.). You are to determine the coal best suited to your application and the optimum level of beneficiation. You are to determine the waste products from your plant and to describe what abatement techniques are needed to meet the given standards. You are to determine the transportation mode for providing fuel to your plant. You are to select one of the possible end use sites for the facility and provide reasons for your selection. You are to estimate the cost of fuel and the capital investment necessary for your application. You may assume that sufficient capital is available to construct each facility but you are expected to optimize these expenditures.

General conditions that apply to all scenarios:

- Particulate emission limits: 0.5 lb/10^6 Btu
- SO^2 emission limits:
  a) 1.2 lb/10^6 Btu within 30 km of city
  b) None, if site is more than 30 km from city
- Adequate water supply at all possible sites
- Possible levels of preparation
  1) Screening and crushing
  2) Screening, crushing, removal of 25% of ash and 10% of sulfur
  3) Screening, crushing, removal of 50% of ash and 20% of sulfur

Scenario Number 1

Application: A new 200 MWe electric power plant

Possible Coals:
1) A large mine that could be dedicated to this facility; located in mountainous, low population area 300 km from city; coal has 8500 Btu/lb; 1% sulfur; 6% ash. The mine mouth cost of coal is \$2/10^6 Btu.
2) Three widely scattered, smaller mines on an island 30 km from city; coal has 11,000 Btu/lb; 1% sulfur; 6% ash. The mine mouth cost of coal is \$1.5/10^6 Btu.

Possible Sites:
1) Near coal supply
2) Agricultural land 10 km from city
3) Forest 25 km from city
4) Agricultural land 35 km from city

Possible Combustors:
1) Pulverized coal
2) Fluidized bed

Scenario Number 2

Application: Convert a 200 x 10^6 Btu/hr oil-fired burner to coal/oil, coal/water, or coal/oil/water burner. Facility has a 20 year lifetime remaining. If a coal/oil mixture is used, the fuel can have a maximum coal content of 40% by weight. If a coal/water mixture is used, the coal content can be as high as 60%. Price of oil is \$4/10^6 Btu.

Possible Coals:

1) A domestic mine located near a large river 100 km from city. Coal has 9,000 Btu/lb, 6% ash, 0.3% sulfur, and 20% moisture. Its mine mouth cost is \$2/10^6 Btu.
2) Imported coal of 12,000 Btu/lb, 12% ash; 1% sulfur and 15% moisture. Port-of-entry cost is \$1.8/10^6 Btu. The port is in the same city as the plant.

Possible Site: Facility is located in a large city.

Combustor: Retain liquid fuel concept.

Additional Considerations:

Estimate the derating of the facility. An objective of this conversion is to optimize the plant performance. Determine advantages of blending coal types.

Scenario Number 3

Application: New plant producing 200 tonnes of steel per day.

Possible Coals:

1) Imported coal of 13,000 Btu/lb, 4% sulfur, 10% ash, 3% moisture, 12% volatile matter. Cost of mine mouth is \$2.5/10^6 Btu at port-of-entry.
2) Domestic coal is 10,000 Btu/lb, 3% sulfur, 8% ash, 2% moisture, and 35% volatile matter. Cost is \$2/10^6 Btu.
3) Domestic coal of 9,000 Btu/lb, 1.5% sulfur, 5% ash, 20% moisture, and 35% volatile matter. Cost at mine mouth is \$2/10^6 Btu.

Siting Considerations:

Market for steel is in large, coastal city
Domestic mines are 100 km north of city.
Iron ore supply is 200 km south of city
Possible sites
1) Near mine-mouth in rural area
2) Near ore supply in rural area
3) In city
4) Agricultural land 10 km from city
5) Agricultural land 35 km from city

Combustor: Coke burning, steel production furnace

Additional Considerations:

Consider advantages of coal blending

Scenario Number 4

Application: A new cement plant producing 300 tonnes of cement per day.

Possible Coals:

1) A mine located in hilly terrain 100 km from the city. Coal has 7,500 Btu/lb, 0.8% sulfur, 5% ash and 35% moisture. Mine-mouth cost is $2/10^6$ Btu.
2) A mine located in flat, forrested terrain about 100 km from the city. Coal has 10,000 Btu/lb, 1.5% sulfur, 5% ash, and 20% moisture. Mine-mouth cost is $1.8/10^6$ Btu.

Possible Sites:

1) Mine-mouth
2) Limestone source 20 km from city in opposite direction as mines
3) In city
4) Agricultural land 10 km from city
5) Forest 35 km from city

Combustor: Cement kiln