CHAPTER 11

Mining Technology

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The Federal Coal Leasing Amendments Act of 1976 charged OTA to assess the feasibility of the use of deep-mining technology on leased areas. With the passage of the Surface Mining Control and Reclamation Act of 1977 congressional interest in the study of deep underground mining technology shifted its principal focus from a concern for the protection of surface resources to a concern for maximum economic recovery and the conservation of the resource. Lessees are required to mine all coal that can be extracted economically and within the limits of safety and technology so that coal reserves are not left in the ground where they can deteriorate and not later be retrieved. Underground mining methods usually leave a significant portion of the coal reserve in the ground, Some underground mines recover only **30** to **50** percent of the minable resource, although, averaged over all underground mines in the United States, the recovery ratio is **63** percent. Surface mines, on the other hand, typically recover from **70** to **90** percent of the minable resource.

[1]The recovery ratios used in this chapter are derived from the following sources: 1) R. L. Lowrie, *Recovery Percentage of Bituminous Coal Deposits in the United States*, Bureau of Mines, RI 7109, 1968; E. S. Secor, G. M. Larwood, A. B. Gupta, and A. S. Lees, *Coal Recovery From Bituminous Coal Surface Mines in the Eastern United States: A Survey*, Bureau of Mines, IC 8738, 1977; and R. G. Reese, B. B. Dash, and P. A. Hamilton, *Coal Recovery From Underground Bituminous Coal Mines in the United States by Mining Methods*, IC 8785, 1978; 2) OTA review of lessee mine plans; and 3) personal communication to OTA from Eugene R. Palowitch, Director, Pittsburgh Mining Technology Center, U.S. Department of Energy.

Introduction and Overview

This chapter summarizes OTA'S review of the mining technologies currently in use on Federal leases and the potential for commercial mining technologies to extract Federal coal reserves from deep underground seams. The chapter discusses:

- three surface mining techniques that are used in the West: 1) area strip, 2) open pit, and 3) terrace pit;
- two methods of underground mining in the West: 1) room and pillar with continuous miners, and 2) longwall mining;
- recent underground mining technology developments in Europe and the Western United States that could affect the production of coal from Federal leases; and
- factors affecting the choice of these underground coal mining technologies in the West, including: 1) capital requirements, 2) resource recovery, 3) labor, 4) production and productivity, 5) environmental impacts, and 6) health and safety.

A number of technological innovations have been developed recently for underground coal mining, but the greatest near-term commercial promise for the expansion of underground coal mining in the Western United States appears to be the implementation of longwall mining techniques developed in Europe. Although longwall mining is used virtually exclusively to produce coal from underground mines in Europe, it accounts for only 5 percent of annual underground coal production in the United States. Longwall systems have been used in several European countries to extract most of the reserves in 30-ft thick seams at depths of 3,000 ft. In the United States, on the other hand, such recovery of thick, deep underground seams is still in the development stage,

Some of the largest underground mines in the West, including several that produce Federal coal, have recently converted to longwall mining. Longwall mining is also scheduled to be installed at other large underground operations in the West. For these reasons, much of this chapter compares longwall mining with the dominant underground mining technology in the West—room-and-pillar mining with continuous miners.

Federal coal reserves in the Rocky Mountain province provide the greatest near-term potential for the application of longwall mining. The first successful longwall operation in the West was the York Canyon Mine of Kaiser Steel located near Raton, N. Mex. Although the York Canyon Mine is not located on Federal leases, New Mexico provides opportunities for the implementation of longwall mining on Federal land.

Longwall systems have also been introduced in several mines with Federal leases in the Book Cliffs Field of central Utah. New concepts are now being implemented and tested to extract coal from thick seams and to mine steeply dipping seams at two mines with Federal leases in Colorado—the Coal Basin Complex of Midcontinent Resources and the Snowmass Mine of Snowmass Coal Co. These projects are likely to encourage the use of longwall mining to extract other thick or steeply pitching coal seams in the area.

Longwall systems are also scheduled to be implemented at two mines with Federal reserves in the Hanna basin of southern Wyoming. In 1981 a longwall system will be introduced at Carbon No. 1 Mine. This system will be the highest longwall unit (14 ft) in the West. Much of the area overlying this operation has already been surface mined. In 1984 Energy Development Co. plans to use a longwall unit at the Vanguard No. 2 Mine.

In the Powder River basin of Wyoming and Montana, where coal is mined inexpensively from large surface mines, it may be technically possible to extract thick underground seams. However, the resource information on deep underground coal deposits in this area is inadequate to assess the economic feasibility of this. The comparatively low-Btu value of coal in the Powder River basin and the very large, inexpensively minable surface deposits in the basin are economic barriers to underground mining in this region at least throughout this decade.

A potential method for recovering energy from coal is through in situ gasification of deep coal seams that cannot be mined by surface mining methods. The thick coal seams in the Powder River basin are considered attractive in their potential for in situ gasification, and two separate small-scale test sites have been developed in Campbell County, Wyo., one by the Department of Energy (Hoe Creek Site) and another by ARCO Coal Co. In situ gasification in this country is still in early experimental stages. A major disadvantage with in situ gasification is that it does not produce pipeline quality gas. Thus, unless there are industries nearby that could use low- or medium-Btu gas, a surface facility must be constructed to upgrade the gas to pipeline quality or perhaps to convert it to methanol. The National Coal Policy Project concluded that even if in situ gasification experiments in the Powder River basin are successful, the distance of the region from centers of demand is likely to limit application of the technology.[2] Considering the present state of development of the technology, in situ gasification is not likely to be used commercially in the Powder River basin until the mid-1990's at the earliest.

To date, the experience with longwall mining both in Europe and the Western United States points to significant potential advantages in terms of increased resource recovery, higher production and productivity, reduction in the cost of labor and frequently in the overall costs per ton of coal, the control of differential subsidence on the surface, and a reduction in the number of unintentional roof falls at the face. One should not conclude, however, that longwall mining will realize these advantages in all underground mining environments or that longwall mining can be

[2]F. X. Murray (cd.), Where We Agree: Report of the National Coal Policy Project (Boulder, Colo.: Westview Press, 1978).

used profitably and efficiently in all of the deep Federal coal seams in the West. The decision to implement a particular underground mining technology at a particular site can be made rationally only after the completion of comprehensive sit e-specific geological, engineering, economic, and environmental assessments,

In spite of the positive experience with longwall mining both in Europe and the United States, many underground coal producers in the West will be reluctant to install this mining technology because of its high initial capital cost. The cost of a typical longwall installation is $9 million; total capital cost of the technology per ton of coal mined over the life of a system is about $1,50. This compares to a capital cost of $0.40/ton of coal mined over the life of the system for the typical room-and-pillar operation in the West, using continuous miners. In many cases, the savings in labor and the other advantages of using longwall mining may not be sufficient to offset this cost differential. Nevertheless, longwall systems are likely to figure prominently in mining underground Federal coal reserves in several areas of New Mexico, Utah, Colorado, and Wyoming.

Review of Coal Mining Technologies Currently Used at Federal Mines

Although underground mining was, at one time, the principal mining method in parts of Colorado, Montana, Wyoming, and North Dakota, and continues to be so in Utah, surface coal mining now predominates in most areas of the West. Because coal seams are generally thicker and nearer the surface in most Western States, compared to the East, they are more amenable to recovery by surface mining techniques. Surface mining operations are usually well-suited to the many areas of the West that have not yet experienced the extensive development of towns, cities, highways, and railroads characteristic of the Midwest and the East.

Surface Mining Techniques

Surface mining of coal is characterized by the use of large, capital-intensive and efficient mining equipment. First, the overlying soil and rock layers (overburden) are removed. The coal is then fractured with explosives or machines, and loaded onto vehicles for haulage from the mine site. Finally, the disturbed land must be fully reclaimed. Principal considerations in the selection of surface mining and reclamation techniques and equipment include the thickness and character of the overburden, the dip of the seam, the thickness and number of recoverable seams, and the physical and chemical characteristics of the coal. The three surface mining techniques most widely used in the West are area strip, open pit, and terrace pit.

Area Strip

Area strip is the principal surface mining technique used in the United States. The technique was perfected in the coalfields of Illinois, Indiana, Kentucky, and Ohio. The capacity of a dragline, the machine used to remove the overburden in strip mining, varies in size from 10 to over 200 cubic yards. Many Eastern mines use stripping shovels instead of draglines; and stripping shovels currently are being used successfully at several strip mines in the West such as the Rosebud Mine in the Montana portion of the Powder River basin which produces Federal coal.

Area strip mining proceeds by first making a box cut into the earth to uncover the initial strip of coal that is to be mined. The strip of coal uncovered will vary from 100 to 200 ft in width and from one-quarter to several miles in length. The actual size of the cut will be determined by the thickness of both the overburden and the coal and the designed production rate of the mine. After the coal has been mined from the bottom of the box cut, the overburden covering the next strip of coal is removed and placed in the void left by the mining of the preceding strip of coal. Mining proceeds with succeeding parallel stripping cuts until the property limits of the mining area are reached (see fig, 49).

Even the largest draglines have limits on how much overburden they can remove from a given operating location. A single dragline can generally remove overburden to depths of 100 ft. However, it is possible to extend the stripping limits to as deep as **200** ft by teaming the principal stripping dragline with additional equipment such as another dragline, a stripping shovel, a bucket-wheel excavator, or fleets of trucks and shovels or scrapers. This additional equipment will increase the total overburden removal costs and can be justified only by significant increases in the amount or quality of the additional coal that can be recovered.

Open Pit

The open pit mining technique currently used in the Western United States was initially developed in the metal mining industry. An open pit mine is characterized by a series of benches, the number of which increases as the mine is deepened. Each one of these benches is **40** to **50** ft in height, and excavation can proceed to depths of hundreds or thousands of feet.

The use of an open pit for overburden removal is justified only where there is an exceptionally thick seam or a series of seams that can be mined in sequence, The single seam mines can be found in the brown coalfields of Germany, but only the multiseam mines are found in the Western United States. The best example of the latter type is FMC's Skull Point Mine located on Federal leases in southwestern Wyoming.

Equipment used for overburden removal in an open pit coal mine is currently limited to truck and shovels or scrapers. The truck and shovel or scraper approach typically provides the most flexibility in the development of a bench system and the mining of coal seams. However, lower overburden removal costs might be achieved if rail or conveyor haulage systems, similar to those used in the copper mines of the Southwestern United States, could be implemented in open pit coal mines,

Terrace Pit

The terrace pit system for surface coal mining has come into use only during the last 5 years (see fig. **50).** This method, which essentially combines the area strip and open pit techniques, is used in the thicker coal beds of northeastern Wyoming and southeastern Montana. In these two areas, the removal of overburden thickness in excess of the 100-ft stripping limit of a dragline is justified economically by the mining of exceptionally thick coal seams.

Terrace pit mines have a system of benches similar to those designed for open pit mining. However, the overburden depths that can be removed economically by the terrace pit method are currently limited to between **200** and 300 ft. so that the maximum number of benches will be about seven, Also, unlike the open pit system, the terrace pit system does not remain in the same location but rather moves across the property in a manner similar to area strip mining. The overburden that is removed from one side of the pit is hauled to the other side of the pit and dumped where the coal has already been mined. As a result, the overburden removal operation of the terrace pit moves constantly in a specified direction, usually down dip during the initial years of mining. The removed overburden is replaced behind the mining operation at a distance determined by the number and size of the benches.

Equipment used for overburden removal and coal extraction in the terrace pit system typically consists of trucks and shovels, although draglines are used at several such mines in the West, including the Rawhide

Figure 49.—Western Strip Mining

Photo credit: Office of Technology Assessmer

Dragline (background) exposes coal seam while front-end loaders (foreground) dump it into trucks for haulage to rail spur or powerplant

Figure 50.—Truck and Shovel Terrace Pit Mine With Two Overburden Benches and Two Coal Seams

SOURCE U S Bureau of Mines

Mine which is located on Federal leases in the Wyoming portion of the Powder River basin. A maximum of two to three shovels will typically be assigned to each overburden bench together with a sufficient number of trucks to haul the material excavated by the shovels to the other side of the pit, The number of shovels used in this operation is determined by the length and the rate of development of the pit. As in open pit mining, other forms of excavation and haulage equipment, such as bucket-wheel excavators and conveyors, are being considered for terrace pit mining. However, the dynamic aspect of terrace pit mining makes it more difficult to use equipment that does not have the mobility characteristic of trucks and shovels,

Underground Mining Techniques

Surface mining is generally preferred by mine operators over underground mining. The reasons for this preference include higher percentage of coal recovery, higher labor productivity, lower operating costs, and fewer safety and health hazards. Also, some environmental impacts of underground mining, such as subsidence, acid mine drainage, and the interruption of aquifers can be greater than those of surface mining, All of these factors are important and will be discussed in more detail later in this chapter. In cases where coal seams are too deeply buried to be recovered economically using surface mining techniques, it is likely that the coal will be mined using one of the two underground mining techniques discussed below, Furthermore, several companies mining Federal coal in the West have had to shift from surface to underground mining as their surface minable reserves became exhausted.

Access to underground mine workings will be by one of three methods. If the coal seam outcrops at the surface it is possible to mine directly into the seam from the surface; this type of mine is referred to as a drift mine. Most underground mines in the West are drift mines. If the minable seam is located under shallow cover then it may be possible to reach the coal bed through the use of an inclined drift (slope); this type of mine is referred to as a slope mine. If neither of these forms of access is possible, then it is necessary to sink a vertical shaft from the surface to the minable seam; this type of mine is referred to as a shaft mine.

The initial capital cost for developing a slope mine may be slightly more than that for developing a shaft mine because, for the same overburden thickness, a slope is approximately three times longer than the depth of a corresponding vertical shaft. However, over the long term, a slope mine has lower operating costs because of the relatively low cost to move men and materials into the mine and coal out. A slope mine is typically more economical when the overburden is less than 500 ft; a shaft mine when it is over 1,000 ft. In the 500- to 1,000ft range a site-specific economic evaluation is usually necessary to determine what type of mine should be developed.

Room and Pillar

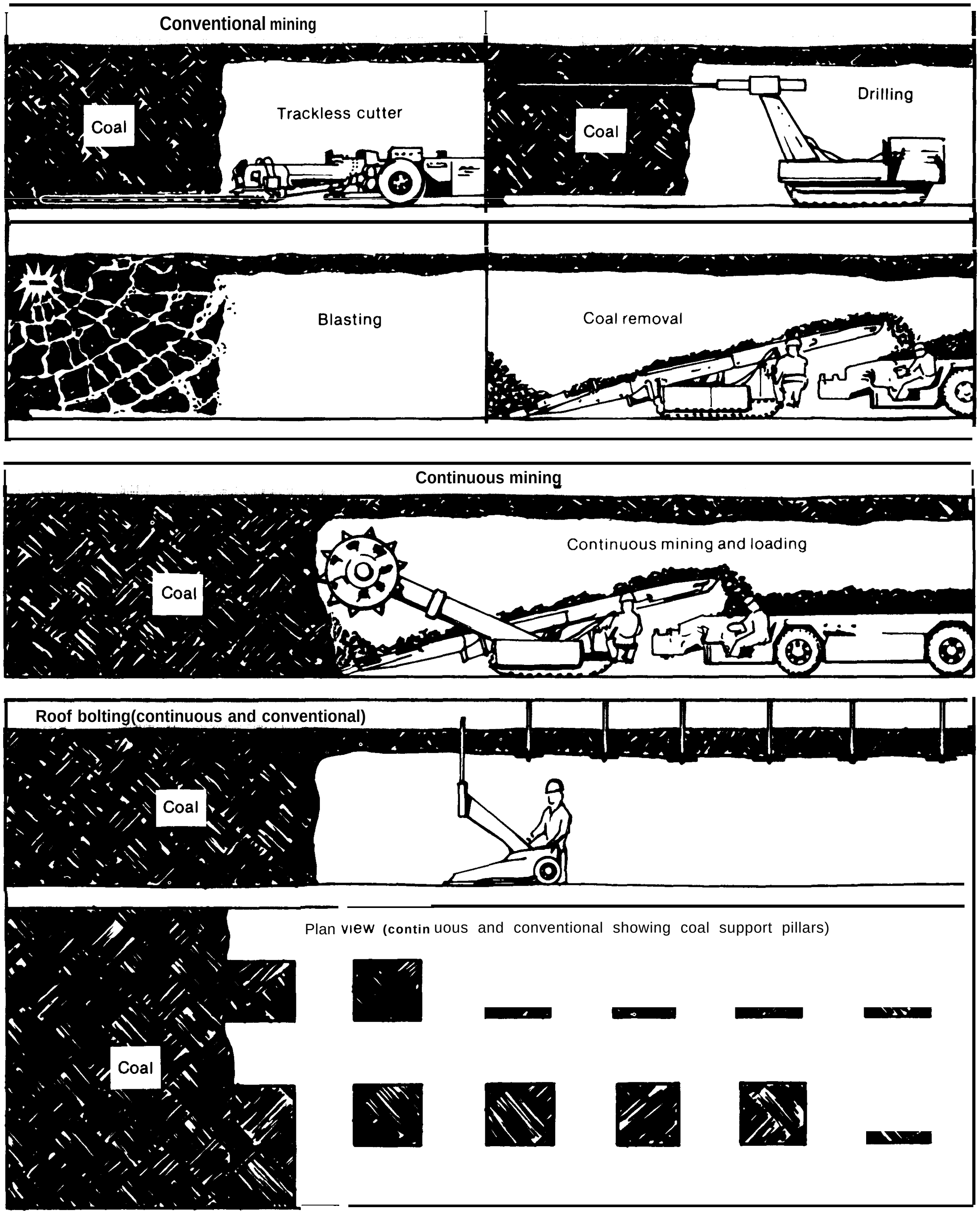
In the room-and-pillar method, the voids left by removed coal form the rooms and the unmined coal forms the pillars (see fig. 51). The pillars are left in place to support the weight of the overlying strata. The principal factors determining the percentage of coal that can be removed from a seam are the thickness of the seam, the strength of the seam and the confining rock strata, the presence of faults or fractures, and the depth of the seam. The deeper the seam, the greater the weight of overlying rock that must be supported; thus the size of the pillars generally will be greater for deeper mines.

The extraction of the coal in a room-and-pillar mine is accomplished using either **conventional mining** or **continuous miners.**

Conventional mining declined in popularity during the 1960’s and most of the 1970’s but continues to account for 35 to 40 percent of the underground coal production in the United States. The first step in conventional mining, which is more labor-intensive than continuous mining, is to cut a slot into the seam with a machine that looks like a large chain saw mounted on a large, rubber-tired vehicle (see fig. 51), Holes are then drilled into the face and loaded with explosives. After blasting, the coal is fragmented and allowed to drop on the floor of the mine. A roof-bolting machine is used to drill vertical holes into the roof and install bolts for roof support. A loading machine is then used to gather up the coal and to load it into rubber-tired shuttle cars which haul the coal from the loader to a conveyor belt for transport out of the mine. In a few instances, a series of bridge conveyors are used in place of the shuttle cars.

Continuous miners are equipped with a rotating head with cutting bits that is used to break coal from the face (see fig. 51). The design of the cutting head and the form of rotation will vary with the manufacturer, but all continuous miners typically break the coal from the face and load it directly into shuttle cars or onto conveyors. As in conventional mining, a roof-bolter is used to install bolts for roof support. The labor requirement for continuous miners is at least 10 percent less than that of conventional mining systems. While continuous miners generally are more efficient, conventional mining can be more readily adapted to certain difficult mining conditions and to large inclusions in the coalbed.

Figure 51 .—Room-and-Pillar Underground Mining



SOURCE Office of Technology Assessment

Longwall Mining

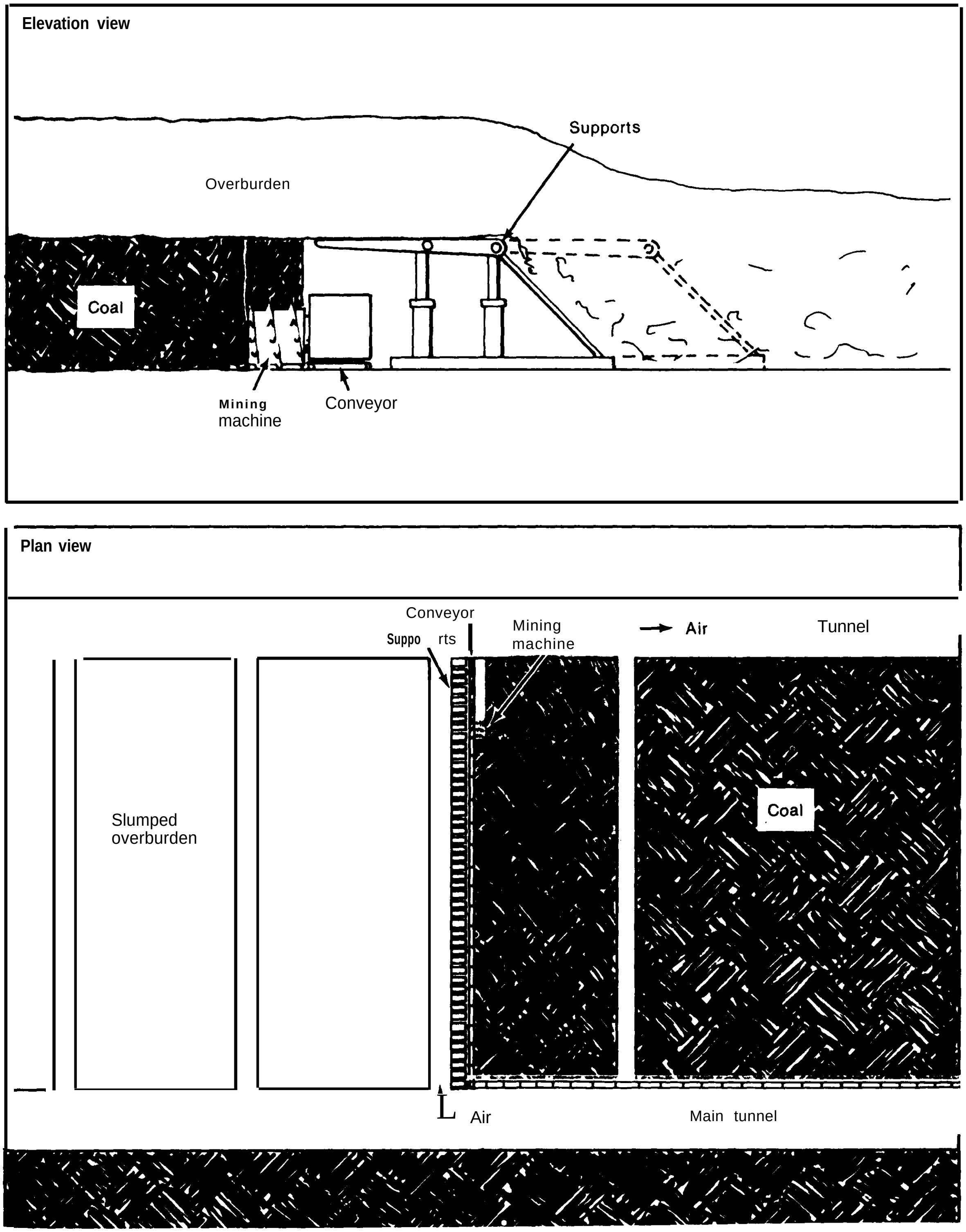
The basic longwall system consists of a set of supports that are located parallel to the mining face, a conveyor system that runs along the base of the face, and a machine that moves back and forth along the face, cutting the coal and loading it onto the face conveyor for transport out of the face area (see fig. **52),** In addition, continuous miners are required for the development of longwall panels. The length of the mining face will depend on a number of factors (discussed in more detail later in the chapter), but will generally range from **400** to **650** ft, with **500** ft being typical.

The basic longwall support system consists of hydraulic rams positioned vertically to support the roof when they are extended. Depending on the size of the mining operation, the rams are arranged into one or more pairs located in the plane perpendicular to the face, When more than one pair of hydraulic rams are used, they will be structurally connected to one or more other pairs to ensure lateral stability. The exact configuration of the rams and the method of interconnecting them will vary according to model or manufacturer. For additional support, a shield support system may be employed. This system uses a protective canopy as a structural part of the support mechanism to protect miners working along the face from roof falls.

The longwall chain conveyor system is mounted on the mine floor in front of the base plate used for the roof support rams or on separate supports, In either case, the conveyor assembly must be flexible to allow for bending as the supports are advanced one after another to keep pace with the advancing face. As the supports are advanced, the roof is allowed to collapse behind them. The typical conveyor mechanism used on a longwall chain conveyor system has a series of horizontal bars or flights that are located perpendicular to the longitudinal axis of the conveyor, These flights are spaced approximately 1 ft apart and are fastened together with chains connected to their ends *or* centers, The chain-connected flights move along the top and bottom surfaces of the chain conveyor system through the force of a gear mechanism which engages the chain. Sideboards are mounted along the top surface of the system so that coal falling into the trough formed by the sideboards will be pulled along by the chain-driven flights.

The machine used to cut the coal from the face and load it on the face conveyor is either a plow or a shearer. Plows are favored in West Germany because of the thin coal seams and soft coal deposits in that country. The cutting action of a plow is just as the name indicates. The height and the depth of the cut will be limited by the amount of pulling force that can be applied to the plow. In the case of shearers, however, the cutting force comes from a rotating drum with cutting bits mounted on it. The diameter of the drum will typically be somewhat greater than one half the face height so that two passes of the drum will be required to mine the full height of the face. The top half of the face is mined first. Since a shearer drum is designed to operate only in one direction, a double-ended shearer makes it possible to cut the upper and lower portions of the face without having to return the shearer to the same end of the face to begin each cut.

Figure 52.—Longwall Mining System



SOURCE Off Ice of Technology Assessment

Analysis of Mining Technology Problems

The preceding descriptions of surface and underground mining techniques currently in use on Federal coal leases are very general. They are intended to introduce the reader to the basic differences between surface and underground coal mining. This section will discuss in more detail the problems that are encountered in using these coal mining technologies. These problems will be illustrated with examples from mines currently operating on Federal coal leases.

Recovery Ratio

Recovery ratio is the percent of minable coal recovered from the seam. Generally, the recovery ratio for surface mining will be higher than that for underground mining because some coal must be left in place in underground mines to support the roof and limit surface subsidence. According to the Bureau of Mines, the average recovery ratio from all surface mines in the United States is 83 percent; for underground mining the national average is 63 percent.

Thick single-seam surface mines often have recovery ratios in excess of 90 percent. For example, the thick-seam mines of the Powder River basin of Wyoming are achieving recovery ratios of 95 percent. The reason for this is that the coal lost at the seam boundaries in a thick seam is a small fraction of the total coal being mined. The operator often does not recover 6 to 12 inches of coal at the upper and lower seam boundaries, because this coal usually contains significantly more mineral matter than the remainder of the seam, The proportionate amount of the seam thickness lost is much less for a 50- or 100-ft thick seam than it is for a 5- or 10-ft thick seam.

A multiseam surface operation will often have a lower recovery ratio than a single-seam mine because a certain thickness of coal is lost for each boundary between a coal seam and the surrounding material. Hence, even though the cumulative thickness of the seams in a multiseam mine approaches or exceeds the seam thickness in many single-seam mines, the percentage of coal **not** recovered will be greater.

Recovery ratios in surface coal mines also can be adversely affected by such factors as extreme seam dip, faults, and characteristics of the overburden material that interfere with stripping operations. Such problems are common in the surface mines of northwestern Colorado and southwestern Wyoming. However, mines such as the Colowyo and the Trapper mines encounter a combination of these problems but still achieve recovery ratios in excess of 80 percent. Seam dip at the Canadian Strip Mine in north-central Colorado is so steep that it has been necessary to implement what is essentially a contour strip operation. Here a bench is cut into the hillside and all of the coal in the bench area is mined. Even though the ratio of waste material removed to coal mined is on the order of 15 or 20 to 1, only a small percentage of the coal is not recovered.

The recovery ratio for underground mining will usually be less than for surface mining as a certain amount of the coal must be left in place around access facilities such as shafts, slopes, drifts, main entries, and submain entries. Additional coal is also lost that is left in boundary pillars around the perimeter of the property and in pillars in the mined out areas to support the roof and prevent or lessen subsidence of the surface.

Recovery ratios for room-and-pillar mines will vary from a low of 20 percent to a high of 80 depending on the completeness of the secondary recovery of pillars from the mining panels. The average recovery ratio for all room-and-pillar mines in the country is 62 percent. Several equally important factors determine the recovery ratio of these mines including the dip of the seam, the presence of igneous or other intrusions in the seam, faults (vertical displacements in the seam), and the depth of the seam. The depth of the seam is important in the West where many mines are

2,000 to **3,000 ft** deep. The greater the depth of the seam, the more overlying rock strata that must be supported by pillars left around access facilities and in the mining areas. To avoid failure of these support pillars due to excessive loading, they must have larger cross-sectional areas, If the pillars are larger, then the amount of coal that can be recovered will be correspondingly less. Support problems caused by the depth of the seam can be aggravated by the presence of faults, poor competency of the rock strata forming the floor and roof of the mine, and excessive water. Several of these conditions are found at mines with Federal coal leases in western Colorado. Conditions became so severe at U.S. Steel's Somerset Mine that one of the mining levels had to be abandoned, Stresses induced in support pillars at this mine caused the pillars to fail explosively, However, according to a spokesman for the Bureau of Mines, this problem has been brought under control at Midcontinent's Coal Basin complex in Colorado,

Recovery ratios for longwall mining range from a low of 50 percent to a high of 80. The average recovery ratio for all longwall mines in the country is 75 percent. * Longwall mining generally results in higher recovery ratios than those achieved in room-and-pillar mining when the latter does not include full extraction of the pillars. A good example of the recovery ratio increases which can be expected from longwall mining when compared to room-and-pillar mining is found in the Deer Creek-Wilberg mine complex of Utah Power & Light in central Utah. These mines had operated as room-and-pillar mines with recovery ratios of 55 to 60 percent. The company has already installed one longwall system and plans to install a second. The recovery ratio for the longwall system at this mine is approximately 80 percent.

Production and Productivity

Although there is no hard and fast relationship between the production rate for a mine and its rate of labor productivity, it is often true that those mines with high production rates also will have relatively high rates of labor productivity, The reason for this is that both surface and underground mines with high production rates generally have training programs and equipment that will generate higher labor productivity y.

The large surface mines of the Western United States have long been characterized by high rates of labor productivity. The productivity of some of these mines is as high as **30** to 35 tons per worker per day. The average productivity rate for all surface coal mines in the United States is approximately 15 tons per worker per day, Since labor is one of the major costs for any mining operation, productivities on the order of 30 or more tons per worker per day translate into significantly reduced unit operating costs. However, high rates of productivity are typically achieved as the result of greater investments in equipment, so that the reduction in unit operating costs will be partially offset by increases in the unit capital costs. Furthermore, capital costs for initial infrastructure development and interest charges are the most significant costs in coal mining.

Because there are fewer operating constraints, surface mining will generally present fewer problems with respect to achieving high production rates and concomitantly high labor productivity rates. The achievement of these goals in underground coal mining, however, requires good mining conditions as well as good management and a willingness to invest in the appropriate equipment. A good example of the high level of productivity that can be achieved in underground mining is the Soldier Canyon Mine of California

[1]Personal communication to OTA from John M. Karhnak, Manager of Ground Control. Division of Minerals. Health & Safety Technology. U.S. Bureau of Mines. Mar. 31, 1981.

*The average recovery ratio for shortwall mining in the United Stales is even higher (84 percent). As in longwall mining, short wa U mining uses chocks for roof support. However, continuous m iners are used in shortwall operations to mine the coal and haulage is done bv shut tle car rather than with a continuous conveyor. Shortwall mining may he used in the future in the West in cases where a 600-ft face is not available. Personal communication to OTA from Daniel J. Snyder, 111, President. Colorado-Westmoreland, Inc., June 15. 1981.

Portland Cement Co. in central Utah. Using a longwall system, this mine is achieving a labor productivity of 23.5 tons per worker per day and an annual production rate of over 1 million tons. This productivity rate is not only much higher than the national average of 8.6 tons per worker per day for underground coal mining but also exceeds that achieved by most surface coal mines,

It is generally accepted that longwall mining represents a better opportunity for achieving higher production rates, higher labor productivity rates, and better safety in underground mining. A room-and-pillar operation using continuous miners can readily achieve shift production rates of 350 to 400 tons. Rates in excess of 700 tons per shift are exceptional, In the case of longwall mining, shift production rates in excess of 1,000 tons are common in the West and rates of 1,500 to 2,000 tons per shift have been achieved at a number of longwall operations.

Environmental

Environmental problems resulting from coal mining operations in the arid West are more likely to be associated with surface mining than underground mining. Environmental issues are discussed in detail in chapter 10. Although the siting of surface facilities for underground mining operations will generally have limited environmental impacts, a potentially greater problem associated with increased underground mining on Federal coal leases is surface subsidence. * The impact from subsidence depends on the location of the mine and is greatest in highly built-up urban areas. This problem is most often associated with cities and towns in the Eastern United States but has also occurred in Western towns such as Rock Springs, Wyo., where buildings and other facilities located in several areas of the city have been endangered.

*Acid mine drainage, which can be an acute problem in many mining areas in the East, is not a significant problem in most arid regions of the West.

Surface subsidence can also be a problem in rural and unpopulated areas. Differential subsidence can break through to the surface in the form of fractures and sinkholes. More typically, subsidence will manifest itself in the form of a generally lowered surface elevation, This will not be a problem unless it occurs under a stream, railroad, highway, building, or dam. Even then, the adverse effects of subsidence can be minimized if the mine is properly planned. In several European countries, especially West Germany, where the art of deploying planned subsidence is well developed, entire towns have been lowered as a result of underground mining without adverse effects.

It is becoming apparent that longwall mining is usually preferred to room-and-pillar mining where surface subsidence may be a problem. The reason for this is that longwall mining is more likely to produce more uniform and predictable subsidence. Concern about the potential impact of surface subsidence on springs and ground water hydrology has been expressed by local residents in mining areas in Utah and Colorado. Subsidence tends to be differential in room-and-pillar mining and may not occur until years after mining operations have been completed. It may then occur without warning and with potentially catastrophic results. However, full recovery of the pillars will usually result in the more uniform subsidence comparable to that achieved with longwall mining.

Roof Support

Deeper mines require that larger support structures be left in place in the underground workings. Greater support can be accomplished by leaving the coal in place or by replacing it with substitute support structures, For longwall mining there is increasing evidence that controlled subsidence of the mined areas reduces support stresses on boundary pillars that are left in place along main and submain entries. In some longwall mines it has been necessary to install supplementary supports such as packs or cribbing, but the amount of support provided has been much less than that required to support the full weight of the overlying rock strata.

Review of Technology Developments in Europe and the Western United States

This section reviews mining technology developments in Europe and the United States and discusses possible solutions of the mining technology problems described in the preceding section.

Because surface mining techniques and equipment in the United States are relatively advanced compared to underground coal mining technology in the United States, only new underground technology developments will be discussed in this section. As the number of underground mining operations increases in the West, improvements in underground mining technology can lead to significant improvements in coal production, recovery ratios, productivity rates, and safety.

Comparison of Mining Conditions in Europe and the Western United States

Mining conditions on Federal coal leases vary from nearly ideal to some of the most difficult conditions anywhere in the world. For example, in certain locations in northwestern Colorado and in northwestern New Mexico the minable seams are a few hundred feet deep and from 6 to 30 ft thick, the dips of the seams range from the horizontal to a few degrees, there are few faults, and the floor and roof rocks are nearly ideal for support. In contrast, the conditions found at some existing mines with Federal leases in western Colorado and central Utah include depths of cover that are over 3,000 ft, seams that range from 4 to over 40 ft in thickness, seam dips that approach 350, extreme fracturing and faulting of both the coal seams and the confining rock strata, and floor and roof rocks of very poor competency. Many mines in Colorado and Utah extract coal from seams that are over 1,000 ft deep.

Mining conditions vary in other areas where there are substantial Federal leaseholdings. For example, in the Powder River basin of northeastern Wyoming the depth of coal seams ranges from **a** few hundred feet to an undesirable 2,000 to 3,000 ft. However, most other mining conditions are good in this area. Difficult mining conditions in the Star Lake-Bisti area of New Mexico include seam dips up to zoo and faults. In Oklahoma, high concentrations of methane gas and undulating, thin seams cause extremely difficult mining conditions on most Federal leases.

Direct comparisons of coal mining in European countries with coal mining in the Western United States can be misleading because many mining conditions are different in these two areas. The principal coal mining countries of Europe—France, Great Britian, Czechoslovakia, the Soviet Union, Poland, and West Germany—are currently mining coal from seams that would be considered unminable in the United States. A condition which is present in all of these countries, but which has not been observed in the Western United States, is extreme folding of the coal seams. In the case of folding, it is necessary to deal not only with steeply dipping seams but vertically oriented seams as well. Most of the coal mined in England is extracted from seams that are deeply buried, thin, folded, and faulted. Both France and Poland are currently operating deep mines with almost full extraction of coal seams 20 to 30 ft thick. However, even though many mining conditions in Europe differ from those in the Western United States, the use of longwall mining in Europe to extract deep, thick seams is relevant to assessing the technical potential for extracting deep, thick seams in the Western United States.

New Equipment Developments

The equipment developments discussed below include both refinements to existing underground mining technology and new equipment concepts that are still in the prototype and testing stage. New equipment and concepts could solve many of the problems described in the section on mining technology problems.

Longwall Mining Improvements

Modern longwall mining technology emerged in its present form in Germany, the Soviet Union, and Great Britain during the latter part of the 1950's after more than 20 years of continuous development in these countries. Refinement and improvement of longwall equipment and techniques have since continued in these countries. The United States has been a late entrant into the use of longwall mining, and the equipment manufacturers in this country have made relatively few contributions to the technology during the past 10 years.

Many of the recent developments in longwall technology have dealt with improvements in reliability and production capability, although there also has been considerable effort to improve safety conditions associated with longwall mining. The discussion of these improvements of longwall mining technology will be organized according to the three principal components of a longwall system; roof support, the face conveyor, and coal cutting and loading.

Principal improvements in the longwall support system have included increases in the load-carrying capability of the hydraulic rams, increased maneuverability of the supports, better stability, and refinements in the controls. Most manufacturers of longwall supports now offer units that have maximum yield loads of 1,000 tons or more, The increases in the maximum yield loads also have been accompanied by the development of shields and chock-shields that offer greater stability and more protection to the miner. Advancement and alinement of the supports now can be done remotely which not only reduces the time required for advancing the support system, but also allows locating miners away from the moving support and out of the way of falling material caused by movement of the support.

The transport of the cut coal away from the longwall face by the face conveyor still remains a major potential bottleneck in the longwall mining system. A breakdown in the conveyor can result from broken flight chains; minor delays also are caused by oversized lumps of coal becoming stuck in conveyor transfer points. The broken flight chain problem has been partially solved by the use of a "twin-inboard" chain at the center of the flight which reduces stress on the flight chains as the flight conveyor bends around curves. The need for a transfer point at the headgate where the face conveyor meets the panel belt conveyor in the headgate entry has been eliminated by the recent innovation of the roller curve in West Germany. The roller curve allows the face conveyor to turn the 900 corner at the headgate and to dump coal directly onto the panel gate conveyor or into a feeder-breaker which reduces the size of oversize lumps and then feeds the coal onto the panel belt conveyor.

The majority of the longwall cutter-loaders installed in the United States are shearers rather than plows. Two major hazards associated with the use of shearers have been high coal dust concentrations created by the cutting action of the rotating shearer drums and the danger from a break in the chain that is used to pull the shearer back and forth along the face. Significant reduction of dust concentrations has been reported through the use of a "Shearer-Clearer" water spray system which was developed by Foster-Miller Associates in conjunction with the U.S. Bureau of Mines. This system partitions the airflow around the shearer into a clean split through the use of water sprays. The coal dust cloud is confined to the vicinity of the coal face while the shearer operators remain in the clean split on the support side of the cutting machine.

The broken chain hazard has been solved by equipment manufacturers in Great Britain, West Germany, and the United States which now offer chainless drives, These drive systems are all based on a variation of the rack and pinion gear system. Initial indications are that these chainless systems already have gained wide acceptance by the operators.

One additional development in longwall technology is a system designed specifically for steeply dipping seams. The system is called the "Troika" and is offered by Hemscheidt America Corp. It is designed for use in seams that dip up to 750 and is scheduled to be used to extract Federal coal from a seam pitching 330 at the Snowmass Mine in Colorado. It consists of three shields connected to a central structural beam by a double-acting ram assembly. The beam is connected mechanically to the center shield and to the outer shields by the rams. The center shield, which has no double-acting ram, is moved by the outer shields with the rams through the beam. The outer shields follow this beam during movement.

The new equipment developments for longwall mining are potentially important, but better use of available equipment is an equally important aspect of technology development for this system. An example of the latter is the use of available longwall technology to extract the maximum thickness possible from seams that are thicker than the approximately 12-ft seams currently being mined with conventional longwall systems.

One approach to thick seam extraction in underground mining is the double lift longwall method currently being developed to mine Federal reserves at the Coal Basin Complex of Midcontinent Resources under a cost-sharing contract with the Department of Energy. With this system, the coal seam is extracted by taking two successive passes of the longwall. Total thickness of the coal seam is 25 ft; by taking two 10- to 12-ft lifts, all but 5 ft of the seam will be recovered. Although this is less than the total seam thickness at Coal Basin, it is a significant improvement over the extraction of 8 to 10 ft of coal achieved with the single lift approach. Conceptually, this method could be extended to extract the full coal seam, using three or more lifts.

Another approach to thick-seam mining using a longwall system, developed in France, uses a single-lift longwall operation under the bottom of the sea. The roof supports on this system have been modified to allow the portions of the seam located above the longwall to cave in behind the supports under the overlying broken roof rock. The broken coal is then collected on a conveyor belt running behind the supports.

Room-and= Pillar Mining Improvements

For some time there has been an awareness that the cutting action used by existing continuous miners is less efficient and produces more dust than alternative cutting actions. Tests of the linear-cutting miner experimental concept developed by the U.S. Bureau of Mines have indicated that deeper cuts at constant depth in the coal face can be made more efficiently, while reducing the respirable dust that is normally generated by continuous miners. It is estimated that this new cutting concept would produce three times the amount of coal with one-third of the dust and would use one-third to two-thirds less electrical power, depending on the cutting depth. However, the development of the commercial machine is not likely for another 20 years.

A concept for extracting more coal from pillars during secondary recovery operations is the underground auger miner developed by FMC under contract to the U.S. Department of Energy. In addition to the recovery of coal in pillars, the system shows a potential for mining out prepared panels of coal at significantly lower cost than conventional methods.

The system consists of an underground augering machine, a two-stage coal conveyor, and auxiliary ventilation and rock-dusting equipment. The auger miner excavates coal by drilling a series of large holes side by side into [he coal seam. The conveyor carries the coal to the mine's face haulage system, The in-hole ventilation and rock-dusting equipment is used to dilute methane gas and coal dust to nonexplosive concentrations,

The availability of efficient and reliable haulage systems has long been one of the goals of underground mining technology development. Existing rubber-belt conveyor systems have gone a long way to satisfy this requirement, but major deficiencies remain at the face. The principal need is for a continuous haulage system which is sufficiently flexible to adapt to the multitude of configurations experienced during the development and product ion from a coal panel. Besides the need for flexible components, there is also a need for an efficient method for transferring coal from one component to another, e.g., from shuttle cars to panel belt conveyors. *

* This need is also eveident for panel development in longwall mining

Long-Airdox has introduced a continuous haulage concept that is based on the use of mobile bridge carriers and piggyback bridge conveyors. A piggyback bridge is atttached directly to the boom of the continuous miner at one end and is supported by a dolly at the other end. This dolly is designed to move freely along rails mounted on top of the sides of a separate mobile bridge. Coal flows from the miner to a piggyback bridge to a mobile bridge to a piggyback bridge, and so on, until it reaches the last piggyback bridge's dolly and is dumped onto the panel belt. Four standard mobile conveyors (each 30 ft) coupled with five standard piggyback conveyors (each 3 to 41 ft) can provide an effective reach of over 300 ft in a seven-entry mining projection.

Other concepts of continuous haulage that have been tested include the use of air and water as the carrying media for crushed coal in pipelines. Although this approach offers some advantages, it is still more difficult to implement than are concepts based on the use of conveyor belts. A slurry pipeline system has been installed in one Eastern mine, however,

Considerations for Using Improved Longwall Mining Techniques on Federal Coal Leases

The preceding sections of this chapter have provided an overview of mining systems currently in use on Federal coal leases and have considered several of the technology problems associated with the use of these systems. This section will address: 1) the cost in capital and labor and the time needed to implement longwall mining and 2) the comparative production advantages and some of the physical, environmental, and social consequences of using this technology.

Capital

During the 20-year period that reliable longwall mining systems have been on the market, an important reason for the reluctance of coal producers to use this technology has been the initial cost of installation. The installation of a complete longwall mining system, not including the cost of development workings and other mine infrastructure, requires the expenditure of a single large lump sum of capital, usually $1.5 million per 100 ft of face length. This cost includes: 1) the face support subsystem, 2) the face conveyor subsystem, and 3) the coal cutting-loading subsystem. The total installed cost of the three longwall subsystems will vary significantly from mine to mine. The more important variables which determine the cost of a specific longwall system include the length of the face, the height of the coal to be cut, the geological conditions of the seam, the thickness and quality of the roof rocks (which determine the capacity of the face support subsystem required), and the rated capacity of the system.

The typical longwall system now being installed in the Western United States has a designed face length of 600 ft and a rated production capacity of 1,250 tons of coal per shift. However, the actual production capacity obtained varies from 700 to 1,500 tons per shift because of variations in mining conditions and in the ability of producers to operate longwall systems. This compares with a national average of 400 tons per shift for longwall systems in 1980.

The cost of this typical longwall installation in 1980 dollars is estimated at approximately $9 million. Assuming that the mine operates 250 days per year and two shifts per day, the rated annual production capacity of the typical longwall system will be 625,000 tons. * If the longwall system is assumed to have a productive life of 10 years, which is not unrealistic if the system is adequately maintained and there is selective replacement of the more expendable system components, then the total production capacity over the 10-year life will be 6,250,000 tons of coal. Hence, the total installed capital cost of the longwall system over the life of the system will be approximately $1.50/ton of coal mined.

The significance of capital cost for longwall mining can be illustrated by the following example. Utah Power & Light installed a longwall system in its Deer Creek mine near Huntington, Utah, in April 1979. The system was designed for a 480-ft face and a 10-ft thick seam. The initial production capacity of the system was 1,500 tons per shift. However, after only 3 months of operation longwall production reached an average of 2,500 tons per shift, Using a schedule of two shifts per day, the initial 3,000-ft long panel was mined out in a period of 6 months for an average production of 2,200 tons per shift.

*This figure takes into account the amount of time the system is not in operation during this period because of maintenance, etc.

The impact of the success of this initial longwall system on the entire Deer Creek operation is dramatic. Prior to the installation of the longwall unit, daily production capacity at the mine was 7,000 tons. To achieve this production rate it was necessary to use as many as 10 continuous miner sections. With the implementation of the longwall system the daily production has increased to in excess of 10,000 tons and the monthly production to 220,000 tons. Of this 220,000 tons, a total of 115,000 tons is produced by the single longwall unit and the balance by eight continuous miner sections. With the installation of a second longwall, the company expects the requirement for continuous miners to drop to four sections. Two of these sections will be used for longwall panel development and two to extract pillars from sections of the mine which have already been mined using the room-and-pillar technique.

Prior to the installation of the first longwall unit the Deer Creek Mine was producing 1.75 million tons of coal per year, This rate was achieved through the use of 10 continuous miner sections. Assuming an average investment of $700,000 per section, the total investment in mining equipment was $7 million. Based on a 10-year life for the continuous miners and auxillary equipment, the total capital cost per ton of coal mined over the 10-year period was $0.40. Assuming an installed cost of $9 million per longwall unit, a similar calculation for the 2-longwall and 4-continuous miner production system now producing 2.64 million tons of coal per year results in a capital investment of $0.80/ton of coal produced over a lo-year period, assuming the longwall units and the continuous miners have productive lives of 10 years. Considering the cost of money at 20 percent and total financing of the equipment, the all continuous miner system cost becomes $0.85/ton and the cost for the mixed system $1,65/ton.

Although the capital cost per ton of coal produced is higher for the longwall system, labor costs are reduced. Assuming that the longwall and the continuous miner sections both require 10-person crews for their operation and that the size of the maintenance support staff is the same for both the all continuous miner mine and the combined longwall and continuous miner mine, the combined operation will require 80 fewer hourly employees to operate on a two shift per day basis. Based on a direct hourly rate of $9/hour and a fringe benefit rate of 35 percent, each of these 80 employees costs approximately $25,000 per year. Therefore, the total savings in labor costs for the mine configuration using the combined systems is $2 million per year, This sum is 14 percent of the difference in capital cost between the combined operation ($21 million) and the all continuous miner operation ($7 million). When the fact that the combined operation produces 900,000 additional tons of coal per year is factored in, then the payback period becomes of the order of 2 years.

There are a number of existing and planned underground mines on Federal coal leases that could use development strategies similar to that of the Deer Creek Mine. The Skyline Mine of Coastal States Energy Co., which is located near Price, Utah, is scheduled to open in 1982 with an initial production rate of 437,000 tons per year, This rate ultimately will be increased to 5.4 million tons per year. Over 40 percent of this production, 2.3 million tons, is scheduled for three longwall units ranging in capacity from 702,000 to 864,000 tons per year. Because of extreme variations in seam thickness and the presence of faulting on the property, problems which do not exist at the Deer Creek Mine, the balance of the annual production will be mined with continuous miners. It is estimated that 14 continuous miners will be required to produce their 3. l-million-ton share of the annual production.

Labor

As the above section shows, increased capital costs for longwall mining can be offset by reduced labor costs and increased production, Because the costs of capital and labor will be the major inputs into any mining system, both surface and underground, there always will be some tradeoff between the two, which will vary from mining system to mining system. However, several aspects of labor requirements for longwall systems differ from the labor requirements for room-and-pillar systems. These differences cannot be readily quantified in terms of direct cost.

Western coal mines usually recruit their miners from the general labor force. Some workers may come to the industry with a background in construction or some other related occupation, but few have any mining experience. Therefore, if a mine using longwall mining hires a new employee, there is frequently no need to retrain an individual recruited from room-and-pillar operations. This ability of the Western coal miner to adapt readily to the longwall mining environment has been noted by a number of companies. As indicated above in the discussion of the Deer Creek Mine, the production rate from its newly installed longwall face increased from 1,500 tons per shift to 2,500 tons per shift in little more than 3 months of operation. The only experiences longwall miners at the time the longwall unit was installed were the three shift foremen. The Coal Basin Mine longwall operation in western Colorado and the Sunnyside Mine in central Utah also have had good experiences with the installation of their first longwall units. Like Deer Creek, these mines have achieved production rates much higher than those obtained at many of the longwall units located in Eastern coal mines.

Another benefit of longwall mining from the point of view of the mine operator is the reduced labor requirement when compared to room-and-pillar systems. This factor is an advantage both with respect to finding enough qualified employees to staff an operation and in reducing the amount of infrastructure needed where a mine is remotely located and requires development of a supporting community infrastructure to serve employees, Since minable coal deposits in the West often are located in sparsely populated areas, the availability and the housing of employees are two major considerations. In the case of a mine such as Skyline, which is located in a large rural area of Utah that already has seen the expansion and development of a number of large mines, attracting skilled labor becomes a problem. Thus, reduction in the total number of operating employees required from 480 for a mine using all continuous miners to 340 for a mine using a combination of continuous miners and longwall units is significant,

There are other advantages to the mine operator of reduced overall manpower requirements. These include the reduced potential for personnel turnover, less need for employee training, and an overall reduction in personnel support costs. Operating with a smaller labor force also means that fewer people will be exposed to the hazards of underground coal mining per ton of coal produced. This will be discussed in greater detail in the section on health and safety,

Production and Productivity

As has been discussed in preceding sections of this chapter, production and productivity are related but separate operational considerations. An increased production rate is of interest to the operator who has the reserves to support large market commitments but who is not able to produce the coal required of these commitments because of deficiencies in the production system. In contrast, productivity is of interest to all mine operators, Productivity is usually discussed in terms of coal output in tons per unit of labor expended, but is equally applicable in terms of coal output per unit of machine time expended. Whether stated in terms of labor productivity or equipment productivity, the objective is to maximize coal production per unit of resource used.

The question of improved productivity and longwall mining has been addressed. In the discussion of the capital cost of longwall mining, the potential for improving labor productivity through the installation of longwall equipment was illustrated by two examples. It was also shown that even though the improved labor productivity was achieved through the use of longwall equipment which was more expensive than the continuous miners it replaced, the overall effect was a reduction in the total cost per ton of coal mined.

The underground coal mining industry in the United States has undergone significant change in the past 10 years. A 500,000-ton-per-year mine, formerly considered a large mine, is now considered of small to average size. With this change, production equipment and the scheduling of equipment have become more complex. Whereas a 50(),0()0-ton mine could operate with two to three continuous miners on a two shift-per-day schedule, mines such as the Skyline Mine discussed above would require 24 continuous miners to sustain its 5,4-million-ton-per-year production rate, Coping with the production scheduling in a mine where there are 24 operating sections which require the assignment of manpower, equipment, maintenance, and transportation is an extensive and demanding task. The Skyline operation is not unique in this respect. Other existing and planned underground mines on Federal leases that eventually will be producing in the 5-million-ton-per-year range include the Price River Coal Co. mine (formerly Braztah) in Utah and the Loma Complex in Colorado. In the 2-million- to 3-million-ton-per-year range there will be SUFCo in Utah, Mt. Gunnison in Colorado, Energy Development in Colorado, and potentially La Ventana in New Mexico, The mines in the l-million- to 2-million-ton-per-year range are even more numerous.

Nearly all of these mines will install longwall units, One of the major considerations in arriving at the decision to use longwall mining at these mines has been the need to achieve high production rates. A single longwall unit can produce 750,000 tons of coal per year. The longwalls at the Deer Creek Mine are producing in excess of 1 million tons per year per unit, The Wilberg Mine, a sister mine of Deer Creek, is installing a longwall unit that is rated at 3,000 tons per shift. This translates into 1.5 million tons per year, Coastal States Energy Co. is currently studying the feasibility of using longwall mining at its SUFCo Mine which is located on Federal leases near Salina, Utah. The minable seam, the Hiawatha, varies from 6 to 15 ft in thickness. However, the average thickness is 12 ft and with the exception of thinning on one part, the lease tends to maintain this average over extensive areas. There is little dip to the seam and little noticeable faulting. In sum, these conditions suggest that installation of at least one longwall unit to replace some of the existing 10 continuous miner units would simplify the operation and might reduce the cost of mining.

In summary, Western underground mines need to continue to pursue methods for increasing their production rates and improving their productivity. These combined goals will lower their unit mining costs and thereby enable them to compete more effectively with the coal mines in the Eastern United States and the large surface mines in the West. Other than reduced mining costs, an additional advantage of the increased production rates could be the ability to use unit-train transportation to move coal to markets and thereby recover some of the transportation cost penalty associated with supplying coal to Midwestern and Eastern markets.

Environmental

In the arid West, the impact of underground coal mining on the environment is generally less than that resulting from surface coal mining. Longwall mining can further reduce the environmental impacts normally resulting from room-and-pillar operations.

Subsidence from underground mining can take the form of either a wide-area lowering of the ground surface or sinkholes and fractures that break through to the surface. The results of several studies, conducted both in the United States* and Europe, indicate that longwall mining is most likely to result in wide-area subsidence and to cause little differential subsidence that can result in breaks in the ground surface. These studies also have indicated that surface subsidence is generally limited to an amount equal to one-half the thickness of the coal being extracted, although it can exceed 50 percent and can go as high as 90 percent of the seam thickness. For the thicker seam longwall operations, this would generally mean a subsidence of about 6 ft. A lowering of the surface elevation of this magnitude could be a problem in the Western United States and would have to be handled on a case-by-case basis. However, the areawide form of subsidence likely to result from longwall operations is preferable to the differential subsidence that is more likely to result from room-and-pillar operations,

*The Department of Energy has supported such studies at two mines with Federal leases, the La Ventana Mine in New Mexico and the Snowmass Mine in Colorado.

Health and Safety

Regardless of the type of mine, underground coal mining takes place in a hazardous environment. Fewer workers will be exposed to these hazards in a longwall operation than in other underground coal production met hods for a given level of production.

Because of the fundamental differences between room-and-pillar and longwall mining systems it is difficult to make a direct comparison as to which provides a healthier or safer environment for the worker. The basic hazards—coal dust, methane gas, spontaneous combustion, roof falls, bumps, and moving machinery in confined spaces—are present in both types of mining. In some cases there are tradeoffs in hazards, The control of excessive coal dust at the longwall face is a problem that must be solved, although there are some potential breakthroughs. On the other hand, however, the protection from roof fall hazards provided by longwall supports is superior to that available to the continuous miner operator.

Equipment advances that improve the underground mining environment with respect

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to worker health and safety will continue. However, the most direct results will be obtained through increases in labor productivity and a concomitant reduction in the number of workers that must be exposed to the dangers of underground coal mining.