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Longwall Mining

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Cover:

Longwall mining is an old mining method that was little used in the United States until recently. Because the development of modern equipment such as this longwall unit raised productivity substantially over the past decade, longwall mines now account for about 40 percent of U.S. underground coal production.

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Preface

Section 205(a)(2) of the Department of Energy Organization Act of 1977 (Public Law 95-91) requires the Administrator of the Energy Information Administration (EIA) to carry out a central, comprehensive, and unified energy data and information program that will collect, evaluate, assemble, analyze, and disseminate data and information relevant to energy resources, reserves, and related economic and statistical information.

The legislation that created EIA vested the organization with an element of statutory independence. EIA does not take positions on policy questions. EIA's responsibility is to provide timely, high-quality information and to perform objective, credible analyses.

As part of EIA's program to provide information on coal, this report, *Longwall Mining*, describes longwall mining and compares it with other underground mining methods. Using data from EIA and private sector surveys, the report describes major changes in the geologic, technological, and operating characteristics of longwall mining over the past decade. Most important, the report shows how these changes led to dramatic improvements in longwall mining productivity. For readers interested in the history of longwall mining and greater detail on recent developments affecting longwall mining, the report includes a bibliography.

Contents

Tables

Figures

Executive Summary

Longwall mining is one of the principal underground mining methods in the United States. Its importance as a coal production technique has grown steadily since the introduction of modern longwall technology into this country in the 1950's and 1960's. In the past decade, longwall production and productivity grew rapidly, as a result of significant improvements in longwall equipment and operating practices. By 1993, longwall mining accounted for 40 percent of the Nation's underground coal production—up from 27 percent in 1983. Labor productivity at longwall mines more than doubled between 1983 and 1993. Productivity is now higher for longwall mining than for other underground production methods, and productivity is expected to keep growing as new technological advances are introduced.

Longwall mining is one of two basic methods of underground coal mining. The other method is room-and-pillar mining, historically the traditional method used in the United States. In room-and-pillar mining, "rooms" are excavated, and pillars of coal are left in place between the rooms to support the mine roof. In contrast, longwall mining involves the essentially complete extraction of the coal contained in a large rectangular block or "panel" of coal, and the roof in the mined-out area is allowed to collapse.

The sequence of operations in longwall mining is basically simple. The rectangular longwall panel, averaging nearly 800 feet wide, 7,000 feet long, and 7 feet high, is "blocked out" by excavating passageways around its perimeter. Room-and-pillar mining is used to block out the panel. Excavation of the coal in the panel is an almost continuous operation. Working under the steel canopies of hydraulic, movable roof supports, a coal cutting machine runs back and forth along the 800-foot face, taking a cut ranging anywhere from a few inches to 3-1/2 feet deep during each pass. The cut coal spills into an armored chain conveyor running along the entire length of the face. This face conveyor dumps the coal onto belt conveyors for transport out of the mine. As the cutting machine passes each roof support, the support is moved closer to the newly cut face to prop up the exposed roof. The roof is allowed to collapse behind the supports as they are advanced towards the face. Mining continues in this manner until the entire panel of coal is removed.

Because longwall mining is essentially a continuous, highly mechanized operation, longwall productivity is potentially higher than room-and-pillar productivity. Longwall mining also offers improved safety through better roof control, more predictable surface subsidence, and better opportunity for full automation. On the other hand, capital costs for longwall equipment are much higher than for room-and-pillar equipment, productivity during development ("blocking out") of the longwall panels is typically low, and large amounts of dust and methane are generated during the mining process.

Changes in Geologic, Technological, and Operating Characteristics Over the Past Decade

Two key factors contributing to the dramatic rise in longwall productivity over the past decade are (1) changes in longwall panel dimensions, and (2) improvements in longwall equipment. Longwall panels have become significantly wider and longer. Average face width increased from 548 feet in 1984 to 759 feet in 1993—a 39-percent increase, while average panel length increased by 21 percent (from 5,651 feet to 6,853 feet). Two longwall units have broken the 1,000-foot mark for face width, and five units are operating in panels over 10,000 feet (approximately 2 miles) long.

The increase in panel size contributed to the productivity improvements in a number of ways. First, the quantity of coal mined by the highly productive longwall units increased relative to the quantity of coal mined by the less productive continuous miners[1] used for longwall panel development. This change in the ratio of longwall to continuous miner production also provided the slower continuous miners with more time to develop new panels, thus enabling them to keep

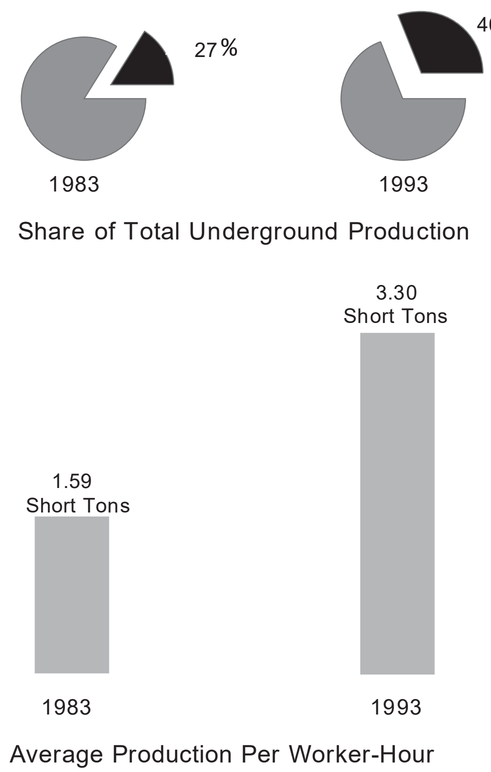
[1]Continuous mining machines, which extract and remove coal from the working face in a continuous operation, are used in both longwall and room-and-pillar mining.

pace with the longwalls. The use of larger panels also reduced the frequency with which the longwall equipment must be moved from a mined-out panel to a new panel. Longwall production comes to a halt during these time-consuming longwall moves.

The move towards larger panels was made possible by improvements in longwall production equipment. Average face conveyor horsepower more than doubled between 1984 and 1993. The increase in conveyor horsepower permitted increases in the capacity and length of face conveyors, and hence allowed increases in face widths. Similarly, average cutting machine (shearer and plow) horsepower increased by 90 percent between 1984 and 1993. Longwall equipment has also become more robust and more reliable.

In addition to changes in panel dimensions and longwall equipment, there have been changes in the geologic conditions under which longwalls operate. Particularly important has been the clear trend away from thinner seam longwall mining. Since thin seam longwalls tend to be less productive than thicker seam operations, this development contributed to the overall improvement in longwall productivity. Finally, there was a significant increase in the size of longwall mines, as measured by their annual production. The proportion of longwall operations producing over 1 million tons[2] per year increased from 47 percent in 1983 to 70 percent in 1993.

Figure ES1. U.S. Longwall Mining Production Shares and Labor Productivity, 1983 Compared With 1993



Sources: Energy Information Administration, 1993 EIA-7A database, and 1983 EIA-7A and EIA-7A Supplement databases.

Changes in Longwall Mining Performance Over the Past Decade

As of 1993, a total of 85 longwall units operated in 73 U.S. coal mines.[3] Most of these mines (53) were located in Appalachia. West Virginia was the leading longwall State, with 21 mines. In 1993, there were 13 longwall mines in the West and 7 operations in the Illinois Basin. Relative to the total underground mine population of roughly 1,200 mines, the longwall mine population is quite small.

However, because longwall mines are almost invariably large operations with high annual production rates, their share of total underground production is disproportionate to their small numbers. In 1993, 40 percent of the total U.S. underground coal output was produced at longwall mines (Figure ES1). This was considerably higher than the 27-percent production share contributed by longwall mines in 1983. Longwall mines now account for 80 percent of underground production in the West, 37 percent in Appalachia, and 27 percent in the Illinois Basin.

The rise in longwall production was largely due to a dramatic increase in longwall labor productivity. Between 1983 and 1993, the average productivity at U.S. longwall mines increased 108 percent, from 1.59 tons to 3.30 tons per worker-hour. Although the productivity of room-and-pillar operations also increased rapidly during this period of declining coal prices and highly competitive markets, operators of room-and-pillar mines were not able to keep pace with longwall operators. As a result, average longwall labor productivity, which was 2 percent lower than the average productivity of room-and-pillar mines in 1983, became 19 percent higher than room-and-pillar productivity by 1993.

[2]Throughout this report, tons refers to short tons.
[3]Some longwall mines operate more than one longwall unit (i.e., set of longwall mining equipment).

There are considerable regional differences in longwall mining productivity. In the West, where the coal seams are substantially thicker and less gassy than in other regions, longwall mining leads other mining methods by a wide margin in terms of productivity. In 1993, western longwall productivity stood at 5.67 tons per worker-hour—40 percent higher than the productivity of continuous miner operations (the prevalent type of room-and-pillar operation). However, in the Illinois Basin, the productivity differential between longwall and continuous mining was insignificant; and in Appalachia, longwall mines had only a 7-percent productivity advantage over continuous mining operations (2.94 tons per worker-hour versus 2.76 tons per worker-hour). In part, this may be because Appalachian longwall mines, producing high-quality coal for metallurgical and export markets, use additional resources for coal cleaning and preparation—processes that reduce the final coal output.

If longwall mines do not have a pronounced productivity advantage over continuous miner operations in the Illinois Basin and Appalachia, why has longwall mining achieved significant market penetration in these regions over the past decade? One possible reason for the trend toward longwall mining is that it has greater potential than other underground mining methods for future productivity improvements. Mining companies must position themselves to take advantage of these potential productivity improvements. Operations that are already using longwall mining will be able to take advantage of future longwall technology developments much more quickly than those lacking longwall experience.

Outlook

The prospects for longwall mining in the United States depend, in large part, on potential technological developments. These include increased use of computers and self-diagnostic equipment, and increased market penetration of recently improved equipment. Probably the most important potential technology development is longwall automation. In a fully automated longwall system, a robotically controlled shearer would advance itself across the face. As it passes each shield, the shield would automatically move to support the newly exposed roof. Such a system would reduce the exposure of workers to health and safety risks, as well as improve productivity. Steps towards full automation have already been taken by a number of longwall operators. For example, Shearer Initiated Support Advancement (SISA) systems, enabling automated control of the shields, are in place at approximately a dozen longwalls.

Legislative developments also may have major impacts on longwall mining in the United States. Potentially important are the mine subsidence provisions in the Energy Policy Act of 1992 (EPACT). In fulfilling the requirements of EPACT, the Office of Surface Mining (OSM) proposed rules on underground mining permit application requirements and underground mining performance standards. In effect, longwall mining could be limited to areas with relatively low concentrations of surface structures.

In 1989, the Energy Information Administration conducted five interviews with representatives of different longwall mining companies, to obtain their views on the prospects for longwall mining. Although the opinions of the interviewees differed on many of the issues addressed, there was unanimous agreement on one point: longwall mining has not yet fulfilled its productivity potential. Predictions on the extent to which longwall productivity will improve over the next 20 years ranged from 20 percent to 100 percent. Factors expected to contribute to this productivity growth include increased belt conveyor haulage capacity, improved equipment reliability, and wider longwall faces.

1. Introduction

Longwall mining is one of the principal underground mining methods in the United States. In 1993, longwall mines accounted for 40 percent of the Nation's underground coal output—compared with 27 percent in 1983. Although basic longwall mining techniques were developed in England in the 17th century, there was little interest in longwall mining in the United States until the 1950's, when new German technology was introduced. As the technology was developed further in the United States, longwall production grew steadily. By 1993, 85 longwall units were operating in 12 States (Figure 1). Labor productivity at longwall mines more than doubled between 1983 and 1993. Productivity is now higher for longwall mining than for other underground production methods, and productivity is expected to keep growing as new technological improvements are introduced. The purposes of this report are to describe the longwall mining process, analyze the most important changes in longwall mining over the past decade, and discuss factors that will shape the future of longwall mining.

Longwall mining techniques are described in Chapter 2 of this report, where they are compared with other (primarily room-and-pillar) underground mining methods. The description of longwall mining includes all three basic components of the longwall system: moveable roof supports, the coal cutting machine, and the armored conveyor at the coal face. The major advantages and disadvantages of longwall mining are pointed out, including a brief discussion of surface subsidence problems. Finally, a brief history of longwall mining is presented, from its roots in 17th-century England to current longwall mining in the United States.

Chapter 3 presents a wide range of data on longwall mining in the United States over the past decade (more precisely, from 1984 through 1993). These data are presented not only at the national level, but also for three major coal-producing regions (Appalachia, the Interior Basin, and the West), and for individual States. Information on geologic conditions illustrates regional differences in seam depth, seam thickness, and mining height. Next, data on face width, panel length, and the number of entries per panel show recent trends in longwall panel layouts.

Chapter 3 continues with a discussion of important changes in the equipment used at longwall mines, including cutting equipment (plows and shearers), roof supports, and face conveyors. The final section of the chapter discusses changes in the operating characteristics of longwall mines, such as mine size and employment levels. These operating characteristics, together with the geologic and technological factors discussed earlier, led to changes in longwall mine production and labor productivity.

Chapter 4 examines changes in the number of longwall mines, longwall mine production, and longwall mining productivity over the period from 1984 through 1993. The chapter shows how the changes in basic conditions that were highlighted in the previous chapter had significant effects on longwall mining productivity. Besides showing important trends in longwall mining, this chapter also makes comparisons between longwall mines and other underground mines. These comparisons are based on aggregate data, covering a variety of conditions such as seam thickness and degree of coal preparation. They are not direct comparisons of production units operating under similar conditions. Again, data are presented at the State and regional levels, as well as at the national level. The chapter concludes with an estimation of the capital and labor costs for two hypothetical longwall mines—one in the East and the other in the West.

The final chapter of this report discusses the outlook for longwall mining in the United States. It focuses on recent technological developments, the current regulatory climate regarding subsidence, and the views of members of the coal industry concerning the prospects for longwall mining.

Figure 1. Location of U.S. Longwall Mining Units, 1993

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels.

2. A Description and History of Longwall Mining

Longwall Mining Compared with Other Underground Coal Mining Techniques

Longwall mining is one of two basic methods of mining coal underground (Figure 2). The other is room-and-pillar mining, historically the standard method in the United States. Both of these methods are well suited to extracting the relatively flat coalbeds (or coal seams) typical of the United States. Although widely used in other countries, longwall mining has only recently become important in the United States, its share of total underground coal production having grown from less than 5 percent before 1980 to 40 percent in 1993.[1] Currently, 85 longwalls operate in the United States, most of them in the Appalachian region.

The basic principle of longwall mining is simple. A coalbed is selected and blocked out into a panel averaging nearly 800 feet in width, 7,000 feet in length, and 7 feet in height, by excavating passageways around its perimeter. A panel of this size contains more than 1 million short tons of coal, most of which is recovered. In the extraction process, numerous pillars of coal are left untouched in certain parts of the mine in order to support the overlying strata. The mined-out area is allowed to collapse, generally causing some surface subsidence.

Extraction by longwall mining is an almost continuous operation involving the use of self-advancing hydraulic roof supports, a sophisticated coal-shearing machine, and an armored conveyor paralleling the coal face. Working under the movable roof supports, the shearing machine rides on the conveyor as it cuts and spills coal onto the conveyor for transport out of the mine. When the shearer has traversed the full length of the coal face, it reverses direction (without turning) and travels back along the face taking the next cut. As the shearer passes each roof support, the support is moved closer to the newly cut face. The steel canopies of the roof supports protect the workers and equipment located along the face, while the roof is allowed to collapse behind the supports as they are advanced. Extraction continues in this manner until the entire panel of coal is removed.

By contrast, the typical underground U.S. coal mine is laid out in a checkerboard of rooms and pillars, and the mining operation involves cyclical, step-by-step mining sequences. The rooms are the empty areas from which coal has been mined, and the pillars are blocks of coal (generally 40 to 80 feet on a side) left to support the mine roof. Room-and-pillar mining generally is limited to depths of about 1,000 feet because at greater depths larger pillars are needed, resulting in smaller coal recovery.

The "continuous" version of room-and-pillar mining is the most common, representing 56 percent of all underground production in 1993. In this method, a continuous mining machine excavates the coal and loads it onto a conveyor or shuttle car in a single step. Despite the term "continuous," the machine operates only part of the working time, because after mining advances about 20 feet, the machine is withdrawn from the face so that roof bolts can be installed to bond the strata and prevent caving.

In "conventional" room-and-pillar mining (which represents 12 percent of underground production), production occurs in five steps: mechanically undercutting the coalbed, drilling holes into the bed for explosives, blasting the coal, loading the broken coal into shuttle cars for delivery to a conveyor, and then bolting the mine roof in the excavated area.

To provide a steady flow of coal in a room-and-pillar mine, several stages of mining occur simultaneously in different rooms. A final phase of mining termed "retreat mining" may be performed to recover additional coal by extracting pillars and allowing the roof to fall. However, this is a complex procedure that requires additional planning.

Advantages of Longwall Mining

Longwall mining is a very efficient coal-producing technique. Longwall productivity is potentially higher than that of room-and-pillar mining, because longwall mining is basically a continuous operation requiring fewer workers and allowing a high rate of production

[1]Energy Information Administration, *Bituminous Coal and Lignite Production and Mine Operations—1978*, DOE/EIA-0118(78) (Washington, DC, June 1980), p. 45; and *Coal Industry Annual 1993*, DOE/EIA-0584(93) (Washington, DC, December 1994), p. 12.

Figure 2. Underground Mining Systems

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels.

to be sustained. The amount of coal recovered is also high, currently reaching 57 percent as a nationwide average, but achieving higher percentages at some mines. Room-and-pillar recovery rates are slightly lower. However, longwall coal recovery may not be significantly different from room-and-pillar mines prac-ticing "retreat mining."

The longwall system also offers a number of other advantages over room-and-pillar mining. It concentrates miners and equipment in fewer working sections, making the mine easier to manage. Safety improves through better roof control and a reduction in the use of moving equipment. This method eliminates roof bolting at the working face to support the mine roof, and it minimizes the need for dusting mine passages with inert material to prevent coal dust explosions. It involves no blasting, with its consequent dangers. It also recovers more coal from deeper coalbeds than does room-and-pillar mining. The coal haulage system is simpler, ventilation is better controlled, and subsidence of the surface is more predictable. Overall, as well, longwall mining offers the best opportunity for automation.

Disadvantages of Longwall Mining

Foremost among longwall mining's drawbacks are capital costs for equipment and installation that are substantially higher than those for room-and-pillar mining. In addition to longwall equipment, continuous mining machines and other equipment used in room-and-pillar mining are required for the development work needed to block out a panel of coal for longwall mining. Because a large initial capital outlay is required with no immediate return from coal production (apart from the coal produced during development work), economics generally restricts longwall mining to large coal companies. Moreover, small coal companies inexperienced in longwall mining may not be able to provide time for the specialized training needed for this mining method.

Longwall mining is a method in which all parts must operate as an integrated system. A failure of one part can disrupt the entire operation, and the impact on meeting contracts for coal sales can be substantial.

Longwall mining also requires a well-maintained ven-tilation system because of the large amounts of dust and methane produced. Dust levels often exceed the maximum allowable limit despite improvements in dust-control technology. When this is noted during a Federal mine inspection, a temporary variance is granted so that the dust levels can be lowered by modifying the coal-cutting sequence and / or by increasing the air flow across the face.

Geologic Considerations

Not all coalbeds are suitable for longwall mining. The technique works best in coalbeds that are extensive, fairly flat-lying, of generally uniform thickness, and free of discontinuities, such as large faults or other geologic features that could interfere with continuous coal extraction. The mine floor must provide a firm base for the movable roof supports used in longwall mining. Important aquifers should not overlie the coalbed. Oil and gas wells in the area to be mined represent ob-stacles, because pillars of coal must be left around the wells to provide protection.

Ideally, the strata overlying the coalbed should cave behind the roof supports soon after the coal is extracted. If the strata "hang up" and break into large blocks, the high stresses placed on the roof supports may interfere with their operation by locking them in place. When large sections of hard-to-cave roof strata eventually fall, dangerous working conditions can occur due to violent air blasts, ground vibrations, and related conditions.

On the other hand, certain geologic conditions strongly favor longwall mining over room-and-pillar mining. In particular, coalbeds deeper than 1,000 feet typically must be extracted using longwall mining. Room-and-pillar mining generally is not economical at such depths because the very large pillars required to support the mine roof significantly reduce the amount of coal that can be recovered. In contrast, longwall mining is well suited to deep coalbeds because there is no need to support the roof. In fact, the roof in deep mines is less likely to "hang up" behind the supports, thereby reducing the stress on the roof supports.

Development of a Longwall Operation

The first step in the development, or preparation, of a panel of coal for longwall mining involves the use of continuous mining machines to dig entries, or passageways, on three sides of a panel, starting from the main entries of the mine. Development work generally requires 9 months to 1 year, depending on the size of the panel. At this stage, a small amount of coal is produced because the entries are excavated through the coalbed, following the room-and-pillar technique. Development work also provides a means for exploring the area to be mined for potentially troublesome geologic conditions. In areas with a history of geologic problems or large variations in coalbed thickness, the panel may be explored prior to development by drilling from the surface.

The Federal Coal Mine Health and Safety Act of 1969 requires that mine entries consist of at least three parallel passageways (three-entry systems), so that if one is accidentally blocked the others afford a means of escape; at least one provides an airway for mine ventilation. However, the Act allows a mining company to use two passageways (two-entry systems) if the safety of its mining plan is approved by the U.S. Mine Safety and Health Administration. Two-entry systems have been approved for use in several western coal mines because they provide better ground stability than the three-entry systems previously used.[2]

In longwall mines, two sets of entries called "panel entries" (or "gate entries"), one on each side of the panel of coal to be mined, are driven from the main mine entries to the end of the panel (Figures 3 and 4). They are then connected at the back of the panel by another set of entries.

Each entry is about 20 feet wide and 6 feet high. Entries are connected at regular intervals by crosscuts, which are dug to allow passage of workers and equipment between adjacent entries. The entries next to the panel that are used to transport miners, coal, and supplies are the "headgate" entries (or "headentry"). On the opposite side of the panel are the "tailgate" entries ("tailentry"), used mainly as an airway in ventilating the mine. Due to the parallel layout of longwall panels, the headgate entries become the tailgate entries of the next panel to be mined. The entries at the back of the panel, where extraction begins, are "bleeder entries" that provide continuity in the mine ventilation system.

Within the entries are unmined parts of the coalbed called "chain pillars" that are left to support the overlying strata. They measure 20 to 150 feet in width and 40 to 200 feet in length, depending on mining conditions. Additional support is provided by roof bolting. Optimizing pillar design for both safety and economics is a key part of planning longwall mines. Miners working in the entries are not protected by powered supports as they are at the face and are exposed to greater roof fall hazards. Thus, pillar design is a key to preserving safety in this area. On the other hand, pillars that are too large can be expensive and wasteful because the coal locked up in them is seldom recovered and is a lost resource. In addition to the chain pillars in the entries, large "barrier pillars" (200 to 500 feet on a side) are left at both ends of the panel to provide roof support and to separate unmined and mined-out panels. A "setup room" is excavated next to the barrier pillar at the rear of the panel to provide space for assembling the longwall equipment.

Extraction by Longwall Mining

After the longwall panel has been blocked out by entries, it is mined on "retreat." This means that extraction begins from the farthest end of the panel and proceeds toward the main entries (toward the mine entrance). This technique contrasts with the "advance" system, common in Europe, in which mining progresses away from the main haulageway toward the far end of the panel. Although advance longwall mining produces large amounts of coal from the onset, the method has disadvantages. Development of the entries on each side of the panel must continue simultaneously with the advance of the longwall face, "deadwork" is required to keep entries open through caved ground ("gob") behind the area extracted, and mine ventilation is more complex than with the retreat method. The advance system was tried in U.S. coalfields, but it was abandoned because of roof failures and poor production. The current trend in European coal mines is toward the greater use of retreat longwall mining.

The longwall mining system comprises three basic equipment components—movable roof supports, a coal extraction machine that moves back and forth across the coal face, and an armored conveyor at the coal face. Almost all movable roof supports in use today are shields, the most stable in a succession of roof support designs. A shield consists of a canopy, a caving shield that prevents rock fragments from getting into the working area, and two to four hydraulically operated legs set on a base. Today's shields typically can support 600 to 800 tons of rock. More than 100 shields, set side by side, are required for a single longwall panel. Apart from supporting the roof, the shields provide 10 to 15 feet of space for miners and equipment to work. As the coal is removed and the face advances, a system of controls and hydraulic cylinders snake both the shields and the conveyor forward. The roof of the mined out section is allowed to collapse behind the shields, forming gob.

Two types of coal-cutting machines are used for longwall mining: shearers and plows. Shearers predominate by far; they were used at 82 of the 85 longwall installations in 1993. A shearer has a large,

[2]U.S. Department of the Interior, Bureau of Mines, "Longwall Gate Road Stability in Four Deep Western U.S. Coal Mines," *Information Circular 9406* (Washington, DC, 1994).

Figure 4. Typical U.S. Longwall Panel Layout
(Not to Scale)

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels.

exceeds the size of the cutting drum, the single-drum ranging shearer makes a return cutting pass to complete coal extraction. A single-drum fixed shearer cannot be adjusted for height and, consequently, is used mostly for mining thin coalbeds of uniform thickness.

The plow is a much simpler machine, used mostly for relatively thin (42 inches or less), soft coalbeds. It consists of a blade with fixed bits or a saw-toothed edge that cuts a slice of coal 3 to 6 inches wide. Unlike the shearer, the plow has no motorized equipment and is pulled along the coal face by a heavy chain at speeds up to 300 feet per minute. In "gassy" coalbeds, which contain relatively large amounts of methane, the plow is less likely to produce sparks that could cause an explosion; in addition, the shallow cut made by the plow releases less methane per pass than does the shearer. However, the plow has several disadvantages. For example, it has little ability to adjust to different bed heights, it cannot cut very hard coal, and its mechanical efficiency is low when compared with a shearer.

Coal cut by either the shearer or plow falls onto an armored chain conveyor, a key part of the longwall system. The conveyor is armored in order to support the weight of the shearer or plow and to withstand the impact of falling coal. It can be advanced without being dismantled. It consists of a series of metal pans about 5 feet long that are bolted end to end so the entire set spans the length of the coal face. Strong enough to carry the weight of the shearing machine, the armored conveyor is also sturdy enough to be "snaked" to negotiate curves when pushed forward as the shearer or plow moves along the coal face and also sturdy enough to transport coal even when not in straight alignment. Coal carried by the armored conveyor empties onto a "stage loader" at the end of the face. The stage loader, a mobile conveyor 30 to 150 feet long and similar in construction to the armored conveyor, connects with a conventional belt conveyor that carries coal to the main haulage way for transport out of the mine.

Following extraction of all of the coal in a panel, a major operation called a "longwall face move" is performed over a period requiring about 2 weeks. During this time, all the equipment is disassembled in a "recovery room" and then moved for setup at a new panel. Generally, one to two longwall panels are extracted annually in a mine.

Surface Subsidence

As the coal panel is mined out, the roof collapses to form a caved area called gob. The collapsed material provides considerable support for the overlying strata, but the strata eventually settle, leading to subsidence on the surface. Although inevitable, subsidence caused by longwall mining is generally uniform and more predictable than subsidence due to room-and-pillar mining. In longwall mining, subsidence generally begins as coal extraction progresses. By contrast, in room-and-pillar mining, the supporting pillars deteriorate at some later time, making subsidence difficult to predict.

The amount of subsidence depends on such factors as time, depth of mining, thickness of the coalbed extracted, thickness and strength of the overlying rock, and any previous mining of overlying coalbeds. The impact of subsidence on surface structures depends on their size and number. Subsidence can also have hydrologic impacts, disrupting the flow of water on the surface and underground. However, subsidence damage to critical areas can be anticipated and minimized when mine planning and mining operations take into account geologic and other subsurface conditions. If the coal company does not own the surface rights, it can be held responsible for subsidence damage. Liability insurance can be purchased to cover damages.

The History of Longwall Mining

Longwall mining is not a new approach to coal mining. In fact, the basic principles of longwall mining have been traced back to the latter part of the 17th century to Shropshire and other counties in England, where it was described as a "totally different method of mining" called the "Shropshire method."[3] Many modifications in the original methods have occurred, but all longwall mining has involved extracting coal from a long wall or face. The area from which the coal was extracted, the "gob" (from a Celtic word for cave or hollow[4]), was partly or wholly filled with stone and refuse, upon which the overlying strata settled.

Until the early 1900's, coal mining in England was mostly by the "bord and pillar" method (equivalent to "room-and-pillar"). The "bords," or passages, were

[3]Robert L. Galloway, *A History of Coal Mining in Great Britain*, Reprint with New Introduction, Bibliography, and Index by Baron F. Duckham; first published by Macmillan & Company in 1882 (New York, NY: Augustus M. Kelley, 1969), p. 86.
[4]Granville Poole, "Historical Survey of Methods of Working," *Historical Review of Coal Mining*, Mining Association of Great Britain (London: Fleetway Press, Ltd., 1924), p. 43.

areas 12 to 20 feet wide from which the coal was extracted; the pillars were made of coal, some 50 feet wide and as many as 100 feet long, that was left unmined to support the overlying strata.[5] Efforts to extract some or all of the coal left in the pillars at a later stage of mining either were not attempted or were not always successful.

As the demand for coal increased, bord and pillar mining soon was regarded as wasteful, and the advantages of the longwall technique were noted: "It enables a colliery to be opened with less capital expenditures . . . and to become remunerative in the smallest possible time . . . The yield per acre is greater . . . Ventilation is easier, the workmen are concentrated, and the expense of supervision is reduced . . . in seams giving off large quantities of explosive gas . . . shot firing can almost entirely be dispensed with [because the] weight on the face is in itself sufficient to bring down the coal . . . ."[6]

The overall layout of early longwall mines was generally circular, with mining radiating out from a central shaft (Figure 5). The main roadways ran diagonally from the shaft pillar like the spokes of a wheel, while the intervening areas were subdivided into smaller and smaller sectors by subsidiary roadways. The roadways were kept open by "pack walls" of waste rock constructed on either side of them. The roof in the working area, or face, was supported by a line of timbers, which were moved forward as mining advanced, and by "packs" or "cribs" of waste rock, while the roof in the mined out area was allowed to collapse.

Longwall mining was practiced on a very small scale in the United States in the late 1800's and early 1900's.[7] The pioneering longwall attempts were generally in thin coalbeds that could not be mined effectively by room-and-pillar techniques, and that required a minimum of packwall construction and backfilling for roof support. Where successful, those early longwall operations resulted in complete removal of the coal at minimal expense, with less timbering, more controlled subsidence, and better ventilation in the working area than room-and-pillar methods.

Until undercutting machines became available in the early 1900's, longwall miners undercut the coal by hand with picks. The early working faces generally were in the form of an arc about 40 feet across, but as mines became deeper and mechanized, straight faces were found to be more efficient.

The undercut coalbed was temporarily supported by short wooden props or "sprags" set every 4 to 6 feet. When the props were knocked out, the undercut coal fell because of its own weight and roof pressure, but if necessary, it was knocked down; explosives were seldom used. The broken coal was then loaded by hand into cars (tubs) for transport out of the mine. By 1924, productivity was improved when conveyors were installed along the longwall face in some mines.

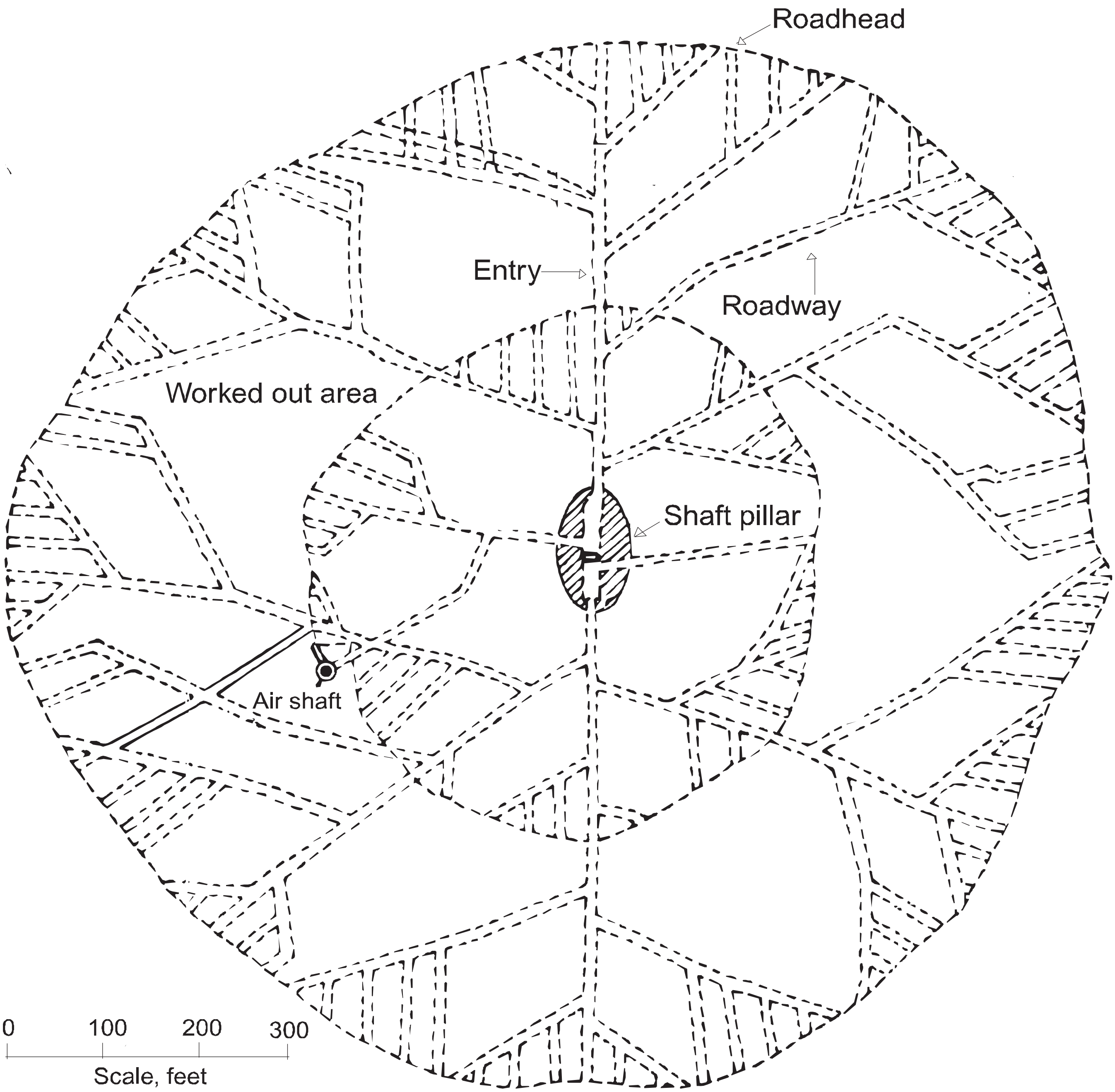
Overall, the experience of early longwall mining in the United States showed that it was not competitive with the room-and-pillar method. Although steel jacks replaced wooden props for roof control around 1912, and mines were becoming mechanized, the large number of workers required to move the jacks and to construct other types of roof supports made longwall mining a labor-intensive effort. With longwall productivity averaging only about 3 tons or less per worker per shift, U.S. underground mining technology focused on improving room-and-pillar mining, a better method for extracting coal from relatively thick beds. In contrast, longwall mining remained predominant in Europe, where conditions were more suitable for the technique because the coalbeds were deeper and overlain by thinly layered strata that caved more easily than those in the typical U.S. coal mine.

1950-1960

After World War II, U.S. interest in longwall mining was renewed by the possibilities of using the German-developed plow (or planer) and "panzer," or armored face conveyor. The plow is pulled across the coalface while riding on a base that slides under the conveyor. It shaves off 2 to 4 inches of coal that spills onto the conveyor. In 1952, Eastern Gas and Fuel Associates, with support from the U.S. Bureau of Mines, tested longwall mining with a plow and face conveyor at the Statesbury mine, near Beckley, West Virginia, to learn if this type of equipment could be used to extract some U.S. coal. Roof support was provided by mechanical props with I-beam caps and wood cribs. The test was successful and the equipment was used in three other longwall operations between 1952 and 1958.

[5]Cedric E. Gregory, *A Concise History of Mining* (NY: Pergamon Press, 1980), p. 110.
[6]H. W. Hughes, *A Text-Book of Coal-Mining*, 6th ed. (London: Charles Griffin & Co., Ltd., 1917), p. 200.
[7]Some systems of early longwall mining are described in "Longwall Mining Methods in Some Mines of the Middle Western States," *Information Circular 6893*, Bureau of Mines, U.S. Department of the Interior (Washington, DC, 1936), and in Robert Peele, "Longwall Methods," *Mining Engineers' Handbook*, 3d ed. (New York: John Wiley & Sons, Inc., 1941), Vol. 1, pp. 10-505 to 10-511.

Figure 5. Early Longwall Mining



Source: U.S. Department of the Interior, Bureau of Mines, "Longwall Mining Methods in Some Mines of the Middle Western States," *Information Circular 6893* (Washington, DC, 1936).

During the 1950-1960 period, there were an average of six longwall operations per year, mostly in West Virginia and Pennsylvania, but also in Arkansas. The plow was the principal coal-cutting machine, replacing the early labor-intensive mechanical undercutting method. However, about three-fourths of the longwall operations were not successful because the coalbeds were not friable enough for extraction with a plow, or because roof control presented problems.

Although the hydraulic props introduced in the late 1950's were an improvement over the earlier mechanical friction props, a large amount of manual labor was still needed to recover and reset the props. Moreover, as the face advanced, wood cribs had to be constructed for additional roof support, requiring additional manual labor. As a consequence, by 1960 longwall mining was generally considered a last resort, used only for extracting thin beds of premium coal when room-and-pillar methods failed. Other factors also constrained the use of longwall mining in the United States. These included the lack of familiarity with the method on the part of the U.S. coal industry, and the high capital investment required for the equipment. Furthermore, by this time, continuous mining machines were improving the efficiency of room-and-pillar mining.

1960-1970

Interest in longwall mining in the United States revived in the 1960's, and the number of installations rose to about 20 before 1970, due mainly to the introduction of self-advancing hydraulic roof supports. These powered supports replaced jacks and wood cribs, eliminating the need for substantial labor. They also had the advantage of being able to push the conveyor forward automatically as the face advanced. Self-advancing hydraulic roof supports were first used, together with a plow, in 1960 to excavate a 52-inch coalbed in Eastern Associates' Keystone mine near Welch, West Virginia.

The first self-advancing roof supports were frames. A frame consisted of two single hydraulic jacks connected to a beam, and two frames were linked together to operate as a pair. They advanced in two steps. While one frame remained set between the roof and floor, the other was lowered and then pushed forward by a ram; the procedure was reversed to move the other frame. Frames with a two-leg design could support as much as 88 tons before yielding; those with four-leg designs were about twice as strong.

Frames successfully supported the roof when the overlying strata caved easily, but they were often inadequate if the strata "hung up." A number of longwall installations in the Illinois Basin were discontinued because frames could not control the mine roof.

In the mid 1960's, better designed, high-capacity, self-advancing roof supports, capable of holding about 700 tons, became available in the form of the chock. Described as a mobile crib, the chock consists of two frame supports tied together with a rigid canopy and semi-rigid base. More stable than frame supports, the chock is also safer because it has a canopy that provides protection against material falling from the mine roof. The chock can also be advanced as a single unit by a hydraulic ram attached to the face conveyor. Chocks were first installed in several longwall operations in West Virginia.

Although the chock represents a great improvement in roof control technology, it can become unstable when the roof caves in large pieces and creates rotational or horizontal stresses. The instability can occur because the chock's canopy is connected to its base only by the hydraulic leg cylinders. Several longwall operations in southern Illinois were abandoned because chocks failed as the result of serious roof control problems.

The 1960's also saw the introduction of the shearing machine in the United States, first at Kaiser Steel Corporation's Sunnyside mine in Utah in 1961, and later in mines in the East. The shearing machine is an electrically powered rotating drum that not only excavates harder coal, but also cuts a wider strip (24 to 28 inches) from the coalbed than the plow.

However, the early shearers were not free of problems. A shearer's performance could be reduced if the supports were not advanced uniformly, resulting in poor alignment of the shearer with the coal face. Furthermore, the shearer's heavier weight required the use of stronger armored face conveyors to support it. Shearers also produced finer sized coal than plows, and this tended to jam face conveyors, reducing productive mining time. Health problems became a concern because the shearer also generated more respirable dust. Nevertheless, by 1966, after improvements were made, shearers produced 42 percent of the coal at U.S. longwall operations. By 1970, shearers outnumbered plows, and the first double-drum ranging shearer was in service in the northern Appalachians.

1970 to 1980

In this period, the last major impediment to the acceptance of longwall mining in the United States was overcome through the introduction of shield supports, a major step in the evolution of roof control. Although new to the U.S. coal mining scene, shields had been used successfully since the 1960's in the Soviet Union and other Eastern European countries.

Safety and productivity factors favored the shield over the chock. The average support capability of a shield and chock are about the same, but the shield is more stable. The shield provides additional roof support because its canopy and base are connected by structural members other than the hydraulic leg cylinders. As a result, the leg cylinders of the shield, unlike those of the chock, are not subjected to damaging bending movements.

The first shields in the United States were installed in 1975 in the Shoemaker mine of Consolidation Coal Company, near Moundsville, West Virginia. Shortly afterwards, shields were applied to other U.S. longwall operations, proving successful in areas where other roof supports failed. The basic shield design was improved, and by the late 1970s, shields were the leading roof supports in longwall installations.

Advances made to the double-drum and ranging arm shearers developed in the 1960's made them more adaptable. Their cutting height could be quickly adjusted when coalbed thickness changed or when it was necessary to leave a layer of coal at the top of the bed to strengthen the mine roof. Improvements were also made in the method of hauling the shearer across the coal face. The early shearers were pulled by chains stretched along the length of the face. If the chain broke, it could cause serious injuries. By the early 1970's, shearers moved by safer “chainless” methods using self-contained traction units. Although development concentrated on the shearer, the plow was also improved. A plow designed to be stronger and more rugged was placed in service in 1974 at Clinchfield Coal Company's No. 2 mine, near Dante, Virginia. It operated successfully in a thin coalbed that had been too hard for earlier plows.

1980-1994

Since 1980, an average of more than 100 longwall installations have been in operation annually in the United States. In recent years, however, the number has declined slightly, reflecting partly economic and market conditions for coal and partly the ability of the current longwall operations to meet demand without the need for additional installations.

Shields have become the predominant type of roof supports in U.S. longwall mines, and shearers the principal cutting machines. The reliability of armored face conveyors, like that of roof supports, has been improved to the extent that they are no longer responsible for major interruptions in longwall mining.

The list of wide-ranging advances in longwall technology includes shearers that are designed to mine relatively thin coalbeds (less than 42 inches). Better dust control has been achieved with water sprays and improved design of cutting drums and cutting bits. Power supply problems for large multiple shearer motors and longer face conveyors have been overcome. With the electrohydraulic control systems available for shield supports, a miner can easily move a group, or batch, of supports from a dust-free location.

Because longwall mining is a repetitive process, it has the potential to be automated. Among the health and safety benefits from an automated longwall installation are the removal of personnel from hazards such as dust exposure, roof falls, and noise. The economic benefits include improved coal quality, higher productivity, reduced maintenance costs (for example, reduced wear on the shearer's cutting bits), increased speed of operation, and better use of personnel.

Automation is being incorporated in all phases of longwall mining. Push-button control to begin a sequence of predetermined patterns is now becoming the norm. Shield advance can be automatically controlled by a signal from the shearer. Sensors and control systems have been developed to detect the coal-rock interface and provide automatic vertical ranging of the shearer drums.

An example of the mature state that longwall mining has reached is the 15-million dollar system installed by the CONSOL Coal Group in 1994 at its Robinson Run mine, near Shinnston, West Virginia. Reportedly the world's most advanced longwall system, it integrates sophisticated computer technology, instrumentation, and robotic controls to automate most of the routine tasks of longwall mining, using a 42-inch coal shearer and 172 hydraulic roof support shields.

At some Western longwall mines, entry is driven horizontally into the base of a high escarpment, such as this one in Utah.

3. Changes in Geologic, Technological, and Operating Characteristics of Longwall Mining, 1984-1993

This chapter analyzes changes in longwall mining characteristics and practices, generally spanning the 1984-1993 period. The data on various geologic conditions, longwall panel layouts, and mining equipment were derived from the annual "longwall census" issues of *Coal* magazine and its forerunner, *Coal Mining*. It should be noted that the longwall census provides data for each longwall unit, rather than for each longwall mine. Since some longwall mines include two or three units, the total number of longwall units exceeds the total number of longwall mines.

Geologic Conditions

Seam Depth

In 1993, the majority (72 percent) of all longwall units were located at depths of 1,000 feet or less, while 18 percent were located at depths greater than 1,500 feet (Table 1). Many of the deepest longwall mines were located in Colorado, Utah, Alabama, and Virginia.

The distribution of longwall units by depth category remained fairly constant over the 1984-1993 period, with one notable exception: there was a significant drop in the proportion of shallow-depth (500-foot or less) longwalls, from 24 percent of the total in 1984 to 13 percent in 1993, and a concurrent increase in the percentage of longwalls operating in the 751- to 1,000-foot range. The decline of shallow-depth longwall mining was due in large part to the reduction in the number of longwalls in Ohio and West Virginia. In both of these States, many longwall units operate in relatively shallow coal seams (Table 2).

In general, longwalls in most northern Appalachian States operate at relatively shallow depths. However,

Table 1. Distribution of Longwall Units, by Seam Depth, 1984, 1988, and 1993

Seam Depth Range (feet)	1984		1988		1993	
	Number of Units	Percent of Total	Number of Units	Percent of Total	Number of Units	Percent of Total
0-500	25	23.6	13	14.6	11	12.9
501-750	38	35.8	33	37.1	29	34.1
751-1,000	13	12.3	13	14.6	21	24.7
1,001-1,250	5	4.7	6	6.7	6	7.1
1,251-1,500	4	3.8	5	5.6	3	3.5
1,501-1,750	7	6.6	6	6.7	5	5.9
1,751-2,000	9	8.5	7	7.9	7	8.2
> 2,000	5	4.7	6	6.7	3	3.5
Total	**106**	**100.0**	**89**	**100.0**	**85**	**100.0**

Notes: For many longwall units (62 in 1984, 51 in 1988, and 60 in 1993), the data sources provide a range of seam depths rather than a single value. In these cases, the median of the range was used as the seam depth for the purpose of developing summary statistics. Also, units for which seam depth data were missing (6 in 1984 and 3 in 1988) were excluded. Percentages may not add to 100 because of independent rounding.

Sources: Mark W. Sprouls, "Longwall Census '84," *Coal Mining,* December 1984, pp. 39-53; Mark W. Sprouls, "Longwall Census '89," *Coal,* February 1989, pp. 33-43; and Paul Merritt, "1994 Longwall Census," *Coal,* February 1994, pp. 26-35.

Table 2. Average Seam Depth of Longwall Units, by State and Region, 1984, 1988, and 1993

State/Region	1984		1988		1993	
	Number of Units	Mean Depth (feet)	Number of Units	Mean Depth (feet)	Number of Units	Mean Depth (feet)
Alabama	6	1,600	10	1,560	9	1,586
Eastern Kentucky	4	862	4	1,075	4	900
Maryland	--	--	1	600	1	550
Ohio	9	458	3	433	4	456
Pennsylvania	13	542	12	662	13	707
Virginia	11	1,313	13	1,400	8	1,604
West Virginia	42	676	27	684	23	724
Appalachia	**85**	**789**	**70**	**949**	**62**	**950**
Illinois	6	606	7	609	9	606
Western Kentucky	--	--	1	675	1	825
Illinois Basin	**6**	**606**	**8**	**617**	**10**	**628**
Colorado	5	2,060	5	1,640	5	920
New Mexico	1	700	--	--	1	550
Utah	8	1,869	5	1,530	6	1,500
Wyoming	1	400	1	400	1	800
West	**15**	**1,757**	**11**	**1,477**	**13**	**1,150**
United States	**106**	**916**	**89**	**984**	**85**	**943**

-- = Not applicable.

Notes: For many longwall units (62 in 1984, 51 in 1988, and 60 in 1993), the data sources provide a range of seam depths rather than a single value. In these cases, the median of the range was used as the seam depth for the purpose of developing summary statistics. Also, units for which seam depth data were missing (4 in 1984 and 3 in 1988) were excluded.

Sources: Mark W. Sprouls, "Longwall Census '84," *Coal Mining,* December 1984, pp. 39-53; Mark W. Sprouls, "Longwall Census '89," *Coal,* February 1989, pp. 33-43; and Paul Merritt, "1994 Longwall Census," *Coal,* February 1994, pp. 26-35.

average depth increases significantly as one moves from northern to southern Appalachia (particularly into Virginia and Alabama).

Average longwall seam depth in Appalachia increased from 789 feet in 1984 to 950 feet in 1993, with virtually all of the increase occurring between 1984 and 1988. This significant increase in Appalachian seam depth suggests that the depletion of the large contiguous reserve blocks suitable for longwall mining may be proceeding more rapidly in Appalachia than in the Illinois Basin and the West. This hypothesis is supported not only by the increase in the average Appalachian longwall depth (indicating a move to less desirable deeper seams), but also by the significant decline in the number of Appalachian longwalls.

Longwall mines in the Illinois Basin operate in relatively shallow seams. Average seam depth has been lower in the Illinois Basin than in either of the other two regions, and it has remained fairly constant over the 1984-1993 period.

The West (particularly Utah) is characterized by relatively deep longwall mines and the greatest average seam depth of any region.[8] However, average seam depth in the West dropped by 35 percent, from 1,757 feet in 1984 to 1,150 feet in 1993. This change was largely due to the closing of some very deep longwall mines in Colorado and the opening of an equal number of mines that were not as deep in the same State.

For the Nation as a whole, average longwall seam depth increased from 916 feet in 1984 to 984 feet in 1988, primarily due to the increase in Appalachian seam depths. The opposite trend occurred from 1988 to 1993, when average seam depth fell to 943 feet, due to the decline in Western longwall depths. Nevertheless,

[8] It should be noted that, for some very deep Western mines, entry is driven horizontally into the base of a high escarpment, although the seam depth is measured from the top of the plateau.

the national average longwall seam depth was 3 percent higher in 1993 than in 1984.

Seam Thickness and Mining Height

There have been significant changes in the distribution of longwall operations by seam thickness and mining height over the past decade. Most importantly, the dis tribution indicates a clear trend away from relatively thin-seam longwall mining.

Mining height (or cutting height) is the vertical distance of the cut through the coal seam. In general, mining height is quite closely related to the thickness of the seam.[9] The percentage of longwall units operating in the lowest (less than 52-inch) mining height range fell from 17 percent in 1984 to 5 percent in 1993 (Table 3). The proportion of longwall units falling within the 52- to 60-inch mining height range dropped from 15 percent to 8 percent over the same period.

The decline in the number of thin-seam operations was a factor in the dramatic increases in underground mine productivity during the decade. Many thin-seam longwalls, which tend to be less productive than thicker-seam operations, were not able to remain competitive as productivity at thicker-seam operations increased over time. Another factor that has tended to decrease the relative importance of thin-seam mining is that double-drum ranging shearers require a minimum clearance of approximately 52 to 54 inches. Below this height, single drum shearers or plows must be used. Improvements in these machines for thin-seam mining appear to be lagging behind improvements in double-drum shearers.

Between 1984 and 1993, the average longwall mining height increased by 5 inches in Appalachia (Table 4), reflecting the decline in the number of thin-seam longwalls, all of which are located in Appalachia. In particular, note the decline in the number of longwall units (and the consequent increase in the average mining height) in Ohio and Virginia. Both of these States are characterized by low average seam thickness and mining height.

Average mining height increased by 26 inches in the West between 1984 and 1993. Partly, this reflected a move toward thicker coal seams. However, mining height also increased relative to seam thickness, suggesting that longwall mining equipment has been adapted to the thicker seams of the West.

In contrast to the increases in Appalachia and the West, average mining height dropped by 5 inches in the Illinois Basin over the same period. This was due to a decline in average seam thickness. Nevertheless, as shown in the next section, the region's longwall mine productivity increased, due in part to the increased face width and length of the longwall panels.

Table 3. Distribution of Longwall Units, by Mining Height, 1984, 1988, and 1993

Mining Height Ranges (inches)	1984		1988		1993	
	Number of Units	Percent of Total	Number of Units	Percent of Total	Number of Units	Percent of Total
< 52	19	17.1	7	7.6	4	4.7
52-60	17	15.3	5	5.4	7	8.2
61-72	20	18.0	24	26.1	25	29.4
73-96	36	32.4	40	43.5	31	36.5
> 96	19	17.1	16	17.4	18	21.2
Total	**111**	**100.0**	**92**	**100.0**	**85**	**100.0**

Notes: For some longwall units (8 in 1984, 13 in 1988, and 35 in 1993), the data sources provide a range, rather than a single value, for mining height. In these cases, the median of the range was used as the seam depth for the purpose of developing summary statistics. Also, one unit for which mining height data was missing in 1984 was excluded. Percentages may not add to 100 because of independent rounding.

Sources: Mark W. Sprouls, “Longwall Census '84,” *Coal Mining,* December 1984, pp. 39-53; Mark W. Sprouls, “Longwall Census '89,” *Coal,* February 1989, pp. 33-43; and Paul Merritt, “1994 Longwall Census,” *Coal,* February 1994, pp. 26-35.

[9]The notable exceptions are in Colorado and Utah, where average mining height is significantly lower than the average seam thickness.

Table 4. Average Mining Height of Longwall Units, by State and Region, 1984, 1988, and 1993

State/Region	1984		1988		1993	
	Number of Units	Mean Height (inches)	Number of Units	Mean Height (inches)	Number of Units	Mean Height (inches)
Alabama	7	74	9	69	9	77
Eastern Kentucky	4	74	4	76	4	78
Maryland	0	--	1	93	1	93
Ohio	9	55	3	69	4	66
Pennsylvania	14	58	12	66	13	58
Virginia	11	59	12	61	8	68
West Virginia	44	70	29	73	23	70
Appalachia	**89**	**66**	**70**	**70**	**62**	**71**
Illinois	6	98	7	85	9	89
Western Kentucky	1	50	1	58	1	58
Illinois Basin	**7**	**91**	**8**	**82**	**10**	**86**
Colorado	5	98	5	109	5	112
New Mexico	1	72	0	--	1	102
Utah	8	102	6	120	6	139
Wyoming	1	126	1	156	1	156
West	**15**	**101**	**12**	**118**	**13**	**127**
United States	**111**	**72**	**90**	**77**	**85**	**81**

-- = Not applicable.

Notes: For some longwall units (8 in 1984, 13 in 1988, and 35 in 1993), the data sources provide a range, rather than a single value, for mining height. In these cases, the median of the range was used as the mining height for the purpose of developing summary statistics. Also, one unit for which mining height data was missing in 1984 and two units in 1988 were excluded from the table.

Sources: Mark W. Sprouls, "Longwall Census '84," *Coal Mining,* December 1984, pp. 39-53; Mark W. Sprouls, "Longwall Census '89," *Coal,* February 1989, pp. 33-43; and Paul Merritt, "1994 Longwall Census," *Coal,* February 1994, pp. 26-35.

Panel Layout

Face Width

The longwall census data clearly illustrate the trend towards wider faces that has occurred over the past decade. In 1984, 81 percent of the longwall panels had faces that fell within the 401- to 600-foot-width range (Table 5). By 1988, only 42 percent of the units fell within that range. In that year, the majority of panels (77 percent of the total) had face widths ranging from 501 to 800 feet. The shift towards increasing width continued during the 1988 through 1993 period. By 1993, most longwall faces (59 percent of the total) fell in the 701- to 900-foot range. More than 10 percent of all units have now moved to a 900- to 1,000-foot face, and two units have broken the 1,000-foot mark.

There are a number of advantages to wider faces. First, the quantity of coal mined per pass of the shearer is directly dependent on the face width. As the tonnage per pass increases, the time spent in production increases relative to the time spent repositioning the shearer at the end of each pass. Second, the wider the face, the less frequently the longwall equipment needs to be moved from one panel to another. This reduces the amount of time that the machinery is not being used for production, as well as the total worker-hours required for making the moves. Third, as the size of the longwall panels increases, the proportion of the mine's coal that is mined by highly productive longwall equipment increases relative to the tonnage mined by less productive continuous miner development units. Finally, the wider panels allow the continuous miners used for developing the longwall mine to keep pace with the more productive longwall units. As longwall

Table 5. Distribution of Longwall Units, by Face Width, 1984, 1988, and 1993

Face Width Range (feet)	1984		1988		1993	
	Number of Units	Percent of Total	Number of Units	Percent of Total	Number of Units	Percent of Total
< 400	8	7.2	2	2.2	0	0.0
401-500	36	32.4	9	9.8	2	2.4
501-600	54	48.6	30	32.6	13	15.3
601-700	10	9.0	20	21.7	10	11.8
701-800	1	0.9	21	22.8	32	37.6
801-900	1	0.9	8	8.7	18	21.2
901-1,000	1	0.9	2	2.2	8	9.4
> 1,000	0	0.0	0	0.0	2	2.4
Total	**111**	**100.0**	**92**	**100.0**	**85**	**100.0**

Notes: In the few cases where a range, rather than a single value, was provided for the face width of a longwall unit, the median was taken as the face width. Also, the face width was not reported for one longwall unit in 1984. Percentages may not add to 100 because of independent rounding.

Sources: Mark W. Sprouls, "Longwall Census '84," *Coal Mining,* December 1984, pp. 39-53; Mark W. Sprouls, "Longwall Census '89," *Coal,* February 1989, pp. 33-43; and Paul Merritt, "1994 Longwall Census," *Coal,* February 1994, pp. 26-35.

technology has improved, increases in the power of coal shearers and conveyors have resulted in such high rates of longwall production that, in some cases, the longwall unit has run out of coal blocked out for longwall mining. This resulted in idle periods for the longwall unit. With wider face widths, it takes longer for the longwall unit to complete mining a panel, giving more time for the slower continuous mining units to block out the next panel.

The upward trend in longwall face widths between 1984 and 1993 occurred in virtually every State and region of the country (Table 6). The national average longwall face width rose from 548 to 759 feet, a 39-percent increase (Figure 6). A change of virtually the same magnitude occurred in Appalachia. The change in average face width was somewhat smaller in the West—from 575 to 738 feet, a 28-percent increase.

In the Illinois Basin, the 49-percent increase in the average face width was larger than in either of the other regions. Also, this increase took place within a relatively short period of time (between 1984 and 1988), while the average face width increased throughout the 1984 through 1993 period in Appalachia and the West. Illinois Basin longwall mines took the lead in the move toward wider faces, perhaps to compensate for the significant decline in average seam thickness (and mining height) that took place between 1984 and 1988. By 1988, the average face width at Illinois Basin operations was over 100 feet greater than at Appalachian and Western mines. In 1993, the Illinois Basin still led the country in terms of average face width, although the regional differences in average face width had narrowed. States currently leading in the trend towards wider faces include Alabama, Ohio, Illinois, and New Mexico. All of these States have average face widths in excess of 800 feet.

Panel Length

Longwall panel lengths increased along with panel widths. In 1990 (the first year for which panel length data were collected in the *Coal* longwall census), 58 percent of longwall units were working in panels ranging from 3,001 to 6,000 feet long. By 1993, most units (61 percent) fell in the 5,001- to 9,000-foot range (Table 7). During the same time period, the proportion of units working in panels greater than 9,000 feet long increased from 4 percent to 13 percent. Currently, four units are operating in panels greater than 2 miles long.

The increase in panel lengths occurred in virtually every State and region of the country (Table 8). Between 1990 and 1993, average panel length increased by 17 percent in Appalachia, 37 percent in the Illinois Basin, and 55 percent in the West. At the national level, the average panel length increased by 21 percent.

Table 6. Average Longwall Face Width, by State and Region, 1984, 1988, and 1993

State/Region	1984		1988		1993	
	Number of Units	Mean Width (feet)	Number of Units	Mean Width (feet)	Number of Units	Mean Width (feet)
Alabama	7	559	10	700	9	831
Eastern Kentucky	4	476	4	578	4	645
Maryland	0	--	1	600	1	750
Ohio	9	517	3	833	4	895
Pennsylvania	13	548	12	629	13	750
Virginia	11	547	13	628	8	715
West Virginia	45	553	29	642	23	745
Appalachia	**89**	**545**	**72**	**649**	**62**	**758**
Illinois	6	528	7	810	9	810
Western Kentucky	1	560	1	670	1	630
Illinois Basin	**7**	**533**	**8**	**793**	**10**	**792**
Colorado	5	546	5	622	5	792
New Mexico	1	600	0	--	1	850
Utah	8	584	6	623	6	693
Wyoming	1	620	1	620	1	620
West	**15**	**575**	**12**	**622**	**13**	**738**
United States	**111**	**548**	**92**	**658**	**85**	**759**

-- = Not applicable.

Notes: In the few cases where a range, rather than a single value, was provided for the face width of a longwall unit, the median was taken as the face width. Also, the face width was not reported for one longwall unit in 1984; this unit was excluded from the calculation of the mean face width.

Sources: Mark W. Sprouls, "Longwall Census '84," *Coal Mining,* December 1984, pp. 39-53; Mark W. Sprouls, "Longwall Census '89," *Coal,* February 1989, pp. 33-43; and Paul Merritt, "1994 Longwall Census," *Coal,* February 1994, pp. 26-35.

At the State level, Ohio and Wyoming led the country in longwall panel length in 1993, with averages of 9,375 feet and 9,000 feet, respectively. Regionally, panels tended to be shorter (and faces narrower) in the West than in the East, although the smaller panel dimensions were counterbalanced by the significantly greater seam thicknesses characteristic of the West. Average panel length in the West may increase dramatically in the future, as Cyprus Amax recently applied for a permit revision that would allow it to operate Colorado longwalls in panels of up to 4 miles in length.[10]

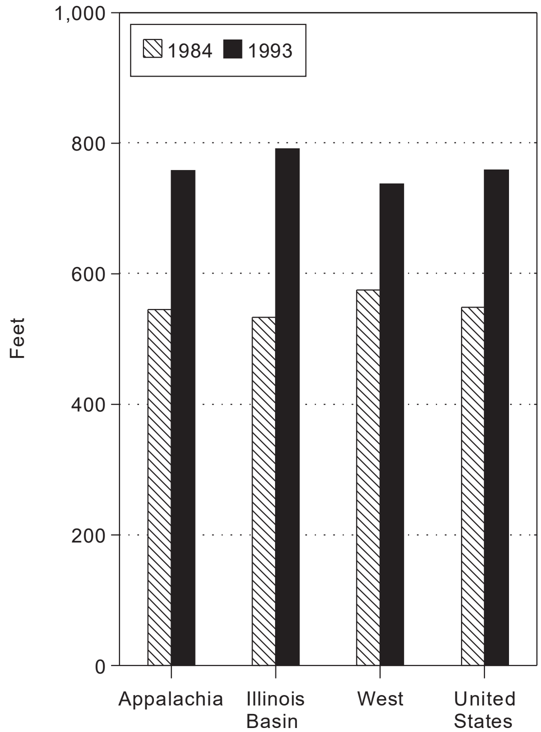
The move towards wider and longer panels was one of the primary contributing factors in the dramatic rise in longwall productivity over the past decade. The use of larger panels translated directly into larger production totals per panel, and hence less downtime spent on longwall moves on a per-ton basis. In addition, the use of larger panels generally reduced the amount of room-and-pillar development work that had to be done in support of the longwalls.

Panel Entries

The vast majority of longwalls utilize either three- or four-entry systems. Three-entry systems are utilized by about half of the longwalls currently in operation, but four-entry systems are also common (found at about 40 percent of the longwall population in 1993).[11] Generally, the Federal Coal Mine Health and Safety Act of 1969 requires a minimum of three entries. However, depending upon mine geologic conditions, exceptions are granted, and 5 percent of longwall units in 1993 had only two entries. Keeping the number of entries as low

[10]"Cyprus Amax Works Toward Higher Mine Output," *Coal Outlook*, November 14, 1994, pp. 4-5.
[11]Paul Merritt, "1994 Longwall Census," *Coal*, February 1994, pp. 26-35.

Figure 6. Average Longwall Face Width, by Region, 1984 and 1993



Sources: Mark W. Sprouls, “Longwall Census '84,” *Coal Mining,* December 1984, pp. 39-53, and Paul Merritt, “1994 Longwall Census,” *Coal,* February 1994, pp. 26-35.

as possible minimizes costs, since it reduces the time and resources spent on panel development, as opposed to production.

Longwalls with four-entry systems predominate in Appalachia, where they constituted 57 percent of the longwall population in 1993. In Alabama, all of the longwalls utilized four entries. Apparently, the very gassy conditions characterizing Alabama's longwalls necessitate the use of four entries, to ensure adequate ventilation of the face. In contrast, none of the mines in the Illinois Basin and the West utilize four entries. In the Illinois Basin, all of the longwall units used three entries. In the West, two-entry systems were significant, being used in 31 percent of the longwall operations in 1993. In general, the thick coal seams characteristic of the West have resulted in larger airways, enabling operators to meet ventilation requirements with fewer entries.

Longwall Mining Equipment

Improvements in longwall mining equipment have been a major factor in the increase in longwall productivity over the past decade. Among the most important changes were the increased horsepower and capacity of cutting machines (principally double-drum shearers) and coal conveyors. Electrohydraulic controls for roof supports were another important development.

Table 7. Distribution of Longwall Units, by Panel Length, 1990 and 1993

Panel Length Range (feet)	1990		1993	
	Number of Units	Percent of Total	Number of Units	Percent of Total
< 3,000	5	6.8	2	2.4
3,001-4,000	15	20.3	12	14.1
4,001-5,000	11	14.9	8	9.4
5,001-6,000	17	23.0	13	15.3
6,001-7,000	8	10.8	13	15.3
7,001-8,000	12	16.2	12	14.1
8,001-9,000	3	4.1	14	16.5
9,001-10,000	2	2.7	6	7.1
> 10,000	1	1.4	5	5.9
Total	**74**	**100.0**	**85**	**100.0**

Notes: Where a range, rather than a single value, was reported for the panel length of a longwall unit, the median of the range was used. In 1990, the first year for which panel length data were collected, the panel length was not reported for 22 of the 96 longwall units. There were no missing panel data for 1993. Percentages may not add to 100 because of independent rounding.

Sources: Paul Merritt, “As Time Changes, So Do Longwalls,” *Coal,* February 1991, pp. 40-49; and Paul Merritt, “1994 Longwall Census,” *Coal*, February 1994, pp. 26-35.

Table 8. Average Longwall Panel Length, by State and Region, 1990 and 1993

State/Region	1990 Number of Units	1990 Mean Length (feet)	1993 Number of Units	1993 Mean Length (feet)
Alabama	8	5,038	9	6,144
Eastern Kentucky	4	5,588	4	7,462
Maryland	1	5,300	1	5,300
Ohio	2	7,550	4	9,375
Pennsylvania	7	6,157	13	6,665
Virginia	10	4,775	8	5,006
West Virginia	25	6,698	23	7,880
Appalachia	**57**	**5,989**	**62**	**7,031**
Illinois	8	5,322	9	7,204
Western Kentucky	1	4,570	1	7,000
Illinois Basin	**9**	**5,238**	**10**	**7,184**
Colorado	5	3,230	5	7,480
New Mexico	1	4,000	1	3,700
Utah	2	4,750	6	4,113
Wyoming	0	--	1	9,000
West	**8**	**3,706**	**13**	**5,753**
United States	**74**	**5,651**	**85**	**6,853**

-- = Not applicable.

Notes: Where a range, rather than a single value, was reported for the panel length of a longwall unit, the median of the range was used. In 1990, the first year for which panel length data were collected, the panel length was not reported for 22 of the 96 longwall units. There were no missing panel data in the 1993 census.

Sources: Paul Merritt, "As Time Changes, So Do Longwalls," *Coal*, February 1991, pp. 40-49; and Paul Merritt, "1994 Longwall Census," *Coal,* February 1994, pp. 26-35.

Shearers and Plows

There are four main types of longwall cutting machines: double-drum (two-drum) ranging shearers, single-drum (one-drum) ranging shearers, single-drum fixed shearers, and plows. The vast majority of longwalls (93 percent of the total in 1993) utilize double-drum ranging shearers (Table 9). This reflects the fact that double-drum shearers are without question the machines of choice in thick seams. However, for seams less than approximately 52 inches thick, the clearance is not adequate for double-drum shearers, and single-drum machines must be used. In very thin seams, plows are utilized.

The relationship between seam thickness and equipment type is reflected in the regional distribution of shearers and plows. In the relatively thick seams of the Illinois Basin and the West, virtually all of the longwalls have used double-drum ranging shearers throughout the past decade. Single-drum shearers and plows are limited to the thinner seams characteristic of the Appalachian States—especially Pennsylvania, Virginia, and West Virginia.

Even in Appalachia, the use of double-drum ranging shearers has increased over time. In 1984, 74 percent of Appalachian longwalls utilized double-drum ranging shearers; by 1993, this type of equipment was used in 90 percent of Appalachian longwalls. This trend parallels the shift away from thin-seam longwall mining during the past decade.

The power of longwall cutting machines increased dramatically over the past decade, at the State and regional levels as well as the national level (Table 10 and Figure 7). For the country as a whole, the average horsepower of longwall cutting machines increased by 35 percent

Table 9. Types of Shearers/Plows Utilized, by Region, 1984, 1988, and 1993

Region and Machine Type	1984		1988		1993	
	Number of Units	Percent of Total	Number of Units	Percent of Total	Number of Units	Percent of Total
Appalachia						
Shearers						
1-Drum (Fixed)	9	10.0	3	4.2	1	1.6
1-Drum	2	2.2	2	2.8	2	3.2
2-Drum	67	74.4	61	84.7	56	90.3
Plow	12	13.3	5	6.9	3	4.8
Colmil	0	0.0	1	1.4	0	0.0
Total	**90**	**100.0**	**72**	**100.0**	**62**	**100.0**
Illinois Basin						
Shearers						
1-Drum	1	14.3	0	0.0	0	0.0
2-Drum	6	85.7	8	100.0	10	100.0
Total	**7**	**100.0**	**8**	**100.0**	**10**	**100.0**
West						
Shearers						
2-Drum	15	100.0	12	100.0	13	100.0
Total	**15**	**100.0**	**12**	**100.0**	**13**	**100.0**
United States						
Shearers						
1-Drum (Fixed)	9	8.0	3	3.3	1	1.2
1-Drum	3	2.7	2	2.2	2	2.4
2-Drum	88	78.6	81	88.0	79	92.9
Plow	12	10.7	5	5.4	3	3.5
Colmil	0	0.0	1	1.1	0	0.0
Total	**112**	**100.0**	**92**	**100.0**	**85**	**100.0**

-- = Not applicable.

Notes: All shearers are "ranging-drum," unless noted otherwise. In 1988, one colmil (which combines features of the plow and the shearer)was being used at one longwall operation. Percentages may not add to 100 because of independent rounding.

Sources: Mark W. Sprouls, "Longwall Census '84," *Coal Mining,* December 1984, pp. 39-53; Mark W. Sprouls, "Longwall Census '89," *Coal,* February 1989, pp. 33-43; and Paul Merritt, "1994 Longwall Census," *Coal,* February 1994, pp. 26-35.

between 1984 and 1988, and by another 41 percent between 1988 and 1993. In part, this was due to the reduction in the number of single-drum shearers and plows, which generally have lower horsepower ratings than double-drum shearers. However, dramatic increases in horsepower ratings occurred even in the Illinois Basin and the West, where virtually all of the longwalls utilized double-drum ranging shearers as far back as 1984. In fact, the percentage increase in average horsepower between 1984 and 1993 was significantly larger in the Illinois Basin and the West than in Appalachia (135 percent and 97 percent for the Illinois Basin and the West, respectively, versus 78 percent for Appalachia).

Clearly, double-drum ranging shearers have undergone major changes over the past decade. The new generation of shearers is much more powerful and reliable, and potentially much more productive, than the equipment utilized a decade ago.

Table 10. Average Shearer/Plow Horsepower, by State and Region, 1984, 1988, and 1993

State/Region	1984		1988		1993	
	Number of Units	Mean Horsepower	Number of Units	Mean Horsepower	Number of Units	Mean Horsepower
Alabama	7	503	9	586	9	603
Eastern Kentucky	4	332	4	464	3	875
Maryland	0	--	1	500	1	500
Ohio	9	419	3	583	4	785
Pennsylvania	14	312	11	547	13	743
Virginia	11	327	13	367	8	590
West Virginia	45	374	27	409	22	612
Appalachia	**90**	**371**	**68**	**459**	**60**	**659**
Illinois	6	386	7	986	9	985
Western Kentucky	1	500	1	500	1	620
Illinois Basin	**7**	**403**	**8**	**925**	**10**	**948**
Colorado	5	386	5	521	5	1037
New Mexico	1	403	0	--	1	585
Utah	8	444	6	576	6	654
Wyoming	1	605	1	605	1	1400
West	**15**	**433**	**12**	**556**	**13**	**853**
United States	**112**	**381**	**88**	**514**	**83**	**724**

-- = Not applicable.

Note: Horsepower data were not reported for four units in 1988 and two units in 1993; these units are excluded from the table.

Sources: Mark W. Sprouls, "Longwall Census '84," *Coal Mining,* December 1984, pp. 39-53; Mark W. Sprouls, "Longwall Census '89," *Coal,* February 1989, pp. 33-43; and Paul Merritt, "1994 Longwall Census," *Coal,* February 1994, pp. 26-35.

Roof Supports

There are three types of longwall roof supports: shields, chocks, and frames. Shields were already well-established as the dominant type of roof support by 1984. In that year, 89 percent of all longwalls utilized shields, while 9 percent used chocks and 2 percent used frames.[12] By 1988, the last frames had disappeared, and only one longwall still relied on chocks in 1993.[13]

One of the most important developments in longwall roof supports over the past decade has been the introduction of electrohydraulic controls. With electrohydraulic controls, a worker in one location can move an entire group of shields. The advantages offered by electrohydraulic controls include faster cycle times, reduced worker exposure to dust, and reduced man-power requirements for support movement. The first roof supports with electrohydraulic controls were introduced into Consolidation Coal Company's Loveridge Mine in 1984. By 1993, 84 percent of all longwalls were using electrohydraulic controls.

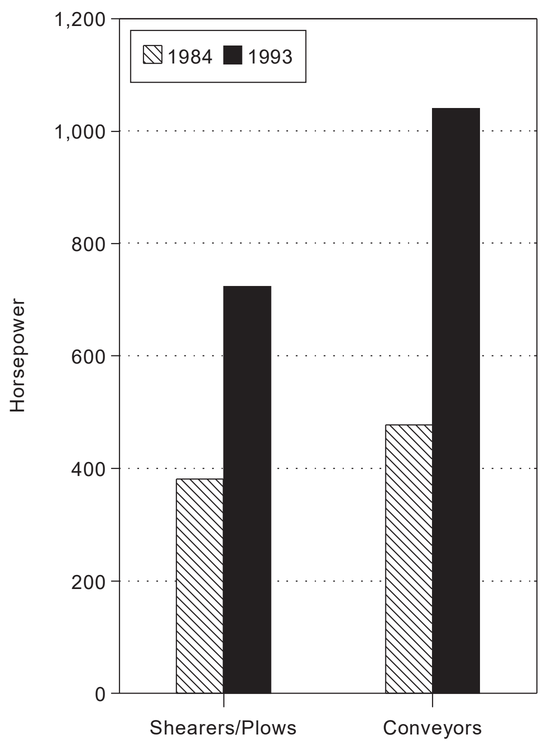
Face Conveyors

Conveyor horsepower, like shearer horsepower, increased dramatically over the past decade. For the United States as a whole, average conveyor horsepower more than doubled between 1984 and 1993 (Table 11). Similar percentage gains occurred in virtually every State and region of the country.

The increase in conveyor horsepower permitted increases in the length and capacity of face conveyors. In

[12]Mark W. Sprouls, "Longwall Census '84, " *Coal Mining*, December 1984, pp. 39-53.
[13]Paul Merritt, "1994 Longwall Census," *Coal*, February 1994, pp. 26-35.

Figure 7. Average U.S. Longwall Mining Equipment Horsepower, 1984 and 1993



Sources: Mark W. Sprouls, "Longwall Census '84," *Coal Mining,* December 1984, pp. 39-53, and Paul Merritt, "1994 Longwall Census," *Coal,* February 1994, pp. 26-35.

turn, the expanded conveyor capacity facilitated the increase in face widths discussed previously. Thus, the improvements in face conveyors have had both a direct effect on productivity (as a result of the increased conveyor capacity) and an indirect productivity effect (through its effect on longwall face widths). The development of fully automated chain tensioning systems was instrumental in this progress. Other important improvements have also been made in conveyor speed and durability.

Operating Characteristics

Mine Size

Mine size is one of the key characteristics differentiating longwall mines from other underground operations. In 1993, 70 percent of all U.S. longwall mines produced over 1 million tons of coal (Table 12). In contrast, the vast majority of room-and-pillar operations (91 percent) produced less than 500,000 tons. This same dichotomy exists at the regional level: in both Appalachia and the West, nearly 70 percent of the longwall mines produced over 1 million tons in 1993, whereas the vast majority of room-and-pillar operations produced less than 500,000 tons.

Large longwall mines also predominate in the Illinois Basin. However, in contrast to other regions, the Illinois Basin is characterized by relatively large room-and-pillar operations. Seventy percent of Illinois Basin room-and-pillar operations produced more than 500,000 tons of coal in 1993. Nonetheless, although the dichotomy is not as sharp as elsewhere, the Illinois Basin's longwall mines tend to be larger than its room-and-pillar operations. In the Illinois Basin, 75 percent of longwall mines produced over 1 million tons in 1993, compared to only 43 percent of room-and-pillar mines.

Although both longwall and room-and-pillar mines generally produced less coal a decade ago, the mine size differences evident in 1993 also appear in the 1983 data. For the United States as a whole, 71 percent of all longwall mines produced over 500,000 tons in 1983, and 47 percent produced over 1 million tons. In contrast, 94 percent of room-and-pillar mines produced less than 500,000 tons.

The mine size differences revealed in Table 12 reflect a fundamental fact—longwall mining is inherently a large-scale mining method. Given the high capital costs associated with a longwall production unit, longwall mines must be large, long-lived operations with high production rates in order to ensure an adequate return on the mine operator's investment.[14] Thus, while longwall mining is clearly gaining ground over other methods among large mine operators, mine size ultimately represents a key limitation on the future use of longwall mining. If a reserve block is too small to support a large operation, it cannot be mined using the longwall method. Such small reserve blocks are common, especially in Appalachia, where the long history of mining has created many small "islands" of coal surrounded by mined-out areas. The future growth of longwall mining depends on the availability of large reserve blocks capable of supporting longwall mines.

Number of Longwall Units per Mine

While longwall mine size has been increasing in terms of productive capacity and annual production, the

[14]Although Table 12 does indicate that a few longwall mines (4 percent of the U.S. total) produced less than 100,000 tons in 1993, in all likelihood the low production rate at these mines resulted from a cutback in capacity utilization—i.e., the mines are probably larger operations that were underutilized in 1993.

Table 11. Average Face Conveyor Horsepower (All Motors Combined), by State and Region, 1984, 1988, and 1993

State/Region	1984		1988		1993	
	Number of Units	Mean Horsepower	Number of Units	Mean Horsepower	Number of Units	Mean Horsepower
Alabama	7	586	10	860	9	1,022
Eastern Kentucky	4	475	4	800	4	1,162
Maryland	0	--	1	700	1	700
Ohio	9	508	3	1,067	4	1,288
Pennsylvania	13	379	11	559	13	1,015
Virginia	11	478	13	593	7	871
West Virginia	44	452	29	645	21	1,062
Appalachia	**88**	**462**	**71**	**680**	**59**	**1,039**
Illinois	6	483	7	1,243	9	1,178
Western Kentucky	0	--	1	550	1	700
Illinois Basin	**6**	**483**	**8**	**1,156**	**10**	**1,130**
Colorado	4	476	5	700	5	1,060
New Mexico	1	450	0	--	1	900
Utah	7	650	6	723	6	882
Wyoming	1	700	1	700	1	1,200
West	**13**	**577**	**12**	**712**	**13**	**976**
United States	**107**	**477**	**91**	**726**	**82**	**1,040**

-- = Not applicable.

Note: Data on conveyor horsepower were not reported for a few longwall units in each year.

Sources: Mark W. Sprouls, "Longwall Census '84," *Coal Mining,* December 1984, pp. 39-53; Mark W. Sprouls, "Longwall Census '89," *Coal,* February 1989, pp. 33-43; and Paul Merritt, "1994 Longwall Census," *Coal,* February 1994, pp. 26-35.

number of longwall mines using more than one longwall production unit declined from 22 in 1984 to 12 in 1993.[15] In 1993, only about 16 percent of U.S. longwall mines used two production units, while 84 percent were one-unit operations.

The national trend towards fewer production units per longwall mine was paralleled by similar regional trends, except in the Illinois Basin. There, the number of two-unit mines increased from two in 1984 to three in 1993, rising from 40 percent to 43 percent of the total.

While the national trend has been towards fewer production units, it is important to keep in mind that the longwall production unit today differs significantly from that found a decade ago. The capital investment represented by a longwall unit, and the productive capacity of a unit, are much greater today than in 1984. Thus, today's longwall operations produce more coal, with fewer production units, than the operations of a decade ago.

Employment

Typically, a longwall mine employs substantially more workers than other types of underground mines. In 1993, longwall mines employed an average of 102 workers per shift.[16] In contrast, room-and-pillar operations employed an average of 21 workers per shift. This difference in employment reflects the fact that longwall mines are substantially larger than other underground operations.

[15]Mark W. Sprouls, "Longwall Census '84," *Coal Mining*, December 1984, pp. 39-53, and Paul Merritt, "1994 Longwall Census," *Coal*, February 1994, pp. 26-35.

[16]Energy Information Administration, 1993 Form EIA-7A. The employment data include all wage and salaried employees on both operating and maintenance shifts, and exclude office workers other than managers and technical / engineering staff. Data used throughout this section are from the Form EIA-7A databases for 1983 and 1993, and the 1983 Form EIA-7A Supplement database.

Table 12. Distribution of Mines by Production Range: Longwall Versus Room-and-Pillar, by State and Region, 1983 and 1993

Production Range by State and Region (thousand short tons)	1983		1993	
	Longwall (percent)	Room-and-Pillar (percent)	Longwall (percent)	Room-and-Pillar (percent)
Alabama				
< 100	0.0	18.2	0.0	0.0
100–500	0.0	18.2	0.0	25.0
500–1,000	33.3	63.6	0.0	25.0
> 1,000	66.7	0.0	100.0	50.0
Eastern Kentucky				
< 100	0.0	77.5	0.0	54.5
100–500	66.7	20.9	0.0	38.8
500–1,000	0.0	1.6	0.0	4.8
> 1,000	33.3	0.0	100.0	1.9
Maryland				
< 100	--	20.0	0.0	100.0
100–500	--	40.0	0.0	0.0
500–1,000	--	40.0	0.0	0.0
> 1,000	--	0.0	100.0	0.0
Ohio				
< 100	0.0	0.0	0.0	50.0
100–500	20.0	42.9	20.0	25.0
500–1,000	40.0	28.6	20.0	0.0
> 1,000	40.0	28.6	60.0	25.0
Pennsylvania				
< 100	0.0	39.8	20.0	44.3
100–500	27.3	37.3	0.0	47.5
500–1,000	9.1	16.9	10.0	8.2
> 1,000	63.6	6.0	70.0	0.0
Virginia				
< 100	0.0	80.7	0.0	55.6
100–500	42.9	18.4	0.0	42.5
500–1,000	57.1	0.9	66.7	2.0
> 1,000	0.0	0.0	33.3	0.0
West Virginia				
< 100	0.0	65.6	4.8	42.6
100–500	16.1	30.0	0.0	50.7
500–1,000	32.2	3.8	23.8	4.2
> 1,000	51.6	0.5	71.4	2.5
Appalachia				
< 100	**0.0**	**71.7**	**5.5**	**50.2**
100–500	**23.3**	**24.0**	**1.8**	**43.5**
500–1,000	**30.0**	**3.7**	**23.6**	**4.5**
> 1,000	**46.7**	**0.6**	**69.1**	**1.9**

See footnotes at end of table.

Table 12. Distribution of Mines by Production Range: Longwall Versus Room-and-Pillar, by State and Region, 1983 and 1993 (Continued)

Production Range by State and Region (thousand short tons)	1983		1993	
	Longwall (percent)	Room-and-Pillar (percent)	Longwall (percent)	Room-and-Pillar (percent)
Illinois				
< 100	0.0	10.7	0.0	0.0
100–500	25.0	25.0	0.0	10.0
500–1,000	0.0	25.0	16.7	30.0
> 1,000	75.0	39.3	83.3	60.0
Western Kentucky				
< 100	--	10.3	0.0	15.8
100–500	--	48.3	50.0	31.6
500–1,000	--	17.2	0.0	21.1
> 1,000	--	24.2	50.0	31.5
Illinois Basin				
< 100	**0.0**	**11.7**	**0.0**	**9.1**
100–500	**25.0**	**36.7**	**12.5**	**22.7**
500–1,000	**0.0**	**20.0**	**12.5**	**25.0**
> 1,000	**75.0**	**31.7**	**75.0**	**43.2**
Colorado				
< 100	0.0	52.6	0.0	14.3
100–500	100.0	26.3	0.0	57.1
500–1,000	0.0	15.8	40.0	14.3
> 1,000	0.0	5.3	60.0	14.3
New Mexico				
< 100	0.0	--	0.0	--
100–500	100.0	--	0.0	--
500–1,000	0.0	--	100.0	--
> 1,000	0.0	--	0.0	--
Utah				
< 100	0.0	30.0	0.0	12.5
100–500	60.0	50.0	0.0	62.5
500–1,000	0.0	15.0	16.7	12.5
> 1,000	40.0	5.0	83.3	12.5
Wyoming				
< 100	0.0	--	0.0	0.0
100–500	0.0	--	0.0	100.0
500–1,000	0.0	--	0.0	0.0
> 1,000	100.0	--	100.0	0.0
West				
< 100	**0.0**	**41.0**	**0.0**	**21.1**
100–500	**66.7**	**38.5**	**0.0**	**57.9**
500–1,000	**0.0**	**15.4**	**30.8**	**10.5**
> 1,000	**33.3**	**5.1**	**69.2**	**10.5**

See footnotes at end of table.

Table 12. Distribution of Mines by Production Range: Longwall Versus Room-and-Pillar, by State and Region, 1983 and 1993 (Continued)

Production Range by State and Region (thousand short tons)	1983		1993	
	Longwall (percent)	Room-and-Pillar (percent)	Longwall (percent)	Room-and-Pillar (percent)
United States				
< 100	**0.0**	**68.6**	**3.9**	**47.8**
100–500	**28.8**	**24.9**	**2.6**	**42.8**
500–1,000	**24.7**	**4.6**	**23.7**	**5.5**
> 1,000	**46.6**	**1.9**	**69.7**	**4.0**

-- = Not applicable.

Notes: Regional and United States distributions include room-and-pillar mines in the following States that have no longwall mines: Tennessee (in Appalachia); Indiana (in the Illinois Basin); and Arkansas, Iowa, Missouri, Montana, and Oklahoma (in the West). Percentages may not add to 100 because of independent rounding.

Sources: Energy Information Administration, 1983 Form EIA-7A "Coal Production Report," 1983 Form EIA-7A Supplement, and 1993 Form EIA-7A, "Coal Production Report."

Over the past decade, the average number of employees per shift declined at both longwall and room-and-pillar operations. In the case of longwall mines, the average number of workers per shift dropped by 21 percent between 1983 and 1993 (from 129 to 102). Fewer workers are needed at longwall operations partly because of the reduction in the number of longwall mines with more than one production unit. The average for room-and-pillar operations decreased by 14 percent (from 24 to 21). During the same period, production increased significantly at both longwall and other underground operations. Thus, due to substantial improvements in productivity over the past decade, fewer workers can produce more coal than was possible in the past.

The size of the workforce at Appalachian and Illinois Basin longwall mines is, on average, the same (108 workers per shift in 1993). However, the difference in workforce size between longwall and other underground operations is much larger in Appalachia than in the Illinois Basin, because room-and-pillar operations tend to be significantly larger in the Illinois Basin than in Appalachia. Illinois, in particular, is characterized by large mines with large staffing requirements. Room-and-pillar operations in Illinois averaged 72 workers per shift in 1993, compared with 96 workers per shift at longwall mines. In contrast, most Appalachian States employed an average of fewer than 20 workers per shift at room-and-pillar operations. Alabama is a notable exception, employing an average of 96 workers per shift at its room-and-pillar operations.

The average workforce size is significantly smaller at Western longwall mines (68 workers per shift, on average) than at Appalachian and Illinois Basin operations. Two factors account for the smaller size of the workforce: (1) no Western mines have more than one longwall unit, and (2) Western mines are significantly more productive (i.e., fewer workers are needed to produce each ton of coal), primarily due to the region's thick coal seams.

Since 1984, the average face width of U.S. longwall mines has increased by nearly 40 percent, to 759 feet, resulting in substantial productivity gains.

4. Changes in Longwall Mining Performance, 1983-1993

The previous chapter noted that various changes in geologic conditions, longwall panel layouts, and mining equipment contributed to the increase in longwall mining productivity over the past decade. This chapter measures the collective impact of those changes by quantifying the changes in the productivity of longwall mines over the 1983-1993 period. Changes in longwall mine production and productivity (output per worker-hour) are examined not only at the national level, but also at the State and regional levels. Therefore, this chapter begins with a discussion of the geographic distribution of longwall mines.

Number and Geographic Distribution of Longwall Mines

For purposes of developing the data for this analysis, any mine with at least one longwall unit was considered a longwall mine. Of course, all U.S. longwall mines utilize room-and-pillar mining for development, and some longwall operations may also use continuous and/or conventional mining to meet a portion of their production requirements. However, in almost all cases, longwall mining is the dominant production method at mines with at least one longwall unit. Longwall units accounted for over half of total 1993 production at all but two longwall operations.[17]

In 1993, there were 85 longwall units operating at 73 longwall mines (Table 13). This total was quite small relative to the total U.S. underground mine population of 1,354. However, because longwall mines are invariably large operations, a simple comparison of the longwall population with the total underground mine population can be misleading. As the next section indicates, longwall mines account for a much larger share of total U.S. underground coal production than of the total number of underground mines.

The longwall mine population declined during the past decade, from 89 mines in 1984 to 73 mines in 1993. However, the total underground mine population declined more rapidly than the longwall population. As a result, the longwall mine population grew as a proportion of the underground mine population, from 4 percent in 1984 and 1988, to 6 percent in 1993.

In terms of the number of mines, Appalachia is by far the most important longwall mining region, accounting for 73 percent of the total U.S. longwall mine population in 1993. West Virginia is by far the most important longwall State, with a total of 21 longwall mines in 1993. West Virginia is followed by Pennsylvania, with 10 longwall mines, and Virginia, with 7 longwall mines.

In Appalachia, the longwalls' share of the total underground mine population rose from 3 percent in 1984 to 5 percent in 1993, despite an absolute decline in the number of longwall mines from 71 to 53. In some parts of Appalachia (Alabama, eastern Kentucky, and Maryland), the number of longwall mines actually increased. However, West Virginia saw a 42-percent decline in its longwall population. The longwall population declined in both relative and absolute terms in West Virginia, Ohio, and Pennsylvania.

In the West, the longwall population remained fairly stable over the past decade, at 11 to 13 mines, despite a significant decline in the total number of western underground mines (from 54 in 1984 to 36 in 1993). More so than in any other region, underground mine operators in the West depend on longwall mining. As of 1993, 36 percent of western underground mines utilized longwalls, compared with only 5 percent of Appalachian operations and 14 percent of Illinois Basin mines. Colorado and Utah are the major underground mining and longwall mining States in the West.

The West's heavy reliance on longwall mining is necessitated, in part, by the fact that western seam depths often exceed 1,000 feet. In addition, the West does not face the same limitations that have constrained longwall mining in other parts of the country—namely, the existence of prime farmland (which limited the use of longwall mining in the Illinois Basin, due to subsidence concerns) and the limited number of large, thickseam reserve blocks capable of supporting longwall mining (which remains a constraint in Appalachia).

[17]Energy Information Administration, 1993 Form EIA-7A, "Coal Production Report."

Table 13. Number of Longwall Mines Compared with Total Number of Underground Mines, by State and Region, 1984, 1988, and 1993

State/Region	1984 Number of Mines	1984 Percent of Total	1988 Number of Mines	1988 Percent of Total	1993 Number of Mines	1993 Percent of Total
Alabama						
Longwall	4	23.5	6	40.0	6	50.0
Total Underground	17	--	15	--	12	--
Eastern Kentucky						
Longwall	3	0.3	4	0.6	4	0.9
Total Underground	900	--	714	--	425	--
Maryland						
Longwall	0	0.0	1	50.0	1	25.0
Total Underground	5	--	2	--	4	--
Ohio						
Longwall	6	42.9	2	12.5	4	44.4
Total Underground	14	--	16	--	9	--
Pennsylvania						
Longwall	13	7.9	9	5.5	10	8.6
Total Underground	165	--	163	--	116	--
Virginia						
Longwall	9	2.1	10	3.3	7	3.9
Total Underground	419	--	304	--	181	--
West Virginia						
Longwall	36	6.5	23	4.8	21	6.2
Total Underground	551	--	477	--	339	--
Appalachia						
Longwall	**71**	**3.3**	**55**	**3.1**	**53**	**4.8**
Total Underground	**2,141**	**--**	**1,765**	**--**	**1,108**	**--**
Illinois						
Longwall	4	12.1	5	17.9	6	23.1
Total Underground	33	--	28	--	26	--
Western Kentucky						
Longwall	1	3.8	1	4.2	1	4.8
Total Underground	26	--	24	--	21	--
Illinois Basin						
Longwall	**5**	**7.8**	**6**	**10.5**	**7**	**13.5**
Total Underground	**64**	**--**	**57**	**--**	**52**	**--**
Colorado						
Longwall	4	16.7	4	26.7	5	38.5
Total Underground	24	--	15	--	13	--

See footnotes at end of table.

Table 13. Number of Longwall Mines Compared with Total Number of Underground Mines, by State and Region, 1984, 1988, and 1993 (Continued)

State/Region	1984		1988		1993	
	Number of Mines	Percent of Total	Number of Mines	Percent of Total	Number of Mines	Percent of Total
New Mexico						
Longwall	1	50.0	0	0.0	1	100.0
Total Underground	2	--	1	--	1	--
Utah						
Longwall	7	29.2	6	30.0	6	40.0
Total Underground	24	--	20	--	15	--
Wyoming						
Longwall	1	100.0	1	25.0	1	25.0
Total Underground	1	--	4	--	4	--
West						
Longwall	**13**	**24.1**	**11**	**26.8**	**13**	**36.1**
Total Underground	**54**	**--**	**41**	**--**	**36**	**--**
United States						
Longwall	**89**	**3.9**	**72**	**3.9**	**73**	**6.1**
Total Underground	**2,259**	**--**	**1,863**	**--**	**1,196**	**--**

-- = Not applicable.

Note: The regional and U.S. underground mine totals include room-and-pillar mines from the following States that have no longwall mines: Tennessee (in Appalachia); Indiana (in the Illinois Basin); and Arkansas, Iowa, Missouri, Montana, and Oklahoma (in the West).

Sources: Mark W. Sprouls, "Longwall Census 1984," *Coal Mining,* December 1984, pp. 39-53; Mark W. Sprouls, "Longwall Census 1989," *Coal,* February 1989, pp. 33-43; Paul Merritt, "1994 Longwall Census," *Coal,* February 1994, pp. 26-35; Energy Information Administration, *Coal Industry Annual 1993,* DOE/EIA-0584(93) (Washington, DC, December 1994), p. 8; *Coal Production 1988*, DOE/EIA-0118(88) (Washington, DC, November 1989), p. 10, and *Coal Production 1984*, DOE/EIA-0118(84) (Washington, D.C., November 1985), p. xvi.

Although smaller than both the Appalachian and Western longwall populations, the number of longwall mines in the Illinois Basin has been growing in both absolute and relative terms. Between 1984 and 1993, the total number of longwall mines in the Illinois Basin increased from five (representing 8 percent of all underground mines in the region) to seven (accounting for 14 percent of the total). Throughout this time period, all but one of the region's mines were located in Illinois. The sole exception was a mine in western Kentucky.

Production from Longwall Mines

Longwall mining has increased its market penetration significantly over the past decade. Since 1983, coal production from longwall units increased not only in absolute terms, but also relative to production by room-and-pillar methods. Total longwall *mine* production (including production from the continuous miner units as well as from the longwall units) grew at a slower rate, partly because the continuous mining machines are used primarily for development rather than production. An important reason for the relatively rapid growth in longwall mine production is that the proportion of the longwall mines' output that is produced by the longwall units has increased substantially over the past decade.

Production Trends

Nationally, longwall mines produced 139 million tons of coal in 1993, or 75 percent more than in 1983 (Table 14). In contrast, total underground coal production increased by only 17 percent over the same period.

Table 14. Longwall Production Compared with Total Underground Mine Production, by State and Region, 1983 and 1993

State/Region	1983 Production (thousand short tons)	1983 Percent of Total	1993 Production (thousand short tons)	1993 Percent of Total
Alabama				
Longwall Units	2,520	23.2	9,467	60.9
Longwall Mines	4,799	44.2	11,582	74.5
Total Underground	10,860	--	15,544	--
Eastern Kentucky				
Longwall Units	941	1.9	4,954	6.9
Longwall Mines	1,716	3.5	6,737	9.4
Total Underground	49,009	--	71,683	--
Maryland				
Longwall Units	0	0.0	2,000	79.5
Longwall Mines	0	0.0	2,500	99.4
Total Underground	1,647	--	2,514	--
Ohio				
Longwall Units	3,364	31.1	7,258	69.5
Longwall Mines	5,979	55.2	8,795	84.3
Total Underground	10,822	--	10,437	--
Pennsylvania				
Longwall Units	5,160	14.8	20,868	56.7
Longwall Mines	10,572	30.4	24,926	67.7
Total Underground	34,799	--	36,795	--
Virginia				
Longwall Units	2,327	8.7	7,262	24.1
Longwall Mines	3,396	12.7	9,630	32.0
Total Underground	26,779	--	30,096	--
West Virginia				
Longwall Units	24,862	27.0	22,609	25.7
Longwall Mines	40,717	44.3	30,215	34.4
Total Underground	91,918	--	87,827	--
Appalachia				
Longwall Units	**39,172**	**17.0**	**74,419**	**29.0**
Longwall Mines	**67,179**	**29.2**	**94,387**	**36.8**
Total Underground	**230,191**	**--**	**256,753**	**--**
Illinois				
Longwall Units	3,403	10.7	8,539	25.8
Longwall Mines	5,880	18.5	10,922	33.0
Total Underground	31,838	--	33,096	--
Western Kentucky				
Longwall Units	0	0.0	2,432	12.0
Longwall Mines	0	0.0	3,895	19.2
Total Underground	15,817	--	20,288	--

See footnotes at end of table.

Table 14. Longwall Production Compared with Total Underground Mine Production, by State and Region, 1983 and 1993 (Continued)

State/Region	1983 Production (thousand short tons)	1983 Percent of Total	1993 Production (thousand short tons)	1993 Percent of Total
Illinois Basin				
Longwall Units	**3,404**	**6.9**	**10,970**	**19.6**
Longwall Mines	**5,880**	**11.9**	**14,816**	**26.5**
Total Underground	**49,437**	**--**	**55,966**	**--**
Colorado				
Longwall Units	715	12.8	7,840	61.1
Longwall Mines	719	12.9	9,623	74.9
Total Underground	5,582	--	12,842	--
New Mexico				
Longwall Units	67	65.0	719	100.0
Longwall Mines	103	100.0	719	100.0
Total Underground	103	--	719	--
Utah				
Longwall Units	3,018	25.7	14,131	64.7
Longwall Mines	4,482	38.1	18,037	82.6
Total Underground	11,756	--	21,841	--
Wyoming				
Longwall Units	882	70.6	1,573	73.6
Longwall Mines	1,250	100.0	1,673	78.3
Total Underground	1,250	--	2,136	--
West				
Longwall Units	**4,682**	**25.0**	**24,264**	**64.5**
Longwall Mines	**6,555**	**35.1**	**30,051**	**79.8**
Total Underground	**18,691**	**--**	**37,645**	**--**
United States				
Longwall Units	**47,257**	**15.8**	**109,653**	**31.3**
Longwall Mines	**79,614**	**26.7**	**139,254**	**39.7**
Total Underground	**298,320**	**--**	**350,365**	**--**

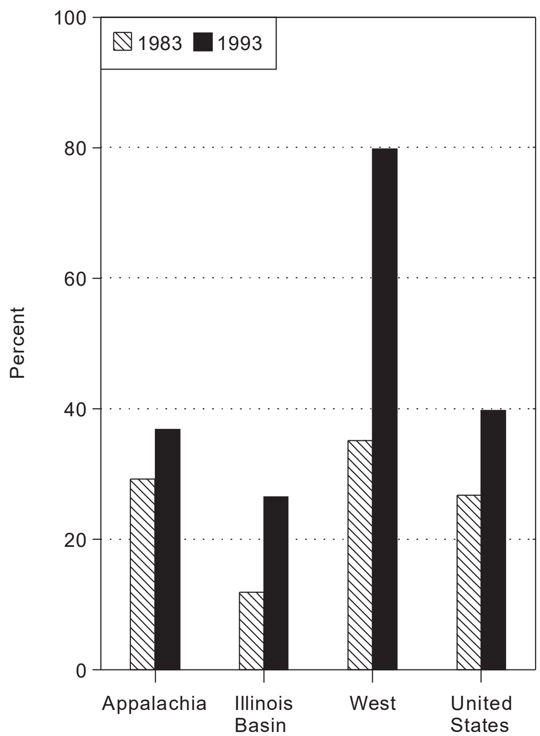
-- = Not applicable.

Notes: Longwall unit production includes only the coal mined by the longwall equipment. It does not include production from the "continuous miners" that are used to develop the longwall mine. Production includes 1993 output from all mines producing more than 10,000 short tons annually, and 1983 output from all mines producing more than 100,000 short tons. The effect of this inconsistency is insignificant, since few, if any, longwall mines produce less than 100,000 tons per year. Production by mining method was not reported by several mines (accounting for about 5 percent of total underground coal production) in 1983. The regional and U.S. underground production totals include production from room-and-pillar mines in the following States that have no longwall mines: Tennessee (in Appalachia); Indiana (in the Illinois Basis); and Arkansas, Iowa, Missouri, Montana, and Oklahoma (in the West). Totals also may not equal sum of components due to independent rounding.

Sources: Energy Information Administration, 1983 Form EIA-7A, "Coal Production Report," and Form EIA-7A Supplement; 1993 Form EIA-7A, "Coal Production Report."

By 1993, longwall mines accounted for 40 percent of underground coal production, up from 27 percent in 1983 (Figure 8).

Figure 8. Longwall Mine Production as a Percentage of Total Underground Mine Production, by Region, 1983 and 1993



Sources: Energy Information Administration, 1993 EIA-7A database, and 1983 EIA-7A and EIA-7A Supplement databases.

In the Illinois Basin and the West, the market penetration achieved by longwall mining is even more dramatic. Western longwall mine production increased from 35 percent to 80 percent of total western underground production between 1983 and 1993. Longwall mining now accounts for the majority of all underground production in Colorado, New Mexico, Utah, and Wyoming.

In the Illinois Basin, longwall mining was a relatively insignificant contributor to total underground production in the early part of the 1980's. Longwall mines accounted for only 12 percent of underground mine output in 1983. However, by 1993, the contribution of longwall mines had risen to 27 percent of the total. Illinois is the primary longwall mining State in the Illinois Basin. Longwall mining has made only modest inroads in West Kentucky, and no longwall mines have been developed in Indiana.

Appalachia traditionally has been, and remains, the stronghold of longwall mining. In 1983, Appalachia accounted for 84 percent of total U.S. longwall mine production. However, by 1993, Appalachia's share of the total had dropped to 68 percent, mostly as a result of the substantial increases in longwall production in the West and the Illinois Basin.[18]

Appalachia's longwall mines produced 94 million tons of coal in 1993, an increase of 27 million tons (40 percent) over 1983. Longwall mines accounted for 37 percent of the region's underground coal production in 1993, up from 29 percent in 1983. By 1993, longwall production amounted to over 50 percent of total underground production in four Appalachian States—Alabama, Maryland, Ohio, and Pennsylvania.

The top two longwall coal-producing States are in Appalachia. In 1993, West Virginia accounted for 22 percent of U.S. longwall mine coal production, followed by Pennsylvania, with 18 percent. The third-largest longwall coal-mining State was Utah, which accounted for 13 percent of U.S. longwall mine production in 1993—more than double its 1983 share.

Percentage of Longwall Mine Output Produced by Longwall Units

Nearly four-fifths of the coal produced by U.S. longwall operations in 1993 was mined by the longwall production units (Table 15). Clearly, a significant portion of the total was produced by other mining methods— primarily continuous miners used for main mine entry and longwall panel development. However, the per-centage of coal produced by continuous miners and other non-longwall equipment at longwall operations has dropped signif-icantly over the past decade, from two-fifths to slightly more than one-fifth of the total production.

The sharp decline in the non-longwall proportion of production is partly due to the increase in longwall panel dimensions. The move towards wider faces and longer panels has resulted in an increase in the amount of coal contained in the longwall panels, relative to the amount of coal that must be extracted by the development units to block out the panels. Hence, longwall unit production has increased as a percentage of total

[18]Another contributing factor is the series of coal miners' strikes that constrained Appalachian coal production in 1993, particularly longwall production in West Virginia.

Table 15. Percentage of Total Longwall Mine Production from Longwall Units, 1983 and 1993

State/Region	1983	1993
Alabama	52.5	81.7
Eastern Kentucky . .	54.8	73.5
Maryland	--	80.0
Ohio	56.3	82.5
Pennsylvania	48.8	83.7
Virginia	68.5	75.4
West Virginia	61.1	74.8
Appalachia	**58.3**	**78.8**
Illinois	57.9	78.2
Western Kentucky . .	--	62.4
Illinois Basin	**57.9**	**74.0**
Colorado	99.4	81.5
New Mexico	65.0	100.0
Utah	67.3	78.4
Wyoming	70.6	94.0
West	**71.4**	**80.7**
United States	**59.4**	**78.7**

-- = Not applicable.
Note: In addition to the output of the longwall units, coal is produced by continuous mining machines in the development of the longwall operations.
Sources: Energy Information Administration, 1983 Form EIA-7A, “Coal Production Report,” and Form EIA-7A Supplement; 1993 Form EIA-7A, “Coal Production Report.”

longwall mine production. It is also quite possible that there has been a reduction in the number of “hybrid” mines, using both longwall and continuous mining for production, over the past decade. Given the major improvements in longwall equipment and productivity since 1983, continuous miners are more likely to be relegated exclusively to development today.

The percentage of total longwall mine production extracted by the longwall units exhibits relatively little regional variation at present. In 1993, the percentage ranged from a high of 81 percent in the West, to 74 percent in the Illinois Basin. Similarly, with only a few exceptions, the proportion falls within a fairly narrow range of 73 to 84 percent at the State level. The exceptions include western Kentucky (62 percent), Wyoming (94 percent), and New Mexico (100 percent).[19]

In the West, the relatively high percentage of longwall mine output that is produced by the longwall units can be explained, in part, by the use of fewer gate entries in this region. As the previous chapter noted, there are no four-entry systems in the West, and nearly one-third of Western longwalls are using two-entry systems. The amount of coal that must be mined during development is heavily dependent on the number of entries that must be driven; the use of fewer entries apparently outweighs the effect of the shorter, narrower panels found in the West.

The relatively low contribution of the longwall units to total longwall mine production in the Illinois Basin is more difficult to explain strictly in terms of mine layout, given the relatively large panels blocked out by three-gate entries in this region. It is believed that a number of hybrid mines, utilizing continuous miners for production as well as development, account for the low ratio of longwall to non-longwall production in the Illinois Basin.

Productivity of Longwall Mines

Longwall mining is more mechanized and capital-intensive than other underground mining methods. Partly because of this, and partly because of the recent trend toward the use of longwall mining, longwall mining is generally perceived to be substantially more productive than other underground mining methods. One of the major purposes of this report is to examine trends in longwall mining productivity and compare them with productivity trends for other mining methods.

The productivity estimates were computed by dividing the total annual production by the total worker-hours, for all mines assigned to a given mining method category. A mine was classified as a longwall operation if it produced any coal using the longwall method. Although continuous mining machines contribute a portion of the production from mines classified as longwall mines (21 percent in 1993), these continuous miners generally serve to develop the longwall panels. They are a necessary and intrinsic component of the longwall system, and are appropriately viewed as constituting a part of the longwall mine.

Room-and-pillar mines were broken down into continuous mining and conventional mining categories. A mine was classified as a continuous miner operation if

[19]The data for the single longwall unit in New Mexico may be erroneous. According to the longwall census, this unit utilizes three-gate entries, and hence must produce some coal using room and pillar mining. Alternatively, it is possible that the mine's continuous miner development units did not operate during 1993.

it did not produce any coal using the longwall method and if more than half of its output was produced by continuous miners. Similarly, mines were classified as conventional operations if they produced no longwall coal and if more than half of their output was accounted for by conventional mining units. For mines using multiple mining methods, the mine's total production and worker-hours for all methods combined were used in calculating productivity.

Productivity of Longwall Mines Compared With Other Mines

For the United States as a whole, longwall mine productivity stood at 3.30 tons per worker-hour in 1993 (Table 16). This was about 19 percent higher than the productivity of room-and-pillar operations (2.78 tons per worker-hour). The productivity of continuous miner operations (2.84 tons per worker-hour) was closer to that of longwall mines, while conventional mines had the lowest average productivity.

In the West, longwall mining leads other mining methods by a wide margin in terms of productivity (Figure 9). In 1993, western longwall productivity stood at 5.67 tons per worker-hour—40 percent higher than the productivity of continuous miner operations. The thicker seams and less gassy conditions at western mines, compared to others, allow adequate ventilation with fewer gate entries, reducing the amount of relatively unproductive mine development work. In general, the continuous miner/longwall ratio in the West may be 6:1 (6 feet of development mining per foot of longwall mining), compared to 12:1 in the East.[20] The significant productivity advantage of longwall mining in the West helps to explain the fact that longwall mining has achieved its most rapid market penetration over the past decade in this region.

In the Illinois Basin, the productivity differential between longwall and continuous mining is slight. In this region, average longwall productivity was 3.06 tons per worker-hour in 1993—only 3 percent higher than the productivity of continuous miner operations. Even more surprisingly, *conventional* mining in the Illinois Basin outperformed continuous and longwall mining in terms of labor productivity. With an average productivity of 4.10 tons per worker-hour in 1993, conventional operations were 34 percent more productive than longwall mines. In the Illinois Basin, the seven conventional operations accounted for only nine percent of the total regional underground production, but these mines have been extraordinarily productive. The region's conventional mines are all located in western Kentucky. In contrast, all but one of the region's longwall operations are located in Illinois.

In Appalachia, the average productivity of longwall mines in 1993 (2.94 tons per worker-hour) was 7 percent higher than the average for continuous miner operations (2.76 tons per worker-hour). In several parts of Appalachia, longwall mines enjoyed a comfortable productivity lead over their continuous mining counterparts. These include Alabama, eastern Kentucky, Maryland, and Pennsylvania. However, in Ohio and West Virginia, continuous miner operations were significantly more productive than longwall mines. In West Virginia—the Nation's leading longwall State— continuous mining productivity was 7 percent higher than longwall mining productivity in 1993. On average, longwall mining productivity is lower in Appalachia than in the Illinois Basin or the West.

Some of the reasons for the relatively low productivity of longwall mining in Appalachia can be gleaned from the geologic, technological, and operating characteristics of longwall mining already discussed. The Appalachian coal seams are thin relative to those in other regions, and they are also sometimes located at great depth. Thus, the ratio of seam thickness to seam depth is lower in Appalachia than in the other regions. Because of the thin seams, the number of panel entries per longwall unit is greater in Appalachia than in the other regions. As noted above, this tends to reduce the mine's productivity, as more resources are used for development work.

Also, relatively unproductive plows and one-drum shearers are used in Appalachia, while the other regions use more productive two-drum shearers. The horsepower of the cutting equipment is also lower in Appalachia than in the other regions. Finally, the difference between longwall mines and room-and-pillar mines in the average number of employees per shift is substantially greater in Appalachia than in the Illinois Basin and the West. In Appalachia, the room-and-pillar mines employ substantially fewer workers per shift than the longwall mines.

Considering that Appalachia accounted for 73 percent of the total number of longwall mines in 1993, and 68 percent of U.S. longwall mine production, it may be surprising that productivity at longwall mines is actually lower than productivity at continuous miner

[20]Andrew P. Schissler, Dominick Rossi, and Sam Cario, "Changes in Design Requirements to Maximize Panel Development Rates," *Longwall U.S.A. 1994 Conference Papers* (Ormond Beach, FL: Maclean Hunter Presentations, Inc., June 1994), pp. 22-25.

Table 16. Longwall Mine Labor Productivity, Compared with Other Underground Mine Productivity, by State and Region, 1983, 1990, and 1993

State/Region	Labor Productivity (tons per worker-hour)			
		Room-and-Pillar		
	Longwall	Continuous	Conventional	Total
Alabama				
1983	1.22	NA	NA	1.15
1990	2.15	1.65	--	1.65
1993	2.27	1.71	--	1.71
Eastern Kentucky				
1983	1.50	NA	NA	1.77
1990	3.02	2.45	2.28	2.43
1993	3.84	2.96	2.47	2.84
Maryland				
1983	--	NA	NA	1.83
1990	3.17	--	--	--
1993	4.36	3.15	--	0.78
Ohio				
1983	1.30	NA	NA	1.27
1990	2.44	2.01	--	2.01
1993	3.15	4.20	2.45	4.06
Pennsylvania				
1983	1.19	NA	NA	1.31
1990	2.48	1.93	1.34	1.92
1993	3.53	2.32	1.62	2.18
Virginia				
1983	1.19	NA	NA	1.64
1990	2.24	2.10	1.84	2.09
1993	2.22	2.20	2.17	2.19
West Virginia				
1983	1.77	NA	NA	1.55
1990	2.54	2.78	2.57	2.77
1993	2.89	3.07	2.74	2.99
Appalachia				
1983	**1.51**	**NA**	**NA**	**1.54**
1990	**2.46**	**2.36**	**2.25**	**2.35**
1993	**2.94**	**2.76**	**2.44**	**2.68**
Illinois				
1983	2.16	NA	NA	1.73
1990	2.83	2.67	3.16	2.69
1993	3.35	2.99	--	2.99
West Kentucky				
1983	--	NA	NA	2.03
1990	2.43	2.78	3.39	3.03
1993	2.47	3.03	4.10	3.30

See footnotes at end of table.

Table 16. Longwall Mine Labor Productivity, Compared with Other Underground Mine Productivity, 1983, 1990, and 1993 (Continued)

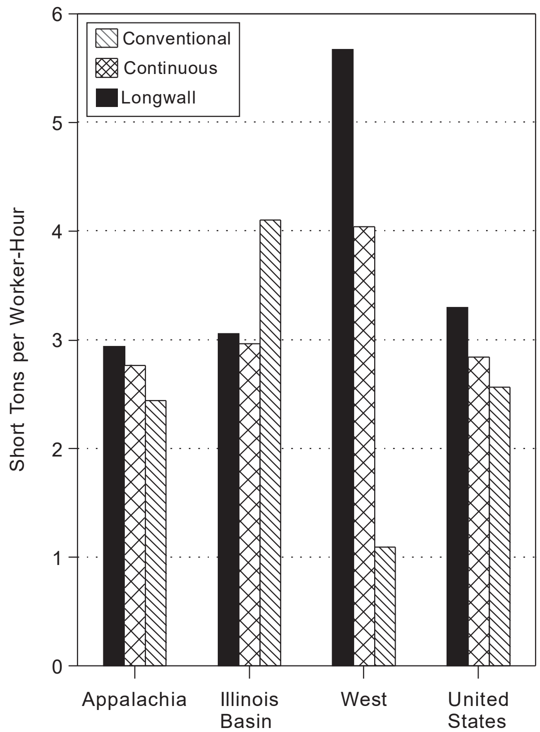
State/Region	Labor Productivity (tons per worker-hour)			
		Room-and-Pillar		
	Longwall	Continuous	Conventional	Total
Illinois Basin				
1983	**2.17**	**NA**	**NA**	**1.83**
1990	**2.76**	**2.72**	**3.35**	**2.84**
1993	**3.06**	**2.96**	**4.10**	**3.07**
Colorado				
1983	1.62	NA	NA	1.92
1990	3.29	3.18	--	3.18
1993	5.92	3.84	--	3.84
New Mexico				
1983	0.93	NA	NA	--
1990	4.27	--	--	--
1993	1.63	--	--	--
Utah				
1983	2.95	NA	NA	2.41
1990	5.40	3.59	--	3.59
1993	6.28	4.80	--	4.52
Wyoming				
1983	2.21	NA	NA	--
1990	3.27	2.60	1.02	1.67
1993	4.63	4.74	1.10	1.94
West				
1983	**2.45**	**NA**	**NA**	**2.20**
1990	**4.35**	**3.37**	**1.02**	**3.28**
1993	**5.67**	**4.04**	**1.09**	**3.76**
United States				
1983	**1.59**	**NA**	**NA**	**1.62**
1990	**2.68**	**2.45**	**2.73**	**2.47**
1993	**3.30**	**2.84**	**2.56**	**2.78**

-- = Not applicable.
NA = Not available.

Notes: Productivity is calculated by dividing coal production by the direct labor hours worked by mine and preparation plant employees. Includes all mines producing more than 10,000 short tons annually, except for 1983, which includes all mines producing more than 100,000 short tons. The effect of this inconsistency in coverage is insignificant for longwall mines, since few, if any, longwall mines produce less than 100,000 tons per year. Since the difference in coverage could have significant effects for continuous and conventional mines, productivity data for those mines are not presented for 1983. Includes employee hours of preparation plants with 5,000 employee hours or more. The productivity estimates for longwall mines include the output of the continuous miners that are used in mine development. Mining method was not reported by several mines, accounting for about 5 percent of total underground coal production in 1983 and 7 percent in 1990. The regional and U.S. productivity averages for room-and-pillar mines include room-and-pillar mines in the following States that have no longwall mines: Tennessee (in Appalachia); Indiana (in the Illinois Basin); and Arkansas, Iowa, Missouri, Montana, and Oklahoma (in the West).

Sources: Energy Information Administration, 1983 Form EIA-7A, “Coal Production Report,” and 1983 Form EIA-7A Supplement; 1990 Form EIA-7A, “Coal Production Report;” and 1993 Form EIA-7A, “Coal Production Report.”

Figure 9. Longwall Mine Productivity Compared with Other Underground Mine Productivity, by Region, 1993



Source: Energy Information Administration, 1993 EIA-7A database.

operations in some key Appalachian States. First, it should be noted that the productivity measure for longwall mines includes the employment input and coal output of the continuous miners used to develop the longwall. The productivity of continuous miners in this type of operation is low relative to the productivity of continuous miners in non-longwall operations. Therefore, the productivity of the longwall *mine* (including the continuous miners) is substantially lower than the productivity of the longwall *unit* (excluding the con-tinuous miners).

In fact, productivity at a longwall mine may depend partly on the balance between the rate of production by the longwall unit and the rate of production by the continuous miners used to develop the longwall. Since the continuous miners are relatively less productive, their share of the mine's output should be minimized. That is why increases in longwall panel size are important for the advancement of longwall productivity. But continuous miners must be used to mine a certain amount of coal in advance of the longwall (for development). If the rate of mine development by the continuous miners is insufficient, the longwall unit must wait, reducing the productivity of the longwall unit.[21]

Probably, the most important reason for the relatively low productivity of longwall mines in Appalachia (compared to other regions) is that many of Appalachia's large longwall mines produce high-quality coal for the metallurgical and export markets. This coal tends to go through more cleaning and preparation than the coal produced by the smaller room-and-pillar mines. The additional coal preparation adds to the labor input at the longwall mines, and also reduces the amount of the final product, thereby tending to reduce the mines' labor productivity.

The interest in longwall mining in this country has always been driven, in large part, by the productivity potential of this highly mechanized method. Of course, labor productivity is only one of many criteria that may be used to evaluate and compare different mining methods. Unit productivity, which measures the amount of coal output by a production unit per shift, is another measure. Between 1983 and 1992, longwall unit productivity rose 166 percent, from an average of 916 tons per shift to 2,440 tons per shift.[22] Although comparable data on continuous miner unit productivity are not available, it is quite clear that continuous miner units are not nearly as productive as longwall units.[23] However, counterbalancing this unit productivity advantage enjoyed by longwalls is the fact that the capital cost of a longwall unit is much higher than that of a continuous miner unit. Other important criteria for evaluating and comparing mining methods include safety, operating costs, mined product quality, and the percentage of the mine's coal that can be recovered. For 1993, it was estimated that 56 percent of the coal at

[21]Andrew P. Schissler, Dominick Rossi, and Sam Cario, "Changes in Design Requirements to Maximize Panel Development Rates," *Longwall U.S.A. 1994 Conference Papers* (Ormond Beach, FL: Maclean Hunter Presentations, Inc., June 1994), pp. 22-25.

[22]Trigg H. Combs, "The 1992 Longwall Productivity Survey," *Coal*, February 1994, p. 37.

[23]Most longwall mines must employ two to three continuous miner units to perform development work for a single longwall unit. Since the quantity of coal mined during longwall development is typically much less than that mined by the longwall unit, and since two to three continuous miner units must be used to "keep up with" the longwall, it is clear that longwall unit productivity is much higher than continuous miner unit productivity.

longwall mines will ultimately be recovered, compared with 53 percent of the coal at room-and-pillar mines.[24]

Another possible reason for the trend toward longwall mining is that the potential for *future* productivity improvements is perceived as being much greater for longwall mining than for continuous mining. As discussed in the following chapter, fully automated longwall systems are beginning to move from the drawing boards into the mines. Although the productivity improvements to be gained through this development and other technological changes cannot be realized at present, mining companies must be in a position to take advantage of these developments. Operations that are already using longwall mining will be able to take advantage of future technological improvements more quickly than those lacking longwall experience.

Productivity Trends

If the past is any indicator, there indeed is reason to believe that longwall mining productivity will rise more rapidly than the productivity of other underground mining methods. Over the past decade, the productivity of longwall mines grew at a much greater rate than the productivity of room-and-pillar mines. Between 1983 and 1993, productivity for longwall mines increased by 108 percent (from 1.59 tons to 3.30 tons per worker-hour), compared with a 72-percent productivity gain for room-and-pillar mines (Table 16).

The most important reasons for the increase in longwall productivity can be found in the factors discussed in the previous chapter—particularly the increases in panel width and length. The increase in panel size contributed to the productivity improvements in several ways. First, the quantity of coal mined by the highly productive longwall units increased relative to the quantity of coal mined by the less productive continuous miners used for longwall panel development. This change in the ratio of longwall to continuous miner production also provided the slower continuous miners with more time to develop new panels, thus enabling them to keep pace with the longwalls. The use of larger panels also reduced the frequency with which the longwall equipment must be moved from a mined-out panel to a new panel. Longwall production comes to a halt during these time-consuming longwall moves.

The move towards larger panels was made possible by improvements in longwall production equipment. Average face conveyor horsepower more than doubled between 1984 and 1993. The increase in conveyor horsepower permitted increases in the capacity and length of face conveyors, and hence allowed increases in face widths. Similarly, average cutting machine (shearer and plow) horsepower increased by 90 percent between 1984 and 1993. Longwall equipment has also become more robust and more reliable.

In addition to changes in panel dimensions and longwall equipment, there have been changes in the geologic conditions under which longwalls operate. Particularly important has been the clear trend away from thinner seam longwall mining. Since thin seam longwalls tend to be less productive than thicker seam operations, this development contributed to the overall improvement in longwall productivity. Finally, there was a significant increase in the size of longwall mines, as measured by their annual production. The proportion of longwall operations producing over 1 million tons per year increased from 47 percent in 1983 to 70 percent in 1993.

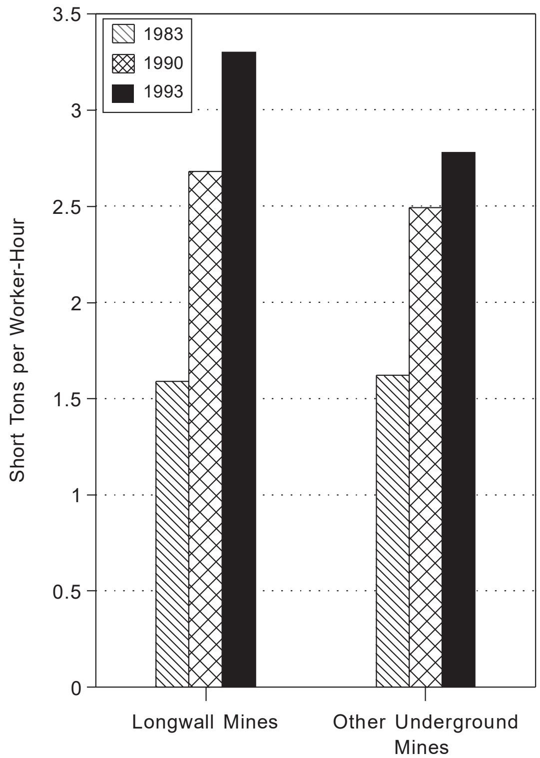
The national productivity trend pattern is repeated in the trends for Appalachia and the West. Appalachian longwall mine productivity increased 95 percent between 1983 and 1993, versus 74 percent for other underground mines. Longwall productivity in the West increased by 131 percent, compared with an 71-percent increase for other underground mines. The relatively high productivity gains in the West probably are due to the substantial increase in average seam thickness or mining height for Western longwalls, as well as their greater increase in average longwall panel length.[25]

The Illinois Basin does not follow the same pattern. There, longwall mine productivity increased by only 41 percent, compared with a 68-percent rise for other mines. This may be due to the relatively small number of longwall mines in the region, with the result that unusual productivity characteristics of one or two mines may have a significant impact on the regional average.

Thus, in general, longwall mine productivity has been increasing at a more rapid pace than the productivity of other underground mines (Figure 10). In view of the

[24]Energy Information Administration, 1993 Form EIA-7A, "Coal Production Report." The surprisingly low recovery percentage for longwall mining may be due to the pillars left in portions of the longwall mine developed by room-and-pillar methods, and the additional coal that is lost during the more extensive preparation of the coal from longwall mines.
[25]See Chapter 3, Tables 4 and 8.

Figure 10. Longwall Mine Productivity Compared with Other Underground Mine Productivity, 1983, 1990, and 1993



Sources: Energy Information Administration, 1993 EIA-7A database, and 1983 EIA-7A and EIA-7A Supplement databases.

technological developments discussed in the next chapter, there is reason to believe that longwall productivity gains will accelerate vis-a-vis those for other underground mining methods.

Longwall Mining Cost Estimates

This section presents summary cost estimates for two hypothetical longwall mines. Detailed, itemized cost estimates for these two model mines were developed in 1990. The model mines were subsequently incorporated into EIA's Resource Allocation and Mine Costing (RAMC) model. The RAMC is an engineering/economic model used to develop supply curves (i.e., relationships between coal production and prices) that are in turn used as inputs by other EIA long-term coal forecasting models (including the Coal Market Module of the National Energy Modeling System, and the Coal Supply and Transportation Model).

Of the two RAMC longwall model mines, one is designed to represent longwall mining as it is practiced in the eastern United States, and the other is designed to typify western longwall operations. However, it must be emphasized that, while different operations may share certain general similarities, every coal mine is a unique entity designed to operate under a unique set of site-specific conditions. In short, there is no "typical" mine or "typical" set of conditions under which mines operate; the use of a single model mine to represent the diversity of operations found in a given region is simply a convenient device designed to yield roughly accurate, though inherently uncertain, estimates of average regional mining costs. The model mines are purely hypothetical and are *not* intended to represent any existing operation, nor can they be used to accurately estimate the costs associated with a specific mine.

Detailed descriptions of the two longwall model mines (including the mining plans, layouts, and operating schedules as well as itemized capital and operating cost estimates) are provided in the report, "Development of RAMC Longwall Model Mines."[26] Table 17, taken from that report, summarizes the key characteristics of the two longwall model mines. The Eastern Mine is a shaft/slope operation, whereas the Western Mine is accessed via drift entries. The depth of cover for both mines is the same (850 feet); however, the Eastern Mine has a mining height of 6 feet, versus 10 feet for the Western Mine. Both mines have a 30-year life.

The Eastern Mine produces 3,041,000 tons of raw coal per year, whereas the annual production of the Western Mine is 2,587,000 raw tons. Both mines utilize one longwall unit; however, the Eastern Mine requires three continuous miner units to support the longwall, whereas the Western Mine uses only two continuous miner development units. Productivity at the Eastern Mine averages 3,575 raw tons per unit shift for the longwall and 575 raw tons per unit shift for the development units. Productivity at the Western Mine is higher (4,900 raw tons per unit shift for the longwall and 700 raw tons per unit shift for the continuous miner units), reflecting the better conditions (particularly the larger seam thicknesses) found in the West.

[26]Science Applications International Corporation, "Development of RAMC Model Mines," unpublished final report prepared for the Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels (Norristown, PA, 1991), March 1991, p. 5.

Table 16. Major Specifications for Eastern and Western Longwall Model Mines

Item	Specifications for: Eastern Mine	Specifications for: Western Mine
Type of Seam Access	Shaft/Slope	Drift
Depth of Cover (feet)	850	850
Mining Height (feet)	6	10
Mine Life (years)	30	30
Annual Raw Production (thousand short tons)	3,041	2,587
Number of Longwall Units	1	1
Number of Continuous Miner Units	3	2
Longwall Productivity (raw tons per unit shift)	3,575	4,900
Continuous Miner Productivity (raw tons per unit shift)	575	700
Longwall Face Width (feet)	750	700
Longwall Panel Length (feet)	6,840	6,080
Number of Longwall Support Entries	4	3
Unionization Status	UMWA[a]	UMWA[a]

[a]United Mine Workers of America.

Source: Science Applications International Corporation, "Development of RAMC Model Mines," unpublished final report prepared for the Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels (Norristown, PA, 1991), March 1991, p. 5.

The longwall face width for the Eastern Mine is 750 feet, and the panel length is 6,840 feet. The panel dimensions are slightly smaller for the Western Mine: 700 feet and 6,080 feet for the face width and panel length, respectively. The number of longwall support entries is four for the Eastern Mine, and three for the Western Mine. The miners at both mines belong to the United Mine Workers of America (UMWA).

The capital and labor cost estimates for the two model mines were escalated from January 1990 to mid-1994 using heavy equipment and mine labor cost indices from the Bureau of Labor Statistics. The total capital costs for the longwall unit are estimated at $13,738,000 for the Eastern Mine and $15,786,000 for the Western Mine (Table 18). These estimates include the costs of the double-drum shearer, the face conveyor, and the shields, as well as the costs of all the auxiliary equipment required for a longwall production unit. The western longwall is more expensive than the eastern longwall primarily because of a difference in the per unit costs of the shields. The western unit's shields are designed for a thicker coal seam. The face conveyor at the Western Mine is also a higher-capacity, higher-cost unit than the one at the Eastern Mine.

Capital costs for a continuous miner unit are estimated at $1,835,000 for the Eastern Mine and $2,567,000 for the Western Mine. These cost estimates include the costs of the continuous miner, the roof bolter, the shuttle cars, and all of the auxiliary equipment required for a continuous miner unit. Capital costs for a continuous miner unit are much lower than capital costs for a longwall. Of course, the productivity of the continuous miner units is also estimated to be much lower than that of the longwalls (575 raw tons per continuous miner unit shift versus 3,575 tons per longwall unit shift at the Eastern Mine).

It should be noted that the Western Mine utilizes three diesel coal haulers per unit, whereas the Eastern Mine uses two cable reel shuttle cars. This difference in the number of shuttle cars, as well as the use of larger, higher-capacity equipment at the Western Mine (made possible by the higher clearance afforded by the thick seam), accounts for the cost differential between the eastern and western continuous miner units. There is a corresponding productivity difference—the Western Mine is estimated to average 700 tons per continuous miner unit shift, versus only 575 tons per continuous miner unit shift for the Eastern operation.

For the Eastern Mine, the total initial capital costs are $54,-033,000 and the total deferred capital costs are $95,893,000. Initial capital and deferred capital costs for the Western Mine are lower—$35,222,000 and $86,845,000, respectively—in part because this mine is a drift operation, and in part because it requires less

Table 17. Estimated Capital Costs for Eastern and Western Longwall Model Mines

Item	Estimated Cost (1994 Dollars)	
	Eastern Mine	Western Mine
Longwall Unit Capital Costs	13,738,000	15,786,000
Continuous Miner Unit Capital Costs	1,835,000	2,567,000
Total Initial Capital Costs	54,033,000	35,222,000
Total Deferred Capital Costs	95,893,000	86,845,000

Source: Science Applications International Corporation, “Development of RAMC Model Mines,” unpublished final report prepared for the Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels (Norristown, PA, 1991), March 1991, p. 6, 144, and 176.

development than the Eastern Mine (e.g., the Western Mine uses only two continuous miner units, whereas the Eastern Mine requires three). The capital estimates for the two mines include all of the underground and surface equipment used to support the production and development units (e.g., conveyor belts, trolley-track systems, and electrical cables and equipment) as well as the surface facilities exclusive of the preparation plant (e.g., shop, warehouse, and office building).

We now turn to a breakdown of the number of workers and estimated labor costs for the two mines. The cost estimates include estimated straight-time and overtime pay for the wage earners, as well as salaries for the salaried workers; benefit costs are not included. A longwall production crew consists of 10 workers (9 union wage earners plus a salaried foreman) at both model mines. Total annual costs per longwall crew are estimated at approximately $440,000 (Table 19).

A continuous miner crew consists of 10 workers (9 wage earners plus a salaried foreman) at the Eastern Mine and 11 workers (10 wage earners plus a salaried foreman) at the Western Mine. Total annual costs for a continuous miner crew are $438,000 at the Eastern Mine and $482,000 at the Western Mine. The crew size at the Western Mine is one worker larger than at the Eastern Mine because the former operation requires operators for three coal diesel haulers, whereas the latter needs only two operators (for two shuttle cars).

The Eastern longwall unit is scheduled to produce coal during three shifts per day. Therefore, it requires a total of three longwall crews (30 workers) at an estimated cost of $1,311,000 per year. In contrast, the Western longwall is scheduled to operate only two shifts per day, requiring two longwall crews (20 workers) at an annual cost of $878,000.

The Eastern Mine includes three continuous miner units, two of which operate two shifts per day and one that operates one shift per day. Thus, the mine requires a total of five development crews (50 workers) at a cost of $2,190,000 per year. The Western Mine utilizes two

Table 18. Estimated Labor Costs for Eastern and Western Longwall Model Mines

Item	Eastern Mine		Western Mine	
	Number of Workers	Annual Cost (1994 dollars)	Number of Workers	Annual Cost (1994 dollars)
Longwall Crew	10	437,000	10	439,000
Continuous Miner Crew	10	438,000	11	482,000
Total Production	30	1,311,000	20	878,000
Total Development	50	2,190,000	33	1,446,000
Total Support	270	11,305,000	157	6,662,000
Total Mine	350	14,806,000	210	8,986,000

Source: Science Applications International Corporation, “Development of RAMC Model Mines,” unpublished final report prepared for the Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels (Norristown, PA, 1991), March 1991, p. 5.

continuous miner units. One of these operates two shifts per day and the other operates one shift per day. This mine therefore requires three continuous miner crews (33 workers) at a cost of $1,446,000.

Additional workers required to support the longwall and continuous miner crews number 270 at the Eastern Mine and 157 at the Western Mine. These support personnel include underground and surface wage earners (e.g., supply motormen, track layers, underground mechanics, surface shop mechanics, pumpers, mine examiners, and general laborers) as well as salaried personnel (upper-level mine management, construction and maintenance foremen, safety inspectors, engineers, surveyors, draftsmen, warehouse workers, and clerical staff). Total annual costs for support personnel are estimated at $11,305,000 for the Eastern Mine and $6,662,000 for the Western Mine.

In sum, total costs for all production, development, and support staff are $14,806,000 (for a total of 350 workers) at the Eastern Mine and $8,986,000 (for 210 workers) at the Western Mine. The cost differential between the two mines reflects the fact that the Eastern Mine operates a total of eight unit-shifts (three longwall and five continuous miner) per day, versus only five unit shifts (two longwall and three continuous miner) at the Western operation.

Perhaps the most important point that can be gleaned from Table 19 is that the workers assigned to longwall production constitute only a small fraction of the total staff required to operate a longwall mine. In the case of the Eastern Mine, only 30 of the 350 employees (9 per-cent) work on the longwall itself. Similarly, only 20 of the 210 employees at the Western Mine (10 percent) work on longwall production crews.

The various longwall support functions (including panel development by the continuous miners) account for over 90 percent of the total staff at both model mines. Although these workers contribute only indirectly to longwall production, their contribution is nonetheless vital—e.g., a longwall production unit could not operate for long without workers dedicated to designing, installing, maintaining, and operating the various mine support systems (e.g., conveyor haulage, worker and supply transportation, ventilation, power, and water). In the next chapter, the potential for reducing longwall mine staff requirements through automation will be discussed. At this point, it is important to note that longwall automation should affect only the size of the longwall production crew. The functions performed by the development and support workers—constituting by far the larger portion of the total mine staff—will not be automated at any time in the foreseeable future.

A face conveyor undergoing compatibility trials with a shearer.

5. The Outlook for Longwall Mining

Future Technology

The preceding chapters have addressed both the historical development and current status and role of longwall mining in the United States. The remainder of this report will consider the outlook for longwall mining.

A number of questions present themselves concerning the future of longwall mining. Has longwall mining already achieved its full potential, or does substantial room for further development and improvement remain? How will longwall technology change, and how will these changes affect the role of longwall mining vis-a-vis other mining methods? Will longwall's share of underground production continue to grow? What are the potential obstacles or impediments to the increased utilization of longwall mining? What impact will potential legislative and regulatory developments have on longwall operations? And what are the views of current mine operators on the prospects for longwall mining?

It is appropriate to begin by addressing the issue of future technology, for the evolution of longwall mining, perhaps more than any other mining method, has been driven by technological change. Over the past decade, significant improvements in longwall equipment have fueled the dramatic rise in productivity. Shields with high-yield capacities and electrohydraulic controls have replaced manually operated frames and chocks. Armored face conveyors have become more robust as well as more powerful, with stronger, heavy duty chains, increased chain speeds, and significantly higher conveying capacities.[27] Shearers have become not only more powerful than before, but more reliable and maintainable as well.[28]

Although evolutionary and incremental in nature, these various developments represent a major improvement in longwall technology when considered as a whole. However, this improvement is essentially quantitative rather than qualitative in nature. Longwall equipment has gained significantly in power, robustness, and reliability, as measured by such quantitative parameters as horsepower and downtime; but despite these changes, longwall mining has retained its basic nature and operating characteristics. One new development looming on the horizon, however, has the potential to change the fundamental nature of longwall mining as it is practiced today: automation.

Longwall Automation

Although it involves the use of highly complex and sophisticated technologies, longwall automation is simple in concept. In a fully automated longwall section, a robotically-controlled shearer capable of detecting the interface between the coal seam and the roof and floor rock would advance itself across the face. As it passes each shield, the shield would be automatically advanced to support the newly exposed roof behind the shearer. By eliminating the need for shearer and shield operators, longwall automation would reduce the exposure of workers to health and safety risks (e.g., respirable dust) as well as improve productivity. Longwall automation would by no means, however, eliminate the need for underground personnel; at the very least, for example, maintenance workers would still be required on the longwall section to keep the automated equipment running, and the large contingent of workers needed to operate the continuous miner development units and perform production support work (such as construction and supply transportation) would remain unchanged. In fact, if automation led to increased face advance rates (and there is some reason to believe that this might occur), additional personnel might be required to ensure that continuous miner development and production support activities kept pace with the longwall.

The fully automated longwall system described above is the ultimate goal, but like most technological advances in the coal industry, this goal is likely to be achieved through limited, incremental steps rather than

[27]Ken Mackie, “Towards the Integrated Longwall Face,” *Longwall U.S.A. 1994 Conference Papers* (Ormond Beach, FL: Maclean Hunter Presentations, Inc., June 1994), p. 57.
[28]J. A. Organiscak, E. D. Thimons, and R. A. Jankowski, “Longwall Shearers Gain in Power and Efficiency,” *Coal*, February 1993, p. 46.

all at once. In fact, incremental movements towards full automation are already well under way.

The first significant step towards realizing the goal of full automation was the introduction of electrohydraulic controls for shields in the mid-1980s. By permitting batch control of a group of shields from a single location, the use of electrohydraulic controls reduced, but did not eliminate, manpower requirements for shield operation. Electrohydraulic controls achieved rapid penetration of the U.S. longwall market. The first electrohydraulic controls were introduced into Consolidation Coal Company's Loveridge Mine in 1984.[29] By 1994, the *Coal* census indicated that 83.5 percent of all longwalls were outfitted with electrohydraulic controls.[30]

Given the success of electrohydraulic controls, the next logical step towards full longwall system automation is complete automation of the shields, through the development of Shearer Initiated Support Advancement (SISA). In fact, shields with electrohydraulic controls can be readily retrofitted with shearer-initiation hardware,[31] and a number of longwalls have now been outfitted with SISA systems.

There are two basic types of SISA systems: impulse and infrared detection. Both types serve the same basic purpose—to determine the shearer's location relative to the shields. Infrared detection is generally considered to be the first generation system, while impulse systems are regarded as second generation developments. Infrared systems utilize an infrared transmitter mounted on the shearer, in conjunction with transceivers mounted on each shield. As the shearer moves along the face, its infrared signal is received by each shield in turn. Each receiving shield transmits the signal to a computer located at the headgate, which identifies the shield and thus determines the shearer's location. Based on this information, the computer signals a microprocessor mounted on the appropriate shield to advance the shield towards the face.

Whereas infrared detection systems locate the shearer relative to the shields, impulse systems locate the shearer relative to the conveyor panline. Under the latter system, magnets located on the shearer's drive sprocket trip switches that send signals down the shearer's electrical cable to a computer at the headgate. Based on these signals, the computer calculates the distance the shearer has travelled from a selected starting point. A variation on this approach is utilized by digital impulse systems, in which a computer onboard the shearer computes the shearer's location and sends this information to the headgate computer. As with infrared detection systems, the headgate computer signals the appropriate shields to move. At present, infrared detection systems appear to be preferred over impulse and digital impulse systems, but the latter systems have their proponents. In a more recent development, both types of systems have been combined in a "checks-and-balances" approach.[32]

Thus far, acceptance of SISA appears to be slower than acceptance of electrohydraulic controls. In 1988, *Coal* magazine reported that two SISA systems were operating in the United States—one at a Consolidation Coal Co. mine and the other at a U.S. Steel operation.[33] In 1991, the same magazine reported that approximately a dozen SISA systems are in operation at least part of the time. However, of these systems, only six "could be described as fully operational all of the time."[34] The slow acceptance of SISA—even at mines where it has been installed—appears to be due, in part, to problems encountered in early applications of the technology. For example, there were early reports of failed reception and false signals in the case of infrared systems. This problem appears to have been overcome by widening the infrared beam so that it is received simultaneously by three shields; if two of the three shields recognize the signal, the computer assumes that the third shield has received it as well. Other early problems have been addressed through the development of "tolerant software," which, for example, allows the computer to bypass an occasional shield that repeatedly fails to reset itself to the prescribed pressure, on the assumption that there is a cavity or crushed roof above the shield's canopy.[35]

The final—and probably most difficult—step in the development of the fully automated longwall is the automation of the shearer. The main obstacle to shearer automation has been finding a reliable means of keeping the shearer from cutting into the roof and floor

[29]Mark W. Sprouls, "Longwall Census '84," *Coal Mining*, December 1984, p. 39.
[30]Paul Merritt, "1994 Longwall Census," *Coal*, February 1994, pp. 26-35.
[31]Arthur P. Sanda, "Longwall Automation Progresses Slowly," May 1991, p. 45.
[32]Sanda, "Longwall Automation," p. 46.
[33]Sprouls, "Longwall Census '88," p. 67.
[34]Sanda, "Longwall Automation," p. 45.
[35]Sanda, "Longwall Automation," p. 46.

rock without leaving significant uncut quantities of coal near the roof and floor. The shearer must, in other words, be able to detect the coal-rock interfaces as closely as possible. If the shearer cuts too much rock, valuable production time is wasted, the cutting bits wear out and must be replaced more frequently, the machine may be damaged, the quality of the mined product is diminished, and in some cases roof control may present increased difficulties. If, on the other hand, significant quantities of coal near the roof and floor are left unmined, valuable product is wasted, and the available clearance for workers and machinery is reduced.

The U.S. Bureau of Mines, coal companies, and equipment manufacturers (both in the United States and abroad) have been attempting to address this "horizon control" problem for several decades. A number of basic approaches to controlling the shearer's cutting horizon have been or are being tried. Probably the simplest of these has been fixed-slaving control, in which the shearer cuts at a fixed height above or below the machine's body. To be successful, this approach requires a seam of uniform or nearly uniform thickness—a condition rarely encountered in practice.[36] In another approach, called memory cut or mimic mining, the shearer follows a cut sequence defined by a human operator, and stored in an onboard computer. The stored cut sequence can be repeated, but when conditions change significantly, it is necessary to redefine the sequence.

A third approach relies on sensing devices to detect the coal-rock interface. A wide variety of detection technologies have been investigated, including, for example, natural gamma radiation, radar, electromagnetism, bit force, vibration, infrared radiation, optical scanning, video cameras, image processing, motor currents, electric spin resonance, and x-ray fluorescence.[37] Some of these technologies have shown considerable promise, at least under certain conditions. For example, natural gamma radiation detection uses highly sensitive instruments to detect the low-level, natural gamma radiation (NGR) emitted from most shales and other rocks. Since coal usually has little radioactivity, the NGR emitted from the roof and floor rock can be used to detect the coal seam thickness and seam boundaries. Different detection technologies can be combined to enhance horizon control under a wide variety of conditions; for example, NGR detection can be combined with vibration-based technologies, which utilize instruments that measure changes in machine vibration as the shearer leaves the coal and begins to cut rock.[38]

In short, the move towards longwall automation is already underway. What are the future prospects for further automation? In a 1991 report published by the Electric Power Research Institute, Suboleski and others say that "nearly automated longwalls" are "almost sure to have an impact on future productivity in the industry over the next 10 years."[39] They note that SISA systems have been included on "the last three-to-four longwall faces installed,"[40] and they also report one "semi-experimental face"[41] with a shearer utilizing NGR detection to maintain horizon control along the roof, in conjunction with vibration sensors for horizon control along the bottom. They note that "the system is reportedly doing well and the company is considering a manless face within the next year or so,"[42] and they conclude that "there is a real possibility that a large number of longwalls will use such a system within the next decade."[43]

Indeed, full longwall automation is no longer a mere possibility—it has already arrived. In a paper presented at the 1994 Longwall USA conference, George R. Ingram of Consolidation Coal Company (Consol) reported his company's success with a fully automated longwall system installed at the Blacksville No. 2 Mine (West Virginia) in December 1991. The system consists of a robotically controlled shearer linked to the shields through a SISA system. Ingram emphasized that the automated longwall is not "purely demonstrational," but rather was designed to function in a normal production mode on a day-to-day basis. Interestingly, Consol's comparisons of the shearer robotic control system with an experienced human operator appear to favor the robotic system: Ingram reports that the experienced operator missed the target coal-rock interface by more than 2 inches 58 percent of the time, whereas

[36]George R. Ingram, "Longwall Automation at Consolidation Coal Company's Blacksville No. 2 Mine," *Longwall U.S.A. 1994 Conference Papers* (Ormond Beach, FL: Maclean Hunter Presentations, Inc., June 1994), p. 33.
[37]J. A. Organiscak, E. D. Thimons, and R. A. Jankowski, "Longwall Shearers Gain in Power and Efficiency," *Coal,* February 1993, p. 46.
[38]J. A. Organiscak, "Survey Shows that Gamma-Ray Sensors Could Prove Highly Useful in U.S. Coal Mines," *Coal*, February 1990, p. 73.
[39]S. C. Suboleski, R. L. Frantz, R. V. Ramani, and G. P. Rao, *Central Appalachia: Coal Mine Productivity and Expansion,* Electric Power Research Institute Final Report IE-7117, September 1991, p. 3-1.
[40]Suboleski, p. 3-3.
[41]Suboleski, p. 3-3.
[42]Suboleski, p. 3-3.
[43]Suboleski, p. 3-3.

the robotic control system missed only 16 percent of the time.[44]

Also interesting is Ingram's statement that “total manpower reduction on the automated longwall section was not the objective of the automation effort.”[45] Job elimination has been described as a “red flag” in discussions of longwall automation, and manufacturers and operators instead emphasize improved health and safety (e.g., reduced worker exposure to dust) and better utilization of workers as the goals of automation.[46] Suboleski and his colleagues, however, predicted that automation will result in the elimination of 300 to 1,000 longwall production crew workers.[47] Ingram, for his part, suggested that it is cost-effective to maintain a full production crew to resume manual operation in the event of a failure in the automation system. Since manual operation requires one headgate operator and three to five face operators, as compared with one headgate operator and one to three face operators during automatic operation, as many as four operators are normally assigned to other tasks, “which further improves productivity and safety.”[48]

Other benefits of the automated system reported by Ingram include increased longwall availability, improved productivity, lower supply costs, improved clean coal yields, reduced exposure of workers to respirable dust, better utilization of available workers, improved management control and communication, increased coal recovery, improved roof control, reduced maintenance and ownership costs, improved troubleshooting, and early warning of some equipment failures. Ingram concluded by noting that, as a result of the success at Blacksville No. 2, Consol planned to install a “second generation” automated longwall at the Robinson Run Mine (West Virginia) in the summer of 1994.[49] A third-generation system is in the planning stages for yet another Consol mine.[50] The fact that it is Consol reporting success with full automation may have significant implications for the future market penetration of this technology. As the leading U.S. longwall operator, with a total of 24 units, Consol's foray into automation will no doubt be watched closely by many other operators.

Other Potential Technology Developments

Longwall automation is unquestionably the most significant technology development looming on the horizon, but there are others as well. Many are related to computers, which will play a central role in automated longwall systems, are likely to find numerous other applications extending well beyond operation of the shearer and shields. In fact, computers are already being used for various maintenance functions, and their role in equipment maintenance will almost certainly expand. Self-diagnostic equipment, capable of indicating the cause of a failure to the mechanic, is beginning to appear in underground mining. Also under development are equipment monitoring systems that will help to prevent failures from occurring in the first place. In one such system, a tape recorder is used to record data on the shearer's operation. Every few days the tape is removed and read by a personal computer; the data can then be used to identify impending failures and schedule preventive maintenance.[51] Real- time transmission of shearer data to a personal computer is another future possibility; the necessary data transmission technology is emerging as part of the SISA system development effort.[52]

Suboleski and others predict that other developments “almost sure to be implemented” in the next 10 years include:

- Longwall cuts will become deeper. Currently, most longwalls take a 30-inch cut, but Suboleski and his colleagues note that one unit is now using a shearer capable of taking a 42-inch cut. They predict that use of a 42-inch shearer drum will

[44]George R. Ingram, “Longwall Automation at Consolidation Coal Company's Blacksville No. 2 Mine,” *Longwall U.S.A. 1994 Conference Papers* (Ormond Beach, FL: Maclean Hunter Presentations, Inc., June 1994), pp. 29, 30, 33, and 34.
[45]Ingram, p. 34.
[46]Sanda, “Longwall Automation,” p. 49.
[47]S. C. Suboleski, R. L. Frantz, R. V. Ramani, and G. P. Rao, *Central Appalachia: Coal Mine Productivity and Expansion*, Electric Power Research Institute Final Report IE-7117, September 1991, p. 3-3.
[48]George R. Ingram, “Longwall Automation at Consolidation Coal Company's Blacksville No. 2 Mine,” Paper presented at June 1994 Longwall USA Conference, p. 34.
[49]This system has been installed.
[50]Ingram, p. 35.
[51]S. C. Suboleski, R. L. Frantz, R. V. Ramani, and G. P. Rao, *Central Appalachia: Coal Mine Productivity and Expansion*, Electric Power Research Institute Final Report IE-7117, September 1991, p. 3-2.
[52]J. A. Organiscak, E. D. Thimons and R. A. Jankowski, “Longwall Shearers Gain in Power and Efficiency,” *Coal*, February 1993, p. 47.

lead to a 10- to 15-percent increase in longwall productivity.

- Lagging longwalls will catch up with the industry leaders.[53] Changes in longwall technology and panel dimensions have occurred at such a rapid pace over the past decade that longwalls which may have been "state of the art" systems just a few years ago may be little better than average by today's standards. Increased market penetration of newer equipment models will help to raise average longwall productivity above current levels.

This discussion has focused on potential developments on the longwall face, but it is important to keep in mind that the longwall itself is part of an integrated system including continuous miner development units and various production support systems (including, for example, the conveyor belts used to haul the coal produced by the longwall to the surface). Although not as dramatic as some of the technology changes likely to occur at the longwall face, potential future developments elsewhere in the mine may nonetheless make an important contribution to improved performance of the longwall system as a whole.

The ability of the continuous miner development units to "keep up with" the longwall is critical to the proper functioning of a longwall mine. As technology improvements on the longwall face lead to higher production rates, the pressure on the development units will increase. One potential technology improvement that would help to alleviate this pressure is the development of continuous miners with higher cutting rates. Over the past 10 years, continuous miner coal cutting rates have increased from a typical level of 5 tons per minute to 10 tons per minute at the better operations. Suboleski and others predict that an increase in continuous miner cutting rates to 10 to 15 tons per minute over the next decade is almost certain. However, they note that this would lead to a productivity increase of only 5 percent if the capacity of the face haulage system is not increased. One possible approach to increasing face haulage capacity is to add a third shuttle car to the continuous miner unit. The use of continuous haulage systems is another possible approach to alleviating the face haulage "bottleneck;" however, Suboleski and his colleagues believe that the prospects for continuous haulage over the next decade are "not good."[54]

The development of self-diagnostic equipment is by no means limited to the longwall unit; increased use of computers for equipment monitoring is likely to have a significant impact on continuous miner development units in the future. Finally, although lagging behind longwall automation development efforts, work towards continuous miner automation has been ongoing for many years. One system under development by the U.S. Bureau of Mines utilizes laser-guided navigation to control the operation of the continuous miner.[55] However, full automation of a continuous miner unit, unlike longwall automation, remains a long-term goal.

Legislative Developments Affecting Longwall Mining

Productivity gains in longwall mining have resulted from a number of operational and equipment changes, such as increases in the horsepower and the capacity of conveyors and increases in the size of longwall panels. Although extended longwall panels offer some major benefits in terms of fewer equipment moves, less entry development, and increased resource recovery, they can introduce health and safety concerns related to increased dust and methane levels, ground control issues, ventilation planning, and other considerations.

Environmental concerns such as global warming, coal industry concerns such as the cost of complying with stricter Federal regulations, citizen and municipal concerns such as protection from subsidence damage, and union concerns such as coal mine health and safety have kept underground mining in the forefront of the volatile topics debated by citizen lobby groups, mining associations, and State and local governments.

Subsidence

The most recent Federal regulation affecting longwall mining is the Energy Policy Act of 1992 (EPACT), Public Law 102-486, 106 Stat. 2776, enacted on October 24, 1992. Section 2504 of that Act amends the Surface Mining Control and Reclamation Act of 1977 (SMCRA) in an attempt to provide for greater stability in the surface mining act program by settling controversies over subsidence protection.

[53]S. C. Suboleski, R. L. Frantz, R. V. Ramani, and G. P. Rao, *Central Appalachia: Coal Mine Productivity and Expansion*, Electric Power Research Institute Final Report IE-7117, September 1991, pages 3-3 and 3-4.
[54]S. C. Suboleski, R. L. Frantz, R. V. Ramani, and G. P. Rao, "Lasers Guide Continuous Miners," *Coal*, September 1991, p. 57.
[55]S. C. Suboleski, R. L. Frantz, R. V. Ramani, and G. P. Rao, "Lasers Guide Continuous Miners," *Coal*, September 1991, p. 57.

Subsidence is the sinking or lowering of the surface land when the rock strata collapse downward into the void created by underground mining. In longwall mining where workers mine 100 percent of the coal in a panel, the mine roof collapses immediately when the roof supports at the working face are moved. The planned subsidence due to longwall mining may cause a drop in surface elevation ranging from 4 to 6 feet. The drop in surface elevation ranges from 60 to 70 percent of the mined height of the coal seam plus any roof or floor materials that have been removed.[56]

Rock strata collapse begins immediately above the void area and eventually propagates upward to the surface above the mine. Strata displacement is largest near the void and gradually decreases toward the surface.[57] The sinking of geologic materials lying over the mined out area continues for years, although it diminishes rapidly after a few months. Once subsidence has decreased to levels that no longer cause damage to structures, the land can usually be developed.[58]

Subsidence from underground mining takes two forms, pit and sag. Pits are usually 6 to 8 feet deep and range from 2 to 40 feet in diameter, although most are less than 16 feet across. Newly formed pits have steep sides with straight or bell-shaped walls (Figure 11).

Sag subsidence forms a gentle depression over a broad area. Some sags may be as large as a whole mine panel several hundred feet long and a few hundred feet wide. Several acres of land may be affected. The ground moves in two directions during sag subsidence. It drops vertically and moves horizontally toward the center of the sag. At the surface, the sag may be much broader than the collapsed part of the mine. For example, a roof failure in a mine 160 feet deep could cause minor surface subsidence more than 75 feet beyond the edge of the undermined area.

The type and extent of damage to surface structures relate to their orientation and position within a sag. Any large cracks that develop in the ground may damage buildings and roads as well as driveways, sidewalks, pipes, sewers, and utilities (Figure 12). The sinking and settling of land over underground mines can cause ponds to form on farmland.[59]

Figure 11. Cross Section of a Typical Pit Subsidence Event

Source: Robert A. Bauer, Billy A. Trent, and Paul B. DuMontelle, "Mine Subsidence in Illinois: Facts for Homeowners," *Environmental Geology*, Department of Energy and Natural Resources, Illinois State Geological Survey, 144 (1993).

In room-and-pillar mining, the location, timing, and damage of subsidence cannot be predicted because subsidence is delayed until the coal pillars are crushed by the weight of the overlying rock. Any individual pillar may collapse shortly after mining has been completed (or in some cases, during mining), or may remain in place for decades after the mine has been abandoned. Subsidence over longwall panels, on the other hand, occurs soon after mining and is thus more predictable than room-and-pillar subsidence.

In room-and-pillar mining, however, it is relatively easy to protect surface structures by leaving large pillars in place under the structures. By properly sizing these protective pillars, subsidence can be prevented over the long term. Continuous and conventional units can mine

[56]Robert Bauer, Billy Trent, and Paul DuMontelle, "Mine Subsidence in Illinois: Facts for Homeowners," *Environmental Geology*, Department of Energy and Natural Resources, Illinois State Geological Survey, 144(1993).

[57]David K. Ingram, "Overview of Mine Subsidence Insurance Programs in the United States," Bureau of Mines Information Circular, U.S. Department of the Interior, IC 9362 (1993).

[58]Robert Bauer, Billy Trent, and Paul DuMontelle, "Mine Subsidence in Illinois: Facts for Homeowners," *Environmental Geology*, Department of Energy and Natural Resources, Illinois State Geological Survey, 144(1993).

[59]Robert Bauer, Billy Trent, and Paul DuMontelle, "Mine Subsidence in Illinois: Facts for Homeowners," *Environmental Geology*, Department of Energy and Natural Resources, Illinois State Geological Survey, 144(1993).

Figure 12. Diagram of a Typical Sag Subsidence Event

Source: Robert A. Bauer, Billy A. Trent, and Paul B. DuMontelle, "Mine Subsidence in Illinois: Facts for Homeowners," *Environmental Geology*, Department of Energy and Natural Resources, Illinois State Geological Survey, 144 (1993).

around the protective pillars with relatively little disruption to production.

Longwall mining, on the other hand, is much less flexible than room-and-pillar mining in this regard. The need to detour around protective pillars would cause major disruptions to a longwall unit. Thus, subsidence regulations may have a major impact on the future of longwall mining in the United States.

Until 1977, it was the State's responsibility to regulate and control subsidence-related problems on non-Federal lands. SMCRA introduced Federal requirements. Under SMCRA, underground coal companies are required to pay a 15-cent fee for every ton of coal produced. This fee, along with the surface mining operation fee (35 cents per ton), is deposited into the Abandoned Mined Land Reclamation Fund. Under SMCRA, subsidence caused by mines abandoned before 1977 is covered by the Abandoned Mined Land Reclamation Fund. Stabil-izing or reclaiming ground that is subsiding because of a mine abandoned before 1977 is considered a reclamation cost. Reclamation costs for uncontrolled subsidence caused by mines abandoned after 1977 are the responsibility of the operating coal company. However, liability for costs of subsidence damage to surface structures caused by mining after 1977 depends upon individual State regulations.[60]

The number of revisions to SMCRA, starting in 1979, and almost 15 years of continual litigation over SMCRA and its regulations suggest that major problems existed with SMCRA from its initial implementation. SMCRA required coal companies to design and implement methods to prevent or to control and minimize the effects of subsidence. However, specific provisions of SMCRA such as requirements for a presubsidence survey and for water replacement interrupted by underground mining were rescinded, modified, or limited to the extent required by State law. Section 516(b)(1) of SMCRA required coal companies to adopt measures to prevent subsidence damage, but did not define material damage.

The enactment of EPACT accomplished three things. It required immediate, prompt repair and compensation

[60]David K. Ingram, *Overview of Mine Subsidence Insurance Program in the United States*, Bureau of Mines Information Circular, U.S. Department of the Interior, IC 9362 (1993).

for material damage to noncommercial buildings and occupied residential dwellings and related structures as a result of subsidence due to underground coal mining operations. It brought to the legislative table an issue that was not uniformly interpreted and implemented in the States, and it gave the Office of Surface Mining (OSM) the task of producing a clear, uniform, enforceable set of regulations on responsibility for subsidence damage.

In response to EPACT, OSM proposed rules on underground mining permit application requirements and underground mining performance standards, allowing a comment period from September 24, 1993, to January 24, 1994. In the proposed rules, OSM added definitions to the terms used in existing or proposed regulations. “Material damage,” for example, would be defined as the functional impairment of surface lands, features, structures, or facilities. As clarified, the definition would include damage that significantly changes the condition or appearance of any structure or facility from its premining condition or causes any significant loss in production or income.

The proposed rules would require operators to provide additional performance bonds, when necessary, to cover subsidence-related damage. There would be expanded baseline survey requirements and new performance standards that would obligate coal mine operators to minimize surface damage even for planned subsidence, as with longwall mining and other full extraction techniques.

The proposed rules include broad water supply provisions that would require underground coal mine operators to replace water supplies used for agricultural, industrial, or other legitimate purposes if the underground or surface source of the water supply is adversely affected by underground mining.

States, organizations representing coal companies, and many other groups commented that the proposed rules, if enacted:

(1) Could result in increased underground mining costs because of restrictions on the use of longwall mining techniques and more burdensome requirements for pre-subsidence surveys.

(2) Would preempt State property laws, State water laws and State regulatory programs, which are working effectively, and would disregard the unique circumstances associated with the regional differences in terrain, geology, and other environmental conditions.

(3) Could take away the operator's right to subside because of the new requirement to minimize material damage in the case of planned subsidence.

Other issues raised were:

(1) Some of the new definitions of terms such as material damage are not clear.

(2) There is no distinction made between planned and unplanned subsidence.

(3) There would be procedural problems in making the rules retroactive to October 24, 1992.

OSM received over 400 comments on the proposed rulemaking on subsidence during the initial comment period. Twenty-six additional comments were received when the comment period was reopened between July 26, 1994 and August 25, 1994 to allow interested persons time to review additional material obtained from discussions of subsidence-related issues with coal operators and citizens during an on-site tour of coal fields and to comment on an alternative provision to clarify the requirement for replacement of water supplies. The final regulation was completed and forwarded to the Office of Management and Budget in January 1995.

Methane Recovery

Another proposed legislative initiative that may affect longwall mining is the Climate Change Action Plan sponsored by the Clinton Administration. The goals of Action Plans 35 and 36 are to reduce methane gas emissions from coal mining and to encourage the recovery of methane for on-site use or sale to pipeline and power generation companies.

Coalbed methane has historically been a serious safety hazard because, in concentrations of 5 to 15 percent, it is explosive. The primary function of coal mine ventilation systems is to keep the methane concentration of the mine air well below the level at which it becomes explosive. The wide mine faces and high production rates characteristic of longwall mining present unique ventilation problems. At gassy operations, the quantity of air needed to dilute the methane at the face is in some cases so large that excessive dust is picked up and carried in the ventilation stream.

For this reason, a number of longwall operations supplement traditional ventilation systems, which are designed to dilute the methane at the face during mining, return it to the air shaft, and vent it to the atmosphere. The supplementary techniques extract the methane through vertical and horizontal drillholes prior to and during mining. For example, methane in the gob area is extracted using vertical "gob wells" drilled from the surface. The methane extracted using this technique and others is often simply vented to the atmosphere.

However, industry interest in recovering the methane for sale or for on-site utilization is increasing. Coalbed methane recovery has also become of interest to the Federal Government in recent years, in part because methane is a greenhouse gas that may contribute to global climate change. Coalbed methane recovery is now seen as a way to reduce greenhouse gas emissions, improve safety and productivity, and enable coal operators to profit from methane through sales to natural gas pipelines.

Coal mining regulations pertaining to methane emissions are found in the Code of Federal Regulations, Part 75.300, Subpart D. Ventilation. The extensive regulations were promulgated on May 15, 1992. As part of the Climate Change Action Plan, the Environmental Protection Agency in a cooperative effort with the coal industry, has introduced a Coalbed Methane Outreach Program which seeks to eliminate some of the legal, institutional and regulatory barriers to developing methane recovery projects.

Pursuant to the Climate Change Action Plan 36 initiative, the Department of Energy's Fossil Energy Office plans to develop projects to demonstrate cost-effective technologies and practices for premining recovery of methane from coal and for inmine degasification streams and to demonstrate the use of fuel cells, gas turbines, and other state-of-the-art technologies for waste methane utilization.

Coalbed methane recovery can turn a safety hazard into valuable energy. The safety operations used to dilute methane consume a great deal of energy and are very expensive. Instead, coal mines can use available technologies to recover high quality methane that can be used as fuel while reducing the methane hazard in mining areas. Since the early 1980's, Jim Walter Resources (JWR) has recovered methane from four coal mines in Alabama. Each year, about 13 billion cubic feet of high-quality methane is produced from a variety of mine degasification approaches and sold to a nearby pipeline. JWR estimates that this program has reduced its mining costs by more than 1 dollar per ton and made the continued operation of these coal mines economical.

Dust Control

Dust control is another area in which the regulations impact longwall mining. The primary source of respirable dust on longwall faces is still the cutting action of the shearer. As a general rule, when more coal is mined, more dust is generated. Thus, the high production rates characteristic of longwall units tend to create dust problems at the face. Furthermore, extended longwalls generally favor the use of the bidirectional cutting sequence, which can result in increased dust levels due to production increases. Dust avoidance procedures commonly employed to reduce dust exposure on unidirectional faces have limited success since the bidirectional cutting sequence place face workers downwind of the dust sources during all phases of the mining cycle. During the downwind cutting pass, the shearer operator(s) are downwind of support advance; during the upwind cutting pass, the support movers are downwind of the shearer. Techniques that several mines have implemented for the control of shearer-generated dust on extended longwall faces include high drum-water flow rates, deep cutting, radio-remote control, and high-pressure drum spray systems.

Coal operators are presently required by Title 30, Part 71, of the Code of Federal Regulations to collect five air samples every 2 months, while the Mine Safety and Health Administration (MSHA) is required to conduct at least one inspection per year. When inspections and sample analysis indicate that dust levels are not in compliance with the standards, coal operators are required to take additional control measures such as increased ventilation, increased sprays, or increased barriers. Increased dust control measures add to the total costs of coal production, however, the cost of increased dust control measures for longwall mining are not significant when compared to the total capital expenditures for longwall equipment (which is generally outfitted with the latest dust control equipment).

Ground Water

Section 720(a)(2) of EPACT requires prompt replacement of certain identified water supplies that are adversely affected by underground coal mining operations. Prior to this legislation, SMCRA regulations were interpreted as being applicable only to damage to water supplies caused by surface mining.

A number of studies have been conducted to determine the effects of longwall mining on ground water systems near coal mines. They have suggested that mining effects on ground water are localized, that these effects are associated with periods of maximum surface subsidence, and that water levels in aquifers at least 330 feet above the mine generally recover to premining levels. In an extensive study to evaluate the effect of longwall mining on rural water supplies and stress relief fracture flow systems, 174 domestic water supplies near longwall operations in the Pittsburgh seam were compared to various physical properties. Sixty-four percent of the domestic water supplies returned to service without the need for intervention, while 36 percent required intervention to reestablish a suitable water supply. This study concluded that longwall mining does not drain the near-surface zone of ground water. According to the findings, the stress-relief fracture ground water flow pattern in the near-surface zone remains essentially unchanged; in this pattern, recharge occurs first at the topographic high areas and then moves toward the valley bottoms. The result of longwall mining upon this flow system is to change individual flow paths and flow rates within this zone, rather than to cause depletion of this near-surface water.[61]

Based on preliminary information, a recent study shows that piezometers installed in large continuous bedrock aquifers near the top of bedrock demonstrate that water levels decline during subsidence, but recover within 3 months. No changes in water levels or chemistry have been observed for wells located in the glacial material above the bedrock.[62]

The Future of Longwall Mining—Industry Views

In the autumn of 1989, EIA conducted a limited number of interviews with representatives of longwall mining companies as part of an analysis of longwall mining costs. A total of five interviews were conducted with engineering and managerial employees of five different companies. One or two company representatives were present at each interview. The companies represented in the interviews currently operate a total of 19 longwall units (22.4 percent of the total) located throughout the United States.

The primary purpose of the interviews was to solicit industry opinions on the short- and long-term prospects for longwall mining. Interviewees were asked to provide their views on future changes in productivity, prospects for legislation and regulation, and the likely extent to which longwall mining would be used in the future. The interviewees' opinions on these issues are summarized in the following pages.

Longwall Productivity

Although the interviewees differed on many of the issues addressed, everyone agreed on one point, that longwall mining had not yet fulfilled its productivity potential. However, predictions on the extent to which longwall productivity would improve in the next 20 years varied widely, ranging from a low of 20 percent to a high of 100 percent. It is interesting to note that, according to the annual longwall productivity survey published in *Coal* magazine, average longwall productivity, measured on a tons per unit shift basis, increased by 35 percent between 1989 and 1992. Hence the more cautious predictions of a 20- to 30-percent productivity increase over the next 20 years appear to have already been exceeded.

When asked which factors would be responsible for future longwall productivity improvements, the interviewees tended to focus on those factors that would have a major impact on productivity at their own mines. Although individual responses reflected site-specific conditions and hence varied widely, a few factors were mentioned in more than one interview— specifically:

- increases in outby haulage capacity
- improvements in equipment reliability
- use of wider longwall faces.

Factors mentioned less frequently included: increased shearer horsepower, improved degasification techniques, improved planning, preventive maintenance, and record keeping, and the design of mine systems specifically for longwall mining.

This list is as interesting for what it excludes as for what it includes. Revolutionary developments that loom on the horizon—most notably automation—were not mentioned as possible contributors to improved longwall productivity over the next 20 years. Instead, operators looked to continued evolutionary, relatively

[61]B.R. Leavitt and J.F. Gibbons, "Effects of Longwall Coal Mining on Rural Water Supplies and Stress-Relief Fracture Flow Systems," presented at the Third Workshop on Surface Subsidence Due to Underground Mining, Morgantown, WV, June 1-4, 1992.

[62]Robert A. Bauer and Paul Dumontelle, "Illinois Mine Subsidence Research Program: What Have We Learned in Five Years?" Illinois Geological Survey, p. 36 (1991).

modest developments as a source of significant productivity gains. A number of the factors cited by the interviewees—namely, increases in haulage capacity, longwall face widths, and shearer horsepower—represent expected continuations in trends that have contributed to the dramatic longwall productivity rise of the past decade. Interestingly, many of the factors cited can be classified as managerial or engineering developments, rather than improvements in longwall technology. Examples include improved planning, improved preventive maintenance, improved record keeping, and design of mine systems specifically for longwall mining. The fact that longwall managers and engineers expect to realize significant productivity improvements through such developments suggests a recognition within the industry that there is still much to learn about this relatively new mining method. To the extent that significant gains can be realized through managerial and engineering initiatives, future productivity improvements can be achieved with relatively low capital investments.

Although automation was not mentioned as an expected contributor to future productivity gains, a number of interviewees stated their belief that automation of the longwall face would continue. Even in the short-term (5-year) future, many of the interviewees expected modest moves towards increased automation and computerization—for example, further development and utilization of shearer-initiated shields, remote control shields, and remote-control shearers, as well as increased equipment monitoring and diagnostics and improvements in horizon control technologies. Interviewees may not have linked automation to future productivity improvements because they were reluctant to comment on somewhat speculative future technological developments. In any event, since operators expect to achieve significant productivity gains (of as much as 100 percent) through relatively modest improvements in equipment, management, and engi-neering practices, the potential impact of a truly revolutionary development, such as the complete automation of the longwall face, *on top of* the anticipated evolutionary developments could far exceed even the most optimistic projections of future productivity growth.

In addition to longwall productivity, interviewees were asked to comment on prospects for improvements in the productivity of the continuous miner units used to support the longwalls. Although most of the interviewees expect continuous miner productivity to improve over the next 20 years, they anticipated less improvement in continuous miner operations than in longwall activity. Opinions on the magnitude of continuous miner productivity improvements ranged from zero to 50 percent. Of the factors expected to contribute to continuous miner productivity improvements, two in particular were mentioned in a number of different interviews: the development of more powerful continuous miners and improvements in face haulage methods (specifically, the development and utilization of continuous haulage and the increased utilization of diesel- and battery-powered coal haulers). Less frequently mentioned factors included the following: development of improved continuous miner roof bolters, improvements in remote control continuous miners, improved degasification techniques, and utilization of extensible line curtain systems in conjunction with remote control continuous miners.

Typically, two or three continuous miner units are required to support a longwall at present. If expectations voiced in the interviews prove true, they have implications for the ratio of continuous miners to longwalls. Either it will be necessary to reduce the amount of continuous miner development work to be performed at longwall mines, or operators will have to employ additional continuous miner units to keep up with the longwalls. The amount of continuous miner development work can be reduced by increasing longwall panel dimensions and / or by reducing the number of longwall gate entries; however, as some interviewees noted, there are economic limits to the continued expansion of the longwall panel. At some point, the additional capital costs of widening the face will exceed the benefits resulting from improved productivity. At the same time, there are regulatory and technical (as well as economic) limits to reductions in the number of gate entries. Ironically, continued improvements in longwall productivity may at some point necessitate increases in the number of continuous miners used in longwall operations—unless continuous miner productivity can keep up with the expected improvements in longwall productivity. Of course, improvements in longwall productivity vis-a-vis the productivity of continuous miners would also presumably result in further market penetration of longwall mining into areas and mines currently dominated by room-and-pillar techniques.

Legislative and Regulatory Developments

When asked to identify possible legislative, regulatory, or enforcement developments that could affect future longwall mining, all of the interviewees mentioned subsidence legislation. All of the interviewees recognized the possibility that subsidence legislation might be passed, and a number of them stated their belief that passage of some form of subsidence legislation was a near certainty. However, views on the impact that such legislation might have were mixed. For example, representatives of one company stated that subsidence legislation would not have a big impact in southern West Virginia (their locality), given the relative sparsity of structures affected by mining. However, the same individuals noted that subsidence legislation could have a very large impact on longwall mining in northern West Virginia and Pennsylvania. A number of interviewees noted that the impact of subsidence legislation would depend on the form the legislation took. Interviewees at one company stated that some special interest groups wanted to "ban subsidence," and expressed their hope that, rather than banning subsidence, legislation would be designed to ensure fair compensation to surface owners. Representatives of another company believed that legislation designed to completely eliminate subsidence was unlikely, but they foresaw the possibility of legislation aimed at eliminating subsidence on land not owned by the mining company. If such legislation were passed, they noted, the mining company would have to purchase the surface rights to additional land, and/or mine around unowned tracts. Of course, the latter alternative would present serious difficulties for longwall mining; it is much easier to mine around blocks of coal using room-and-pillar methods. For this reason, subsidence legislation could have a much larger impact on longwall mining than on continuous mining. The subsidence issue undoubtedly represents a key uncertainty for the future of longwall mining.

Other legislative and regulatory issues identified as having the potential to affect longwall mining included the following: ground water, new longwall ventilation regulations, acid mine drainage, and acid rain.

Future Reserve Development Using Longwall Mining

Perhaps the most important question asked during the interviews was the following:

> Roughly, what percentage of the underground minable reserves currently owned or controlled by your company do you think will be developed using longwall mines?

Representatives of one company indicated that a significant percentage of their company's reserves would be developed using room-and-pillar mining, for two reasons. First, some of the reserves are located in properties too small to allow the utilization of longwall mining, and second, some of the reserves are located in thin seams. The interviewees said that improvements must be made in thin-seam longwall equipment to permit the wide application of such equipment.

But most of the interviewees stated that 100 percent, or nearly 100 percent, of their companies' reserves would be developed using longwall mines. In one case, exclusive reliance on longwall mining appeared to be necessary given the depth of the company's reserves, but in most of the interviews, longwall mining represented an economic choice rather than a technical necessity. These interviewees indicated that longwall mining would be used in *all* reserve blocks large enough to support a longwall operation; however, they expected to use continuous mining to develop small properties.

The interviews summarized in this section may provide a somewhat biased view of the coal industry's attitudes towards longwall mining because all of the interviewees worked for companies already using the longwall method. However, based on the interviews, it appears that those industry representatives best able to assess the relative merits of longwall mining—by virtue of their own experience with it—were committed to the method. For these managers and engineers, longwall mining was the method of choice—at least in seams greater than approximately 52 inches thick. Certain conditions preclude the use of longwall mining in such seams. For one, the mining property must contain sufficient reserves to ensure an adequate return on the high capital investment necessary to open a longwall operation. Furthermore, subsidence regulations may tend to limit longwall mining to reserves with a low concentration of surface structures above them. In the long run, longwall mining will probably flourish wherever such reserves exist in abundance.

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Operating at a depth of 2,140 feet, this Alabama longwall unit mines coal from the deepest vertical shaft coal mine in North America.