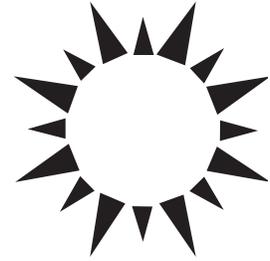


# Coal Mining, Design and Methods of

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## Glossary

- area mining** A surface system that removes coal in areas.
- contour mining** A surface system that removes coal following the contours of hillsides.
- extraction ratio** The ratio of coal mined divided by the coal originally in place before mining commenced, expressed as a percentage.
- full extraction mining** An underground system that removes the coal in large areas causing the void to be filled with caved rock.
- interburden** The rock that occurs in between coal seams.
- overburden** The rock that occurs over coal seams.
- partial extraction mining** An underground mining system that removes coal in small areas in which the roof rock remains stable.
- raw in place tons** The total weight of coal contained within coal seams of a reserve, including in-seam impurities.
- raw recoverable tons** The total weight of coal, including in-seam impurities that would be mined by a specific underground or surface mine plan applied to a reserve.
- salable tons** The total weight of coal mined and sold. The impurities are removed by surface coal processing methods applied at the mine.
- strip mining** A surface system of mining that removes coal in rectangular and parallel pits.

The design and methods of coal mining is made up of the use of land, labor, and capital to remove, mine, or extract coal from a reserve, utilizing a planned and systematic approach called a mine plan. A reserve of coal is represented by a seam of coal, which is a layered deposit of the mineral. A coal reserve is

usually described by the quantity of weight, expressed in tons contained within a specified boundary in plan. Tonnage for a reserve can be quantified several ways that include raw in-place tons, raw recoverable tons, and salable tons.

## 1. INTRODUCTION

### 1.1 Coal Geology

Coal seams originate and are formed by the consolidation of biota, minerals, and natural chemicals through geologic time. Compression, heat, sedimentation, erosion, and chemical energy are agents of the coal formation process.

Multiple coal seams can exist in a reserve, with each coal seam separated by sedimentary rock interburden. Coal, and the rock above and below the coal seam, is primarily layered sedimentary rock in origin, as opposed to igneous or metamorphic rock. The noncoal layers are usually sandstone, limestone, shale, siltstone, and mudstone. The layers can be very symmetric and consistent in thickness, or they can appear in the reserve in nonregular patterns such as sandstone channels, which can exist above the coal seam or replace the coal seam by scouring during geologic formation. Sandstone channels can also create vertical downward displacement of the coal seam by differential compaction. Chemical and heat processes during mineral formation can also produce small pockets of nonsedimentary rock within the coal seam and surrounding rock such as iron pyrite, mica, and other minerals. These minerals, depending on their hardness, can interrupt the mining process as most coal mining methods are designed to extract soft mineral having uniaxial compressive strength less than 6000 psi to 8000 psi.

The processes of the geologic environment in which the coal was formed determines the end characteristics of the coal seam, such as thickness, seam pitch, energy value (generally quantified as BTU per lb), nonvolatile content, moisture content, depth below the surface, structure (faults, folds, rock fractures), the presence of an igneous intrusives called dikes, and characteristics of the rock immediately above and below the coal seam. All of these characteristics affect the mine design and methods. Layered coal seams and surrounding rock thickness range from less than 1 ft to over 150 ft. Figure 1 shows a typical cross section of coal seams interspersed in layers of sandstone and shale.

## 1.2 Mining Methods

Coal is mined by three methods: surface, underground, or *in situ*. The percentage of coal produced by each mining method can be identified from production statistics kept by the Energy Information Administration (EIA), a U.S. agency. According to the EIA, in 2002 745 surface mines produced 736 million tons (67% of total U.S. production) and 654 underground mines produced 357 million tons (33% of total U.S. production). For practical purposes, coal produced from *in situ* mining methods is nil.

Coal mine design and methods are chosen based on the reserve characteristics. Where the coal seam is near the ground surface, surface mining methods prevail over underground methods. Generally, surface mining methods are less expensive than underground methods when the strip ratio is less than an economic limit. Strip ratio is the quantity of overburden (expressed in cubic yards) that has to be removed to uncover 1 ton of coal. Companies change mining method from surface to underground when the strip ratio from an existing surface mine increases due to seam pitch, which in turn increases production cost. At the economic limit, the cost of production from surface methods equals underground methods.

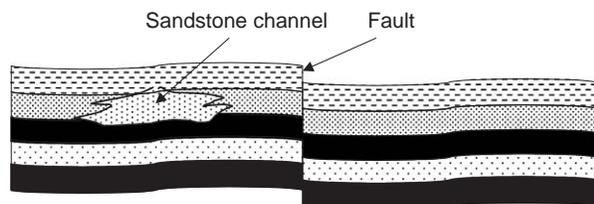


FIGURE 1 Typical cross section of shale, siltstone, coal, sandstone, and coal reserve.

## 2. SURFACE MINING METHODS AND DESIGN

The surface mining method of coal involves three ordered steps: overburden removal, coal seam removal, and reclamation. The first step in surface mining is to remove the rock over the coal seam called the overburden (Fig. 2).

Overburden is first drilled and fractured with explosives. The overburden is then removed and displaced to a previously mined pit, where the coal has already been removed, or to other disposal areas. Other disposal areas can include adjacent hollows, or topographic lows. After the overburden is removed, the coal seam that is now exposed is removed by digging methods and hauled or conveyed to surface facilities that process the coal for shipment. Downstream transportation such as railroads or overland trucks hauls the coal to markets. The third step in surface mining is reclamation. Reclamation in surface mining consists of placing the overburden rock into the hole, pit, or hollow, and recovering the rock with topsoil that was removed and stockpiled before the overburden removal began. Vegetation is replanted in the topsoil to complete the reclamation process.

Overburden removal, coal seam removal, and reclamation occur in order, and simultaneously within the life of a mine or reserve. In other words, a mine does not remove all of the overburden in a deposit before removing the coal. Surface mine design involves the planning of a series of pits *within* the overall deposit boundary that allow overburden removal, followed by coal seam removal, which is then followed by reclamation. The planning process of these sequential operations is called operations planning or sequencing.

The primary surface mine design parameter and driver of unit production cost is the strip ratio. Strip ratios for minable coal reserves range from 1:1 to over 35:1. A decrease in the strip ratio will decrease

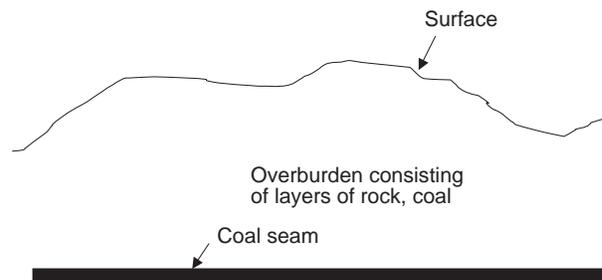


FIGURE 2 Step 1 in the surface mining process, overburden removal (in cross section).

the cost of producing the coal. Underground mining methods are employed when the amount of overburden that would have to be removed by surface mining methods is cost prohibitive (i.e., the strip ratio is beyond an economic limit).

Surface mine design is determined by the stripping ratio, the overall shape of the reserve from a plan view, and the type of rock. Three main surface methods are utilized, with each having the same common steps of overburden removal, coal seam removal, and reclamation. The three surface mining methods are contour stripping, area stripping, and strip mining.

## 2.1 Contour Stripping

Coal seams and associated overburden can outcrop on the edges of hills and mountains. Figure 3 shows a cross-section of a typical contour mine plan. Contour surface mining takes advantage of the low strip ratio coal reserves adjacent to the outcrop. Contour mining equipment includes a drill, loader, bulldozers, and trucks. The steps in contour mining begin with drilling and blasting a triangle shaped portion of overburden (in cross section) above the coal to be mined. The fractured overburden is then loaded into rubber-tired trucks. The loading equipment utilizes buckets such as front-end loaders, front-loading shovels, and backhoes. The coal seam is now uncovered and is loaded with the same type of bucket-equipped machinery as loaded the overburden. Some coals require drilling and blasting as the breakout force required to remove the coal without fragmentation by explosives is beyond the capabilities of the bucket-equipped machinery. Dumping the overburden into the pit begins reclamation. The overburden is usually hauled around the active pit where coal is being removed. The overburden is

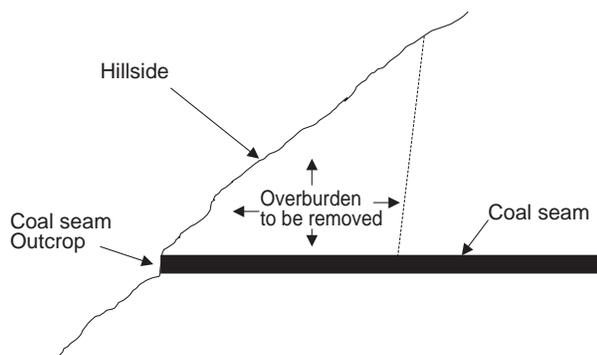


FIGURE 3 Contour mine design, surface mining method (in cross section).

dumped and regraded to replicate as much as possible the original contour or slope of the hillside. Bulldozers grade and smooth the overburden in preparation for topsoil application. Topsoil is placed on the smoothed overburden and replanted with vegetation. Contour stripping gets its name because the mining operation follows the contour of where the coal outcrop meanders along the hillside (Fig. 4).

The advantages of contour mining include the ability to control strip ratio during the mining process. The strip ratio is controlled by the height of the triangle portion of overburden removed. Controlling the ratio allows the unit cost of production to be largely controlled. The disadvantages of contour mining include the difficulty of maintaining the stability of steep, reclaimed hillsides and the limited width for effective operations on the coal seam bench.

## 2.2 Area Stripping

Area stripping is a surface mining method that is usually employed in combination with strip mining. Area stripping utilizes truck and shovels to remove the overburden down to a predetermined depth in the layers of rock and coal. The strip mining method continues to mine the overburden below the depth at which the area was area-stripped. Draglines or continuous excavators, which are used to strip the overburden from the lower seams, are large pieces of equipment and require large, level areas from which to work. Draglines and continuous excavators have dig depth limitations. Area stripping allows the draglines and continuous excavators to operate within their depth limitations. When area stripping is used in combination with draglines and continuous excavators, area stripping is called prestripping. The purpose of prestripping is to provide a flat surface for the dragline or excavator on which to set, move, and operate. The depth of overburden rock removed by area stripping is governed by dig depth capacity of the equipment utilized for subsequent strip mining.

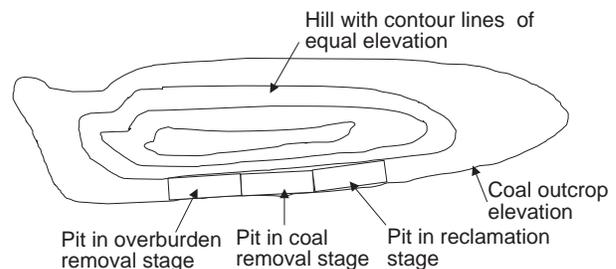


FIGURE 4 Contour mine design (in plan view).

Usually, the prestripping mine plan is arranged in rectangular blocks of overburden to be removed that coincide with pits to be mined by stripping methods underneath the prestripping area (Fig. 5).

Area stripping application includes the removal of overburden in reserves that are not conducive to strip mining because the lack of rectangular areas (in plan). The machinery used for area stripping such as shovels, front-end loaders, and trucks allow for flexibility in the mine design layout.

### 2.3 Strip Mining

Strip mining is employed in coal reserves where the overburden is removed in rectangular blocks in plan view called pits or strips. The pits are parallel and adjacent to each other. Strip mining is fundamentally different from contour or area mining on how the overburden is displaced, called spoil handling. In contour or area stripping, the overburden is hauled with different equipment than what digs or removes the overburden. In strip mining, the overburden is mined and moved by the same equipment: draglines or continuous excavators. The movement of overburden in strip mining is called the casting process.

The operating sequence for each pit includes drilling and blasting, followed by overburden casting, then coal removal. Some overlap exists in operational steps between pits. Draglines and continuous excavators move or displace the overburden from the active pit to the previous pit that has had the coal removed.

The primary planning mechanism used in strip mining is the range diagram, which is a cross-sectional plan of the shape of the pit in various stages of mining. The range diagram allows the dragline or continuous excavator equipment characteristics of dig depth, reach, and physical size to be placed on the geologic dimensions of depth to seams (overburden), and depth between seams (interburden). By comparing machinery specifications with dimensional characteristics of the geology, the mine designer can plan the pit width and dig depth (Fig. 6).

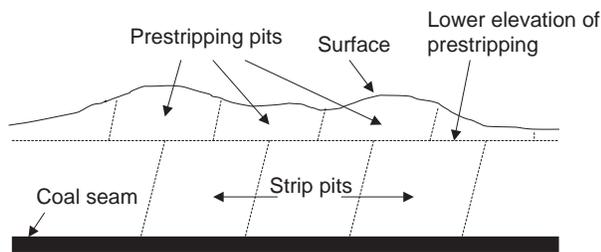


FIGURE 5 Prestrip surface mining method (in cross section).

As the dragline or continuous excavator moves the overburden to the adjacent empty pit where the coal has been removed, the rock swells in volume. Earth or rock increases in volume, called the swell factor, when the material is removed from its *in situ* or in-ground state and placed into a pit or on the surface. The range diagram allows the mine planner to identify the equipment dump height required to keep the displaced overburden (spoil) from crowding the machinery and mining operations. In certain cases of mining multiple coal seams from one pit, a coal seam can provide the boundary between the prestrip and strip elevations.

In a relatively new technique that originated in 1970s to early 1980s, explosives are used to move or throw the overburden into the previous pit in a process called cast blasting. The difference in the quantity of explosives required to fragment rock in place versus fragment and cast or throw the rock across the active pit and into the previous pit is cost-effective. Many surface strip mines use explosives to move overburden in addition to the primary swing equipment (dragline or continuous excavator), displacing up to 35% of the overburden by cast blasting. When cast blasting is used, the dragline may excavate from the spoil side of the pit, sitting on the leveled, blasted overburden.

Surface mine design principles emanate from the operational characteristics of surface mining, which are drilling and blasting, spoil handling, coal removal, and haulage. Except in a few circumstances, overburden in surface mining requires the rock to be fractured by explosives to allow it to be excavated. The goal of drill and blast design is to optimize rock fracturing, which optimizes digging productivity. Fracturing is optimized by using the correct amount of explosive per cubic yard of overburden employed in the drill hole spacing in plan view. The amount of explosive in weight per cubic yard of overburden is called the powder factor. Drill and blast design is

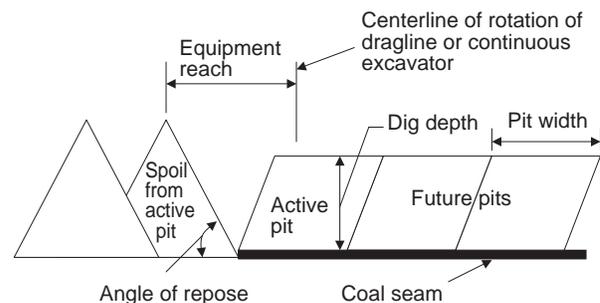


FIGURE 6 Range diagram for the strip mining method (in cross section).

accomplished by empirical methods and by experience. The drill hole layout and powder factor change when cast blasting is utilized.

Spoil handling design is of critical importance, as this function is usually the most expensive cost element in surface mining. When the surface mining method utilizes trucks, spoil handling is designed to minimize the overall haul distance for logical units of spoil volume, which may be driven by pit layout, topography, or area stripping requirements. Mine plan alternatives are evaluated to minimize the distance that spoil volumes are moved from the beginning centroid of mass to the ending centroid of mass. Spoil handling design goals for strip mining surface methods that utilize draglines and continuous excavators also include the minimization of spoil haulage distance. For the dragline, the average swing angle is identified by evaluating alternative mine plan layouts. The goal is to minimize the swing angle, which maximizes productivity.

The goals of coal removal and haulage design in surface mining include minimizing the distance coal is hauled from pits to surface processing and loadout facilities in near term years, locating haul road ramps out of the pits to minimize interference with overburden removal, and engaging excavation practices and equipment that minimize coal dilution by mining noncoal rock floor.

Surface mining has two design parameters that affect mine cost, which are minimizing rehandle and maximizing pit recovery. Rehandle occurs when overburden is handled twice and sometimes multiple times during excavation and spoil placement. Having 0% rehandle of the original in-place overburden is not achievable because of inherent design requirements of surface mining such as ramps into the pit and mining conditions such as sloughing ground that covers the coal. Simulating alternative mine plans and anticipating where overburden will be placed can minimize rehandle. Rehandle can more than double the cost of mining portions of the overburden.

The goal of coal pit recovery is to obtain as close to 100% as possible. One method to maximize pit recovery is to minimize drill and blast damage to the top of the coal. Drill and blast damage is reduced by stopping the drill holes from touching the coal seam or by placing nonexplosive material in each drill hole, called stemming. Pit recovery is also maximized by matching the pit width with the characteristics of the machinery used to extract the coal. Again, the range diagram as a planning tool is used in this evaluation.

### 3. UNDERGROUND METHODS AND DESIGN

Underground coal mining methods fall in two categories: full extraction and partial extraction. Full-extraction underground mining creates a sufficiently large void by coal extraction to cause the roof rock to cave into the void in a predictable and systematic manner. Partial-extraction systems disallow caving by mining reduced areas which sustains the roof rock above the tunnel in a stable or uncaved *in situ* state. When coal seams are completely below the ground surface, vertical shafts and tunnels driven on angles to the seam below called slopes are mined through the overburden rock to access the seam. When the edges of coal seams are exposed to the surface, called outcrops, access to the main reserve can be obtained by the creation of tunnels in the coal seam. Coal outcrops occur when sedimentary rock and coal is layered within a hill or mountain and the rock and coal outcrops above the surface ground level of drainages that define the topography. The main coal reserve is divided up into areas or panels (in plan view) that allow orderly extraction of the coal by the chosen equipment and panel mining method.

Tunnels excavated in coal are called entries. Entries are mined to gain access to the reserve and the production panels. Entries are excavated adjacent to one another in sets of entries. The sets of entries have additional tunnels, called crosscuts that are normally excavated at right angles to the entries. The entries and crosscuts form pillars of coal. The entire set of entries, crosscuts, and pillars, are referred to as mains, submains, or gateroads, depending on the degree of proximity to production panels. Entries excavated in production panels are sometimes called rooms.

#### 3.1 Panel-Mining Methods

The methods to mine panels of coal in an underground mine layout are partial extraction using continuous miners to mine rooms, partial extraction using conventional mining methods to mine rooms, full extraction using continuous miners to mine rooms and pillars, full extraction using longwalls to extract a block of coal outlined by entries around the panel perimeter, and other underground methods.

#### 3.2 Partial Extraction with Continuous Miners

Continuous miners are machines that mechanically mine or extract the coal without the use of

explosives. Continuous miners consist of a rotating drum having carbide-tipped steel bits that strike the coalface. As the bits strike the face, tension cracks are created on the coal surface. These cracks separate blocks of coal. The blocks of coal are propelled out of the face by the bits and drop into a portion of the continuous miner called the gathering pan. The action of the bits extracting the coal by the creation of tension cracks is called mechanical mining. Coal is conveyed through the continuous miner and is loaded onto vehicles that haul the coal to be further transloaded onto conveyors, which convey the coal out of the mine to surface processing facilities.

Within panels, continuous miners and associated equipment mine entries and crosscuts leaving the pillars of coal. Panels are arranged adjacent to one another, usually with the long axis of the panel dimension 90° to the main or submain entries (Fig. 7). Panel size is determined by the size and shape of the overall reserve in plan view.

### 3.3 Partial Extraction with Conventional Methods

In partial extraction with conventional methods, explosives fragment the coal at the face in contrast to continuous miners where bits or tools mechanically mine the coal. In conventional mining, holes are drilled in the coalface allowing explosives to be loaded into the holes. The explosives fracture and loosen the coal allowing loading and removal of the coal into the haulage system of the mine. Rubber-tired scoops load the coal. Thus, entries and crosscuts are created by the conventional method. Panel layout for conventional methods is the same as for continuous mining.

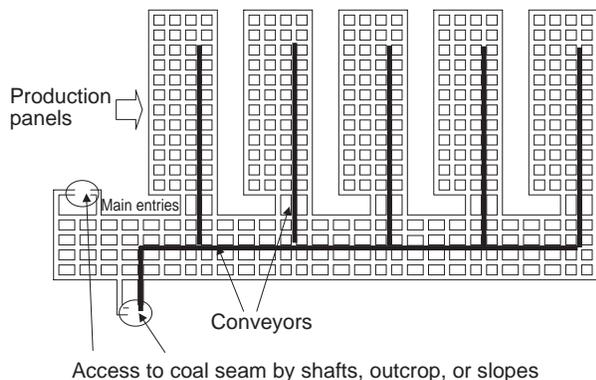


FIGURE 7 Partial extraction with continuous miners (plan view).

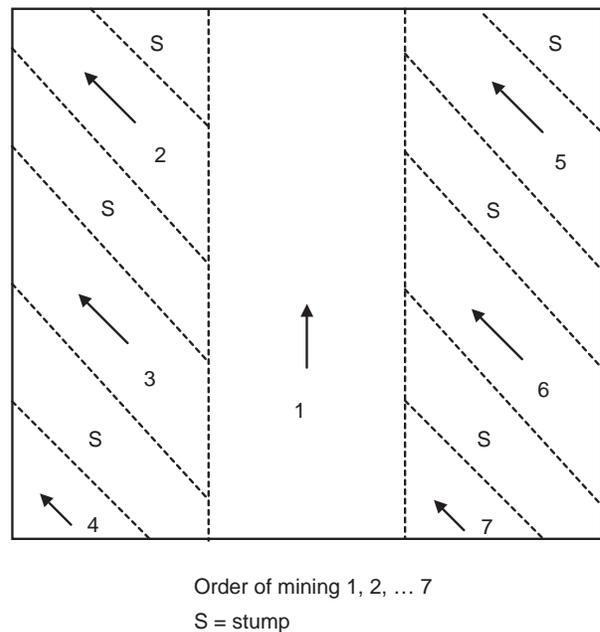
### 3.4 Full Extraction Using Continuous Miners

Full extraction using continuous miners is the same as partial extraction except that the pillars that are surrounded by entries and crosscuts in the panels are mined and removed. By removing the pillars, a sufficiently large area is created that causes the roof rock to become unstable and fall into the void. The caving process in full extraction techniques is an integral part of the mining method. Figure 8 shows the general method of individual pillar extraction.

The stumps shown in Fig. 8 are small coal pillars that are left after the extraction process. The stumps are necessary to provide roof support for the pillar during mining, but are not sufficiently large to inhibit the caving process.

### 3.5 Full Extraction Using Longwalls

The longwall method utilizes a machine group that consists of shields, face conveyor, stage loader, and shearer. This group of equipment is installed along one entry that bounds the short dimension of a rectangular block of coal. The block of coal is entirely surrounded by entries that outline the perimeter, and this block area is called a longwall panel. The longwall equipment extracts the coal from this rectangular panel. Each longwall panel is separated from an adjacent panel by a group of entries called the gateroad system. These entries, as



Order of mining 1, 2, ... 7  
S = stump

FIGURE 8 Typical pillar extraction sequence (plan view).

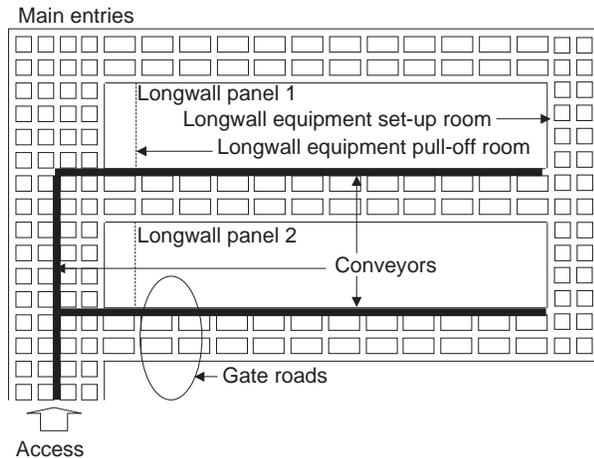


FIGURE 9 Longwall mine plan (plan view).

with the mains and submains, are mined with continuous miners. Once the longwall extracts the coal from the rectangular block, the equipment is disassembled at the pull-off room and moved and reassembled at the end of the next panel of coal in the startup room (Fig. 9).

Access to a coal seam for the longwall mining method is accomplished by outcrop access, shafts, or slopes. Gateroad systems can consist of one to five entries. Figure 9 portrays an example mine plan consisting of two longwall panels. The number of longwall panels contained within a mine plan is determined by the shape of the reserve and by safety considerations. The larger the reserve, the more longwall panels can be planned parallel to each other. Longwall panels are sometimes grouped together into subsets called districts. Longwall districts within an overall mine plan are separated by large blocks of coal called barrier pillars. Barrier pillars compartmentalize the reserve. A compartmentalized reserve allows worked out areas to be sealed, which increases safety and efficiency with respect to handling water, gas, and material.

Longwall panels range in size (in plan view), from 500 ft wide by 2000 ft long to over 1200 ft wide by 20,000 ft long. Size is determined by the reserve and the availability of capital to buy equipment. Some large underground mines have as much as 50 longwall panels separated into six or more districts.

### 3.6 Other Underground Methods

Other underground methods still incorporate entries, crosscuts, and pillars, but differ from previous methods by the method to extract the coal from the

working face. They are hand loading and hydraulic mining. Hand loading is using human-powered pick and shovels to remove and load coal from a face into haulage equipment. This method is not used in the United States.

Hydraulic mining utilizes the force of water sprayed under high pressure to extract coal. Hydraulic mining utilizes continuous miners to mine entries to gain access to production panels. Once a production panel is established, high-pressure water cannons are used to break the coal off the face. The coal-water mixture falls into a metal sluice trough that carries the coal to further haulage equipment, usually conveyors. Production panels in a hydraulic mine are oriented to utilize gravity to carry the coal-water mixture away from the face and in the troughs. Hand loading and hydraulic mining can be either partial or full extraction depending on the extent of pillar removal in the panels.

### 3.7 *In Situ* Methods

*In situ* methods extract the coal with no human contact inside the coal seam, such as miners going underground to attend machinery. These methods include augering, highwall mining, and leaching or dissolving the coal by heat, pressure, or chemical means followed by capture of the media.

Augering consists of extracting coal from an outcrop by the repeated and parallel boring of holes into the seam. The machine, called an auger, is literally a large drill that bores 1.5 ft to 5 ft diameter holes up to 600 ft deep into the coal seam. Augering sometimes occurs in tandem with the surface contour mining method. Contour surface mining creates a flat bench on which to operate the auger.

Highwall mining is similar to augering. Highwall mining bores rectangular holes into a coal seam from an outcrop using a remote-controlled continuous miner connected to an extensible conveyor, or haulage machine. Highwall mining also can work in tandem with contour mining.

### 3.8 Underground Mine Design Parameters

As introduced, underground mining methods fall into two groups: full extraction and partial extraction. Key mine design considerations for underground mining include roof control, ventilation, seam pitch, extraction ratio, and industrial engineering as it pertains to maximizing safety and productivity.

### 3.9 Roof Control

Roof control is defined as the systematic design and installation of coal pillars and artificial structures to support the roof, floor, and sides of entries to protect the miner from falling and propelled rock. Roof, floor, and entry sides are subjected to three main forces that cause instability and require that support be installed in underground coal mines. These forces are gravity, mining-induced forces, or forces derived tectonics and mountain building. Gravity primarily loads underground workings with vertical stress. The general rule for U.S. underground mining is that gravity stress equals 1.1 psi per ft of depth of overburden. This value is derived from an assumed weight of sedimentary rock that overlays coal seams of 158.4 lb per ft<sup>3</sup>.

Mining-induced forces are caused by the transference of overburden load from the void to pillars adjacent to the void's perimeter. As the void increases in size during full extraction, the weight transferred to the abutment pillars increases until the rock caves. In partial extraction mine design, the void area is limited to the spans across the entry roof. The roof rock in the entry remains stable. In full extraction mining, the caved rock is called gob or goaf, which is broken rock. As the gob consolidates and forms the ability to support weight, some load that was originally transferred to the pillars is reaccepted and transferred back to the gob. This process is called gob formation.

Tectonic forces in mining are caused by plate tectonics, regional mountain building forces, stress that resides in structural geology such as faults and slips, and other natural geologic processes. The result of tectonic force and stress in underground coal mining is increased stress in all directions, particularly in the horizontal plane, or the plane parallel to the bedding (layers of rock). Coal mining can reactivate stresses along structural geologic features. The primary coal mine design criteria for high horizontal stress is that the long axis of a production panel rectangle (in plan view) be oriented 15° to 45° off the maximum horizontal stress. Other than high horizontal stress, other forces from tectonic origin are difficult to incorporate into design because of the uncertainty of the force's magnitude, direction, and dynamics.

The primary design criteria in roof control in underground coal mining is to control the roof overhead where miners work and to provide abutment support in the form of pillars and blocks of coal on the edges of the excavation or void area. Pillars are designed by empirical methods and by mathematical stress modeling. Empirical formulas have

been derived from actual mine case histories in all coal producing regions of the world. Most of these formulas have three primary variables to determine pillar strength: *in situ* coal strength, pillar height, and pillar width.

For pillar design in the United States, the vertical stress, assumed to be 1.1 psi per foot of depth, plus other mining induced stresses caused by load transfer would be compared against pillar strength. A pillar size would be chosen that has a satisfactory safety factor. The safety factor is strength divided by load. Each empirical method and mathematical stress modeling approach has recommended design pillar safety factors. Pillar design needs to recognize the variability of geology and the nonhomogeneous nature of coal. Rock mechanics design for underground coal mines requires a thorough design analysis of the local site geology and the comparison of mining conditions at neighboring mines. Civil engineering structures have more uniform design methodology because materials used in buildings, bridges, roads, and other structures are composed of homogeneous materials and the forces demanded on a structure are more predictable.

The main fixture used for primary support in underground coal mining is the roof bolt. A roof bolt is a steel rod from 0.5 in. to more than 1.5 in. diameter and from 2 ft to over 10 ft long. Roof bolts are installed on cycle, meaning that the bolts are installed after the entry or tunnel is excavated a specific distance. This distance the entry is advanced is called the depth-of-cut. The depth-of-cut of an entry, which ranges from 2 ft to over 40 ft, is determined by the ability of the roof rock to remain in place before being bolted; that is, to be stable. Roof bolts are anchored in a hole drilled into the roof by resin grout or by mechanical systems. Roof bolts systems bind the layered roof rock together by forming a beam or by suspending the rock layers from a zone of competent anchorage in the geologic cross section.

Roof is also supported by what is called secondary support. Secondary support is installed after the entry is advanced and after roof bolts are installed. Secondary support is generically called cribbing, which is named after wooden blocks stacked Lincoln-log style to form a vertical, free-standing structure that is wedged between the roof and floor of the entry. Other forms of cribbing or secondary support, in addition to wood blocks, include columns of cementaceous grout, steel structures, wooden posts, and wooden block structures (other than Lincoln-log stacked). Secondary support is used to fortify the

entries around a full-extraction area to assist in roof support when ground load is transferred from the void to abutment pillars. The distance the load is transferred is a function of the strength and thickness characteristics of the rock over the void. The presence of strong and massive sandstones in the overburden can resist caving over long spans. The cantilevering nature of the sandstone beam can create large stress increases in the abutment areas, which requires special mine designs be implemented.

### 3.10 Ventilation

Ventilation, along with roof control, is critical to the safe and efficient extract of coal in underground coal mining. Ventilation is necessary to provide air to all areas of an underground coal mine, except those areas that have been intentionally sealed, to dilute mine gases, dilute airborne dust, and provide fresh air for miners. A coal mine is ventilated by main mine fans located on the surface, which either push air through the mine called a blowing system or pull air through the mine called an exhausting system. Ventilated air moves through the mine in the entries that comprise independent circuits of air called splits. The main fan that pumps air through the mine is designed to deliver a minimum quantity of air to each area of the mine where miners and equipment extract the coal. The fan size and horsepower are designed to overcome friction losses that accumulate because of turbulent airflow against the rubbing surface of the entry roof, floor, and sides. The fan creates a pressure differential that causes air to flow from areas of high pressure to areas of low pressure. Air pressure differential can also be created by atmospheric variations caused by weather patterns and seasonal and daily temperature fluctuations. These pressure variations can move air through mines, particularly in abandoned mines or idled mines that are missing mechanical ventilation devices (fans). This form of ventilation is called natural ventilation. Ventilation design for mines with regard to the size of main fans must recognize natural ventilation.

Ventilation circuits within underground coal mines can be a single split or a double split of air. Double split is often called fishtail ventilation (Fig. 10).

As shown in Fig. 10, air movement is directed to the working faces in the entries. The stoppings shown are called ventilation control devices. Stoppings are walls, usually constructed of cinder block and mortar, built in the crosscuts to separate air circuits or splits of air. Without the stoppings, air flow would short circuit and mix with other air

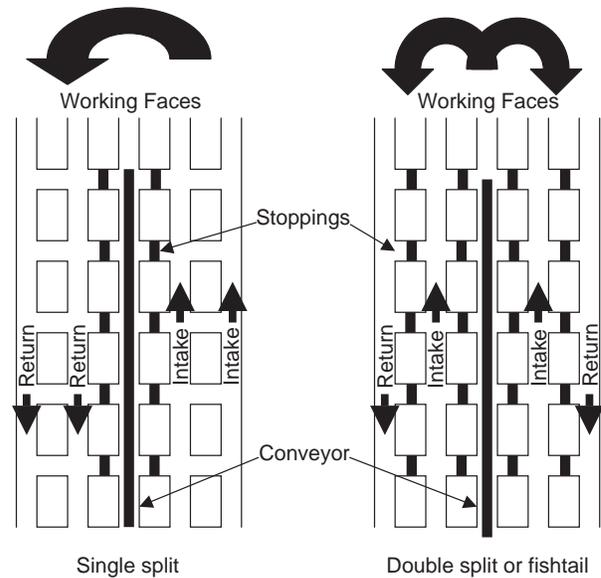


FIGURE 10 Single and double-split ventilation showing air flow (plan view).

before reaching the working faces. Intake air is fresh air delivered to the working face that has not been used to ventilate other working faces where coal is produced. Return air is air that has been used to ventilate the working face. Return air contains coal dust and mine gases, particularly methane that has been liberated from the coal during production. Sometimes two different airways cross at an entry and a crosscut. A ventilation control device called overcast or undercast separates the two different types of air (i.e., intake and return).

Figures 7, 9, and 10 illustrate the entries containing the conveyor. The entry containing the conveyor usually contains a minimum of airflow and is not used to ventilate the working face. The airflow velocity is lessened in this entry to keep coal dust from becoming airborne.

Some mines utilize conveyor air to ventilate the working face. This practice occurs in longwall mines with long panels. Long panels require parallel intake or return air splits to increase air quantity to the working face and minimize resistance.

Ventilation design for a coal mine is based on choosing a mine fan or fans, as in the case of a mine with multiple access openings, that can overcome the resistance to airflow and maintain the required air quantity at the working faces. Mine resistance varies with air quantity and obeys basic empirical laws that have friction factors based on measured data. Increasing the number of parallel entries of the split reduces resistance in that split.

### 3.11 Seam Pitch

Mines are designed to incorporate seam pitch. Rarely are coal seams completely flat. Geologic processes of coal formation, deposition, and structure cause seams to have pitch, which can vary from 0 degrees to vertical. Partial- and-full extraction mining methods can efficiently handle up to approximately 10 degrees of pitch. An underground mine plan is designed to take advantage of pitch when possible for water handling, pumping, material haulage, and gas migration.

### 3.12 Extraction Ratio

The extraction ratio is defined as the volume of coal mined divided by the total volume of coal within a reserve. Coal is a nonrenewable resource. Once it is combusted to make steam for electrical power generation, steel production, or other uses, all that remains is ash and gaseous substances. Maximizing the volume of coal mined from a given reserve is important for the overall energy cycle and to minimize the cost of production. With the exception of in situ mining systems, partial extraction underground coal mining methods range in extraction ratio from 20% to 50%, and full-extraction mining methods have extraction ratios that range from 50% to over 85%. Achieving a 100% volumetric extraction ratio is difficult for three reasons. First, pillars that are necessary for roof support in the plan cannot be mined. Second, coal is sometimes left in place on the floor or roof of an entry to improve the quality of the coal extracted. The immediate top or bottom layer of a coal seam can have a greater content of noncombustible material than the central portion of the coal seam. Finally, underground coal mining methods and machinery have a maximum practical mining height of approximately 14.5 ft.

Surface mining methods cannot achieve 100% extraction. Coal is damaged from drilling and blasting and cannot be recovered. Also, overburden dilution in pit recovery operations reduces recovery.

### 3.13 Industrial Engineering

Underground coal mining, as in any producing enterprise, requires an infusion of industrial engineering to maximize safety and productivity. Coal mine design practice has shown that safety and productivity are mutually inclusive goals.

Underground mining methods are a mix of continuous and batch processes. For example, while the continuous miner is extracting the coal from the

face of the entry, the process is in continuous mode. The continuous miner has to stop mining frequently to allow loaded shuttle cars to switch out with empty shuttle cars, to advance the face ventilation system, and to allow roof bolts to be installed. These stoppages cause the face operations to be an overall batch process. Once the shuttle cars dump the coal onto a conveyor belt, the material is continuously transported outside to a stockpile. The coal is then fed through a processing facility that crushes the coal and removes impurities to customer specifications in continuous processing. Underground coal mine design is optimized when the batch processes that occur in underground mining are engineered to become continuous processes. An example of an effort in this area has been the introduction of continuous haulage equipment, which in certain conditions replace the shuttle car: a batch process.

Mine surveying plays a key role in both surface and underground coal mining. Surveying is used to direct the mining advancement as planned, to monitor performance giving feedback on issues of underground extraction ratio and surface pit recovery, to define overburden rehandle, and to perform checks against weighed coal production for inventory control.

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### Further Reading

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Underground coal mining releases more methane than surface or open-pit mining because of the higher gas content of deeper seams. Total national emissions from coal mining, regardless of the selected methodology, should be calculated as the sum of emissions from underground mining, surface mining, post-mining activities, and emissions avoided due to recovery. The Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC Guidelines) provide two general approaches to estimating CH<sub>4</sub> emissions from coal mining. For countries with significant underground mining, the Tier 3 method is much more reliable because it takes into account variability in geologic formations and mining practices. Coal mining has had many developments over the recent years, from the early days of men tunnelling, digging and manually extracting the coal on carts, to large open cut and long wall mines. Mining at this scale requires the use of draglines, trucks, conveyors, hydraulic jacks and shearers. YouTube Encyclopedic. By 1912, surface mining was conducted with steam shovels designed for coal mining. Methods of extraction. The most economical method of coal extraction from coal seams depends on the depth and quality of the seams, and the geology and environmental factors. Coal mining processes are differentiated by whether they operate on the surface or underground. The methods of mining of coal varies from deposit to deposit. This report highlights the coal mining methods, their significances, issues of concern and the stages of using coal after mining. 1.

Introduction: Coal is a readily combustible rock containing more than 50 percent by weight of carbonaceous. Coal seams as much as five metres thick can be mined in a single "lift" by the longwall method, and seams up to seven metres thick have been extracted by conventional mining systems in one pass. However, when a seam exceeds these thicknesses, its extraction usually involves dividing the seam.