COLORADO
DEPARTMENT OF NATURAL RESOURCES

ROCK TALK

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Colorado Coal: energy security for the future

Coal is an abundant and affordable fossil fuel. Our civilization depends on coal and its future importance is underscored by the fact that it is far more abundant in the United States than oil or natural gas. Without coal our very specialized world would not run so efficiently. It is used to generate electricity, to make steel, coal gas, fertilizers, chemicals, and even to make hydrogen for fuel cells.

Coal's primary use is to generate electricity, providing over 50 percent of the U.S. electrical needs (Fig. 1). It will supply the "base load" electricity for the country far into the future. Coal is the largest strategic energy reserve in the U.S., because there are more coal reserves beneath our 38 coal-producing states than any other country in the world. The electricity generated by coal runs most of the everyday activities in our lives including our computer and communications networks, our commerce, and our personal use such as refrigerators, stereos, lights, and televisions, to name a few.

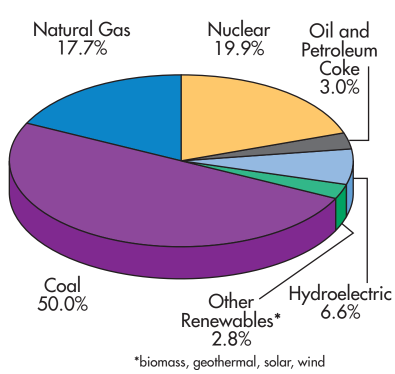


Figure 1. National electric generation by fuel source, 2004. Source: U.S. Dept of Energy's Energy Information Administration (EIA).

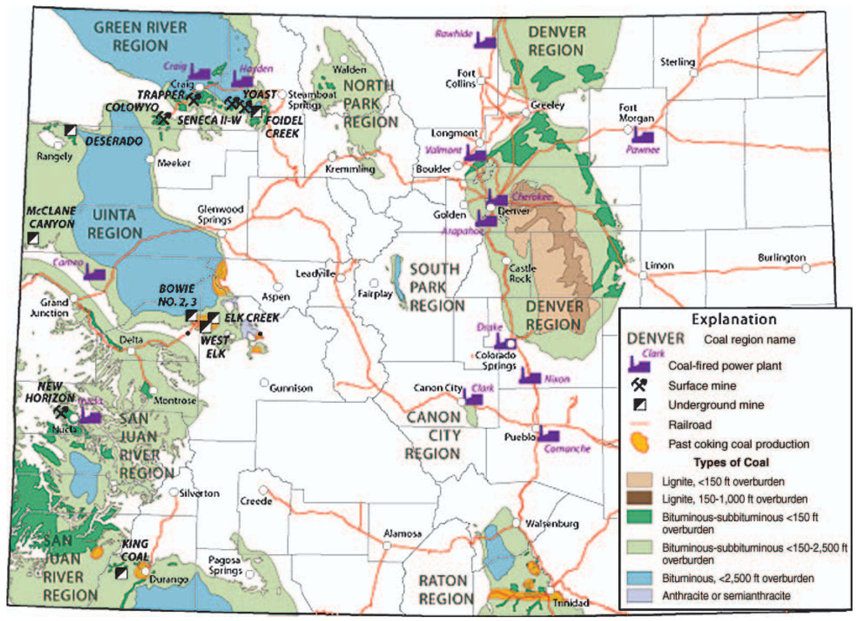


Figure 2. Coal regions of Colorado showing active coal mines and coal-fired power plants. The types of coal mined are also shown for each region.

In Colorado, over 80 percent of our electricity is supplied by coal power. Coal is a cheaper fuel to burn than gas or oil so the cost to the consumer is less. The coal we burn (called "steam" coal when used to heat a boiler) comes from both Colorado and Wyoming. Colorado has great resources of this steam coal.

Coal-bearing formations underlie about 28 percent of the state (Fig.2). Over 16 billion tons of minable coal remain in the state's reserve base. In 2004, Colorado produced 40 million tons of coal from our 12 mines, making us the sixth largest coal producing state in the nation. In the 145 years since coal mining began in Colorado, over 1.24 billion tons of coal have been extracted. In 2004, about one-third of the coal produced in Colorado was consumed in state, while two-thirds was shipped to other states and Mexico.

Commercial industries use some of Colorado's coal supplies. It is used in iron and steel processing, cement manufacturing, and some chemical and mechanical industries as well.

Coal is a valuable resource with many uses. Although you can't put coal into your gas tank and run your car, coal can supply energy to run a multitude of other facets of our lives. One of these is called "coal gasification," a process that

*See **Fuel** on page 3*

Inside this issue: Coal Mining, Coal Geology, Coal Resources, Coal Mine Reclamation, Coal Mine Subsidence, Coal Quality Studies, and other useful information about Colorado Coal

From the Division Director—

Colorado is rich in energy resources. For example, Colorado has the nation's largest proven reserves of natural gas found in coal beds (coalbed methane). Colorado also has all or parts of three of the ten largest natural gas fields in the U.S. Four other Colorado fields are listed in the top fifty gas fields by the Federal Government's Energy Information Administration.

Two of Colorado's many oil fields contain proven reserves that rank them as 26th and 55th largest in the country. Colorado's oil producers have succeeded in halting a long decline in production and have actually accomplished a slight increase in the past five years. As world oil production begins to peak, the federal government and private industry are once again turning a sharp eye to Colorado's giant oil shale resources.

Nuclear power generation has steadily increased during the past ten years in the U.S., even though no new plants have been built. Colorado, a leader in uranium production in the 1950s, has opened four uranium mines during the past year due to uranium's price increases.

More than half the electricity in the U.S. is generated in coal-powered plants. More than 80 percent of electricity in Colorado is generated by coal. Colorado contains the nation's largest reserves of low-sulfur environmental compliance coal, which means that coal mining will remain an important part of Colorado's economy for the foreseeable future.

The words "coal mining" can stir strong emotions. They also stir a variety of misconceptions. This issue is an effort to present useful information about coal, coal mining, and its uses.

Many people do not realize how tightly regulated the coal mining industry is in Colorado. The Division of Minerals and Geology works together with coal companies to achieve high standards of operation and reclamation. At least one of Colorado's companies voluntarily goes beyond existing regulations and strives to meet the environmental standards of the Kyoto accords.

Coal is important today, and it is an important part of the future as we try to develop new energy sources. The ability to convert to other forms of energy is simply not something that can happen overnight. Coal will be a major source of electrical power for decades to come. The western U.S. has substantial supplies of coal that are increasingly making up for the dwindling supplies of coal in the eastern U.S.

Vince Matthews

Coal Geology in Colorado

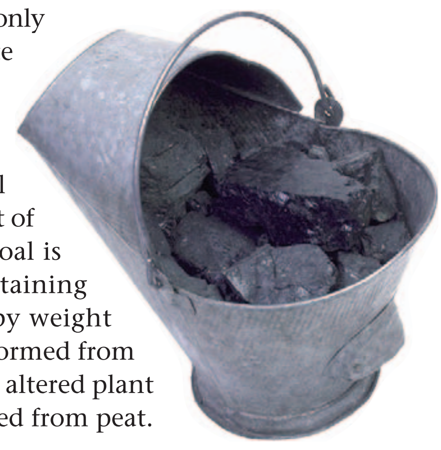
Colorado's 16.36 billion short tons of coal reserves are found in eight sedimentary basins in Colorado (Fig. 2). These Cretaceous and Tertiary age coal layers range from a few inches to over 50 feet thick.

Most coal beds in Colorado were deposited during the Cretaceous Period and are interbedded, or layered with shale, sandstone, and siltstone. Coal was deposited along ancient coastal plains next to ancient beach fronts. Over time these shorelines moved back and forth in response to sea level changes. Near the end of the Cretaceous period the sea gradually retreated to the northeast from what is present day Colorado.

The early Tertiary Period was a time of mountain building and basin development in the Rocky Mountains. Tertiary coals were formed in northern and eastern Colorado as the seaway retreated and are preserved today in the Raton and Denver Basins. The state's thickest coal beds are Tertiary in age at North Park near Cowdrey.

What is coal?

Coal is a solid but brittle, carbonaceous black sedimentary rock that burns. It is made up of carbon, hydrogen, oxygen, nitrogen, and lesser amounts of sulfur and other trace elements. Coal is divided into four classes: lignite, subbituminous (Fig.5), bituminous, and anthracite. Of the commonly minable coals, anthracite is the hardest and has the most carbon, giving it a higher heat value. Lignite is the softest coal and has the least amount of carbon. By definition, coal is a combustible rock containing more than 50 percent by weight carbonaceous material formed from compaction of variously altered plant remains originally derived from peat.



For links to Web pages on coal visit: http://geosurvey.state.co.us

Fuel from page 1

converts coal from a solid state to a gaseous state. The resultant gas is similar to natural gas, and it can be used to create chemicals, fertilizers, and electric power. This type of gas was used in the 1800s by many towns for gas lanterns before electric lights. Today, coal gasification is used to more efficiently make electricity. By-products of this process are methanol and ethylene, which can be used in making plastics, tar, and medicines.

The most useful form of coal gasification is in an electricity-generating power plant. This gas is burned in a combustion turbine, which drives the electric generator. Burning coal gas produces lower levels of sulfur and carbon dioxide emissions than direct burning of coal, thereby improving air quality.

Fuel cells and hydrogen-based technologies may provide the most viable option for pollution-free vehicles. This technology is very expensive at current rates. Coal gasification provides one of the cheapest ways to produce hydrogen from coal.

Coal is also used for industrial purposes. A special type of bituminous coal called "coking" coal is used in the steelmaking industry. Coke is a hard, dry carbon product produced by baking coal at very high temperatures in a reduced oxygen environment. This baking process removes most of the gasses leaving a solid substance that burns at higher temperatures than regular coal. There are two grades of coking coal: the lower is chemical grade coke that is used for reducing phosphate rock in electric furnaces and in the production of calcium carbide. The higher grade is metallurgical coke that produces a much higher temperature and is used as the heat source in blast furnaces for making steel and melting iron. Although Colorado has over two billion tons of coking coal reserves, no coking coal is mined today.

Coal is used in the Portland cement manufacturing business. Rotary kilns heat limestone to create lime, which is the main ingredient in cement. Coal is used as a fuel source because it heats to very high temperatures. In Colorado, coal is also used to heat a kiln in a process that expands shale. A company near Boulder creates lightweight aggregate (wall board, cinder blocks) from this shale. Other industrial uses for coal include heating the boilers at the Coors Brewery in Golden and heating boilers at the Western Sugar Co-op's sugar beet refinery in Fort Morgan.

Coal is also used in smaller amounts by blacksmiths. Iron anvils, such as used by blacksmiths and farriers, can be heated to high temperatures using coking coal or anthracite. This very specific coal market consumes about 10,000 tons of coal in Colorado each year. Another unique use of Colorado coal is the "stoker" coal product. Large chunks of coal from the King Coal Mine in La Plata County are sold to the Durango & Silverton Railway for the scenic trains that run between Durango and Silverton.

Figure 3. Subbituminous coal from the Laramie Formation near Morrison, Colorado.

Coal Quality

Not all coal is composed of the same compounds. Different types of coal are characterized by their unique properties, which produce different results when burned. These properties are empirically determined by coal quality tests. The most basic test is the Proximate Analysis, or chemical analysis that determines the amount of moisture, volatile matter, fixed carbon, and ash that are in coal. Ash consists of the impurities in coal such as silica, iron, alumina, and other incombustible matter. Fixed carbon is the nonvolatile part of the coal minus the ash. Volatile matter is the gas in the coal, and moisture is the water in coal. A typical Cretaceous Colorado coal might have values ranging from 5.4–8.1 percent ash, 37–41 percent volatile matter, 52–56 percent fixed carbon, 19–21 percent moisture.

Another coal quality test is the Ultimate Analysis, which indicates the major elements in any sample of coal. Coal is composed of many elemental compounds, mostly carbon and oxygen. From this data one can determine things such as how much silica and iron are in coal. Many times sulfur and heat value are added to the test, with results like 0.4–0.7 percent sulfur and 9,940 Btu/lb. From this data and using ASTM standards for coal we can determine that the coal in Colorado is a low sulfur, low ash, sub-bituminous coal.

Why is Colorado coal so low in sulfur?

Over 36 percent of Colorado's coal reserves are low sulfur coal (< 0.61 lbs per thousand Btu). About 24 percent is medium quality sulfur coal (0.61–1.67 lbs per thousand Btu). This compares to Illinois coal which is only 5 percent low or medium sulfur coal. Why is western U.S. coal so much lower in sulfur content than the eastern U.S. coal?

Some scientists claim that eastern U.S. coal from the Carboniferous Period is higher in sulfur because it was deposited in a fresh water environment and soon covered by an ancient seaway. After the

*See **Quality** on page 5*

How and when was coal formed?

Coal is a hydrocarbon-rich, fossil-fuel resource, and like other fossil fuels it was formed millions of years ago. Much of the coal in the eastern U.S. comes from swamps that existed during the Carboniferous Period, 355 to 295 million years ago. However in the western U.S. coal swamps formed between 100 and 55 million years ago, in the Middle to Late Cretaceous Period and the Paleocene Epoch of the Tertiary Period.

During this time, Colorado was situated along the shoreline of a large, shallow seaway that extended from Canada to Mexico throughout the central U.S. This shoreline moved back and forth during the course of time. Fresh-water swamps formed along the coastal plains adjacent to the shoreline of this seaway. The climate was very warm and humid, with abundant vegetation on the coastal plain. During that period Colorado's environment looked similar to modern-day South Carolina's coastal plains and swamps, but with dinosaurs.

As the vegetation died and sank to the bottom of the fresh-water swamps, it built up large deposits of decomposed, spongy organic matter called "peat." This saturated peat built up to form bogs that were a few feet to over hundreds of feet thick. Over geologic time, sand and clay sediments covered this peat. More and more sediment was deposited on top of the peat weighing it down and squeezing the water out of the peat (Fig. 4). Burial compacted the peat and eventually turned the sediments into rock. High temperatures and pressures over millions of years converted the peat into different types of coal. Generally, the greater the pressure, the harder the type of coal that is formed. This entire process is called "coalification."

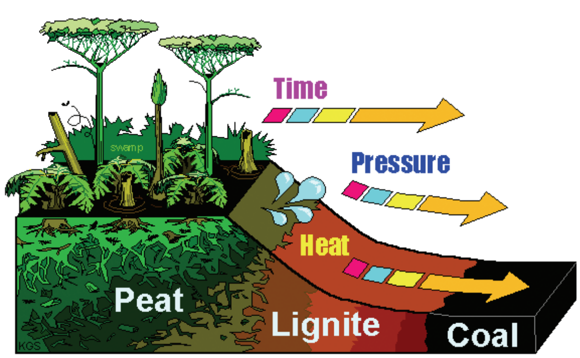


Figure 4. The coalification process from swamp to coal. Note how a thick section of peat is compressed by heat and pressure into a thin section of coal. **Modified from the Kentucky Geological Survey.**

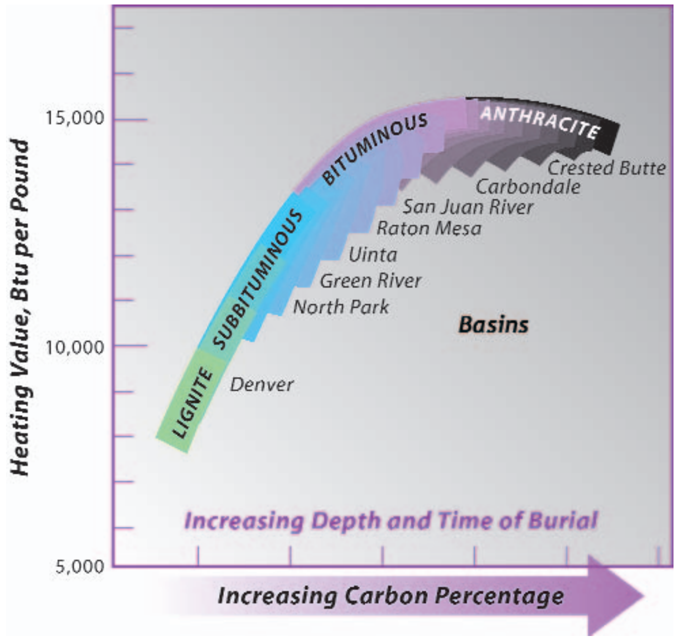


Figure 5. Diagram of coal rank in terms of carbon content (or depth and time of burial) and heating value.

Mountain-building processes also affect coalification. Thermal processes within the coal beds can be initiated by igneous intrusive activity and deep-seated uplift. Tertiary-age uplifts and intrusions into the coal-bearing rocks affected the coal beds. Generally, these coal beds were thermally cooked, which upgrades the "rank" of the coal (Fig. 5). Bituminous coals can be upgraded to anthracite rank when thermally cooked by igneous intrusions. Anthracite altered by igneous intrusions is located in Crested Butte, Somerset, and Walsenburg.

How much energy is in coal?

The amount of energy given off by coal is defined by the heat value measured in British thermal units, or Btu's. This is the amount of heat energy it takes to raise the temperature of one pound of water by one degree Fahrenheit at sea level. One Btu is about equivalent to the amount of energy in a single match. It takes about 2,000 Btu's to make a pot of coffee. One pound of Colorado coal has about 10,000 Btu's, or the equivalent of making five pots of coffee.

Igneous dikes and sills also crosscut and alter coal rank. Igneous sills even replace coal beds by injecting themselves preferentially along weak horizontal coal bed layers and altering the surrounding rocks. This process bakes coal into natural "coke." This type of coal is found near the Spanish Peaks and the town of Aguilar.

Fun fact: Dinosaur tracks from the Cretaceous Period are commonly found in the roof rock of many Colorado and Utah coal mines.

What is coal rank?

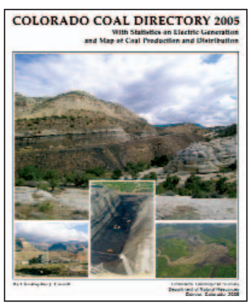
The degree of heat value is a measure to which the peat has undergone thermal alteration to form coal. This **rank**, as it is called, is based on the carbon content in the coal measured as the heat value per pound (or Btu). Rank is categorized by varying coal rock types from peat to anthracite (Fig. 5).

Anthracite is the hardest coal and gives off the most amount of heat when it burns. The reserves for anthracite are small. Because it is hard to crush and burn, anthracite is not used much as steam coal. Over 80 percent of Colorado coal is bituminous and used primarily as steam coal at power plants. Softer than anthracite, bituminous coal fractures, or "cleats" easily, and can be mined easily.

What are macerals?

When coal is observed under a microscope, various forms or parts of plants can be seen. Since trees are the primary vegetation in swamps much of the macroscopic fossil material looks similar. But under the microscope, there are smaller ancient plant and tree parts that make up coal on the microscopic level called macerals, which are considered the basic building blocks of coal. Macerals are characterized in three major groupings:

- ***Vitrinite***, the most common maceral, is the decomposition product of plant cell walls like cellulose and lignin.
- ***Exinite*** is composed of spores, cuticles, resins and waxes like the outer surfaces of leaves.
- ***Inertinite*** is charcoal from fires that occurred in the peat bogs during early deposition.



Colorado Coal Directory 2005

This new CGS coal publication is a compilation of statistical information on the active coal mines in Colorado. Data includes geologic, coal production, coal quality, mine ownership, with maps showing permit boundaries and extent of mining. The book includes statistics on Colorado coal production and distribution as well as annual energy power generation and consumption from coal, natural gas, and fuel oil power plants, and statistics on hydroelectric and wind energy producers. The plate in the book shows distribution and estimated volume of coal from both Colorado and Wyoming sources.

Visit our online bookstore at http://dnr.state.co.us/geostore/default.aspx for more information.

Quality *from page 3*

swamps were covered by seawater, which was high in sulfur content, the seas dried up and sulfur was deposited in the coal. Coal from the Cretaceous and Paleocene in the western U.S. was generally deposited in fresh-water swamps along prograding shorelines where the shore moved out to sea and the coal was covered by non-marine rocks. This, along with the fact that our coal basins have not been exposed to much groundwater flow, may be the reason for the low concentrations of sulfur in Colorado coal.

Why are trace elements in coal important?

Trace elements such as arsenic, mercury, cadmium and zinc have an affinity for sulfur and attach themselves to coal. Coal acts like a sponge in groundwater and adsorbs like a charcoal filter. Much of the world's coal contains hazardous concentrations of mercury and sulfur. Coal-fired power plants are the largest source of mercury emissions in the U.S.

For this reason, the Environmental Protection Agency (EPA) is working on new rules to protect the environment from air pollution stemming from coal-fired power plants. In particular, mercury emissions from coal-fired power plants are to be regulated. The new rules, adopted March 15, 2005, cap and reduce mercury emissions from coal-fired power plants. With enforcement by April 2008, the EPA goal is to reduce mercury emissions by nearly 70 percent. Fortunately for Colorado, our Cretaceous-aged coals have the lowest mercury concentrations in the nation.

Facts about coal

- It takes about one-half ton of coal to create enough electricity to run a kitchen stove for a year.
- The U.S. has more coal that can be mined than the rest of the world has oil that can be pumped from the ground.
- One ton of 10,000 Btu/lb coal is equivalent to 3.41 barrels of oil.
- An electric water heater takes about two tons of coal a year worth of electricity.
- An electric refrigerator uses one-half ton of coal a year.
- The first prototype of the underground "continuous" miner was invented at the Baum Mine in Erie, Colorado, in 1943.
- Colorado has the largest reserve of "compliance" bituminous coal in the nation.
- A 100-watt light bulb burning on the porch overnight for 10 hours takes one pound of coal.

- Every ton of recycled steel saves 1,000 pounds of coal from being mined.
- One cord of wood (4 feet x 4 feet x 8 feet) is equivalent to the heating value of one ton of coal or 200 gallons of fuel oil.
- To maintain our standard of living, each person in the U.S. uses the energy equivalent of 7,643 pounds of coal every year.
- Two billion kilowatt-hours of electricity are generated by coal-fired power plants in the U.S. annually.
- Electricity consumption in the U.S. is expected to increase by 50 percent by 2027.
- World coal production in 2003 was 5.25 billion tons; in the U.S. 1.069 billion tons; in Colorado 35.8 million tons.

History of coal mining in Colorado

Coal was first produced near Boulder in 1859 when Joseph Marshall excavated coal from an outcrop on his property and sold it to homesteaders for heating fuel. The first coal production records date back to 1864 when 500 tons were mined. Early coal mines in the 1870s and 1880s lead to the establishment of the towns of Erie, Louisville, Lafayette, and Superior. Railroads were built to haul the coal to markets in Denver. This coal was used for home heating. The mining towns of Central City and Blackhawk used the local wood forests for building construction and fuel in the long winters. Soon wood became scarce, and coal was then used for fuel.

Coal mines in Redstone and Trinidad boomed around the turn of the 20th Century to supply "coking" coal for the steel plant near Pueblo. The rich quality coal was first baked in coking-ovens to drive off the gases. These "beehive" coke ovens can still be seen today near Redstone, Cokedale, and four other historic locations around the state. The coke was shipped to the steel mill and used to fire very high temperatures for melting iron.

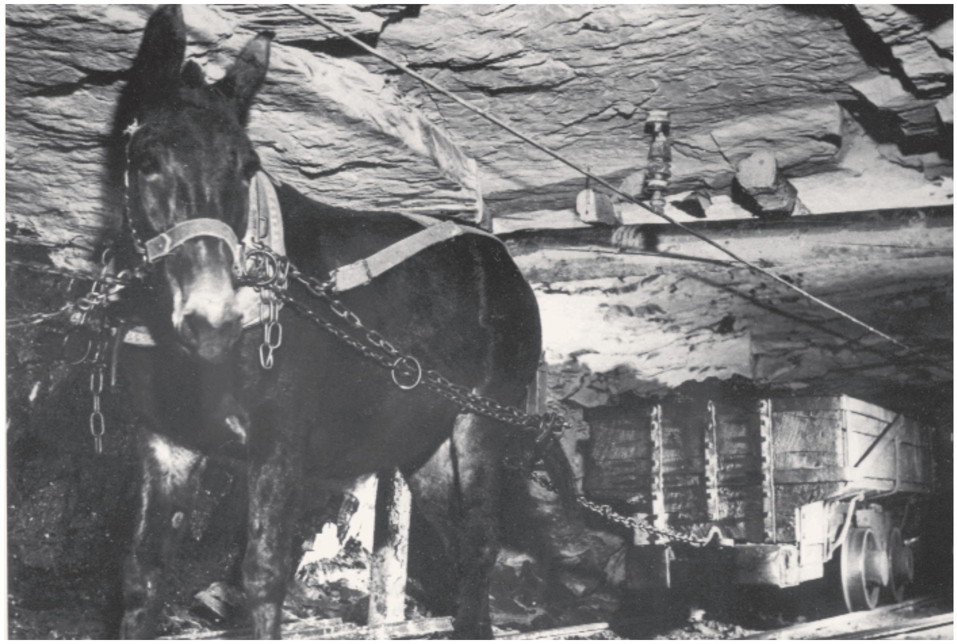
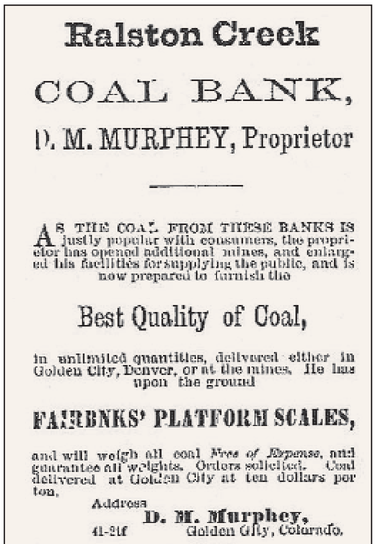


Figure 6. Mules were used to haul ore carts underground.



Ralston Creek

COAL BANK,

D. M. MURPHEY, Proprietor

As the coal from these banks is justly popular with consumers, the proprietor has opened additional mines, and enlarged his facilities for supplying the public, and is now prepared to furnish the

Best Quality of Coal,

in unlimited quantities, delivered either in Golden City, Denver, or at the mines. He has upon the ground

FAIRBANKS' PLATFORM SCALES,

and will weigh all coal *Free of Expense*, and guarantee all weights. Orders solicited. Coal delivered at Golden City at ten dollars per ton.

Address D. M. Murphey, Golden City, Colorado.

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Colo. Transcript advertisement, June 2, 1869.

The Mining Occupation

Coal mining was a dangerous occupation in the late 1800s. Unsophisticated mechanical devices, inadequate tools, dynamite, underground rails and mules (Fig. 6), and poor ventilation systems characterized that work environment.

The Colorado coal industry is famous for its labor-disputes. In 1913, the Great Colorado Coal War broke out when miners went on strike in both the southern coal fields near Trinidad and in the northern fields near Lafayette. Labor tensions reached their peak after one year when Colorado Fuel & Iron (CF&I) coal company representatives engaged the Colorado militia to crush the strike. The militia burned the tent colony of striking miners in Ludlow, resulting in the deaths of 27 women and children. The public outcry from this event led to the first union labor and management meetings and cooperative agreements, the development of labor relations departments in corporations, and the establishment of safety and decent working conditions at the hazardous Colorado coal mines.

Before 1914, it was common law that workers "assumed the risk" when entering a coal mine. Workers received no compensation if hurt on the job because of assumed awareness of the risks involved, or that he, or careless co-workers, were at fault. "Contributory negligence" held that workers were responsible. This changed after the incident at Ludlow when the coal company owner, John D. Rockefeller, and labor organizers met to establish new compensation laws and better working conditions and hours for miners. By 1925, coal miners also received collective bargaining rights as well.

Production History

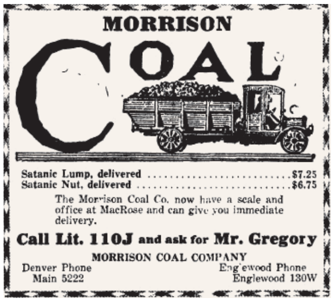
Early coal production peaked in 1917 with over 12 million tons produced in that year (Fig. 7). Unfortunately, it also marked the highest death tolls from coal mining. That year 121 miners lost their lives in a coal mine explosion at the

Josephine Roche

Josephine Roche was an early pioneer of the labor movement in Colorado. As majority shareholder in Rocky Mountain Fuel Co., she disapproved of working conditions in her mines. In 1929, two years after the violent strike at the Columbine Mine, she agreed to a two-year contract with the United Mine Workers that raised wages and instituted more humane working conditions and hours. She continued what her critics called her "highly touted social experiment" through the Depression and in a fierce wage war against Rockefeller's Colorado Fuel and Iron Co. until her company declared bankruptcy in 1944. Miners remember her as "a good old soul."

—Courtesy of Lafayette Mining Museum.

Hastings Mine in Las Animas County. With completion of the Moffat Tunnel in 1928, coal fields in northwest Colorado opened near Oak Creek with high-grade bituminous coal production. Coal production dropped during the Great Depression, but came back somewhat during World War II. Colorado coal mines are famous for inventing the first automated continuous mining machine in 1943. After the war, natural gas became the fuel of choice for home heating, and coal production dropped off steadily. It wasn't until the 1970s that coal mining picked up again as it was then used for driving steam turbines at electrical power plants.



By 1980, coal production increased again as coal-fired generation of electricity boomed. Exploration for coal in the 1970s and 1980s was intense. Coal leasing was very active and the price of coal went up. The development of longwall mining equipment increased the productivity, efficiency, and safety of underground mining. The use of larger and larger surface mining shovels and draglines also increased production.

Since passage of the Clean Air Act of 1990, Colorado coal production has boomed. Due to our low-sulfur and low ash content, Colorado coal is considered "Environmentally-compliant." Colorado coal is blended at power plants in the eastern U.S. that use higher sulfur coal from Midwestern and Appalachian coal regions. Typical Colorado coal is between 0.4–0.7 percent sulfur, while Central Appalachian and Illinois coals are mostly over 1.0 percent sulfur. Much of the high-sulfur coal can be burned by first washing it to remove the impurities, or by using smokestacks with environmental control technologies. Since the environmentally compliant cut-off for sulfur is 0.7 percent, Colorado coal can usually be burned at power plants without the added expense of washing coal.

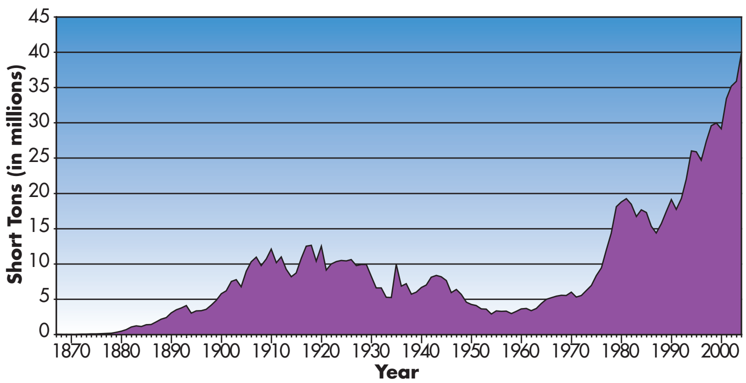


Figure 7. Annual coal production in Colorado from 1864–2004.

Coal Mining in Colorado Today

Colorado's coal production continues to grow. In 1994, over 26 million tons of coal were extracted from 17 mines. Only ten years later, in 2004, Colorado's 12 coal mines produced 40 million tons of coal, or four percent of the nation's coal. The eight underground mines produced over 30 million tons, and the four surface mines produced 10 million tons. All of the currently active mines are located on the western slope, from Steamboat Springs to Durango. Coal was produced from eight counties last year: Delta, Gunnison, La Plata, Garfield, Moffat, Montrose, Rio Blanco, and Routt. Gunnison County had the largest production of any single county, producing over 13.14 million tons of coal from the Elk Creek and West Elk mines. The four largest producing mines, Foidel Creek (Twentymile), Elk Creek, West Elk, and Colowyo, together accounted for over 70 percent of the state's coal production. The largest producer was Twentymile Coal Company's Foidel Creek underground mine in Routt County with 8.56 million tons. This mine broke the Colorado record for annual coal production for a single mine in 2004 (Fig. 8).

Most of the coal produced on the western slope is transported by rail to coal-fired power plants along the Front Range, or to plants in the midwest and southeast U.S., even as far as Boston. Coal is sold and traded on the coal market for shipments from the mine to various power plants. Most of the coal contracts range from one to 25 years time. Some coal is sold on the spot market, which has a daily fluctuating price. In 2004, the spot market price for Colorado coal jumped from \$17 per ton to over \$29 per ton. Using an average of \$20 per ton, the value of Colorado coal sales in 2004 was approximately \$800 million. Although coal prices are high, 2005 coal sales are still up, as demand for Colorado's compliant coal is very strong. Coal orders for 2005 are already filled at many mines.

Figure 8. Coal conveyors at the Peabody Energy Company's Twentymile/Foidel Creek Mine, Routt County.

Mining Methods

Coal is either mined from the surface or underground (Fig. 9). The particular mining method chosen depends on surface terrain conditions, coal layering, access, and/or reclamation laws. Surface mining is regulated by a set of rules governing the recovery and revegetation of original topography, while underground mining is mostly regulated by safety concerns. If the coal seams are shallow and close together, then surface mining is considered. However, if the seams are thick (greater than five feet thick), and deeper (between 200 and 2,500 feet deep), then underground mining is considered.

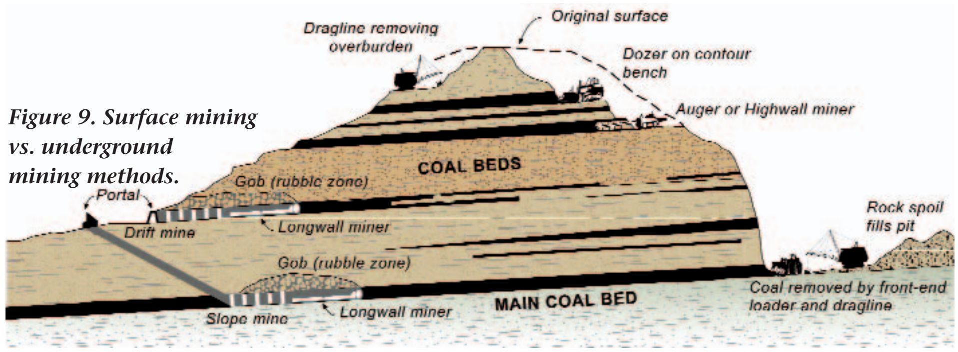


Figure 9. Surface mining vs. underground mining methods.

Underground Mining

Over two-thirds of the coal produced in Colorado today is mined by underground methods. A deep coal seam is accessed by an opening to the surface called a portal. The portal openings are called drift, slope, or shaft mines. Drift mines cut down the coal bed from the outcrop, slope mines cut through overburden rock at an angle to get to the coal, and shaft mines access the coal through a vertical shaft. Mining begins with a cutting machine called a "continuous miner" creating a box work called room and pillar mining. As the rooms are cut the coal is loaded onto a shuttle car and carried to a conveyor belt that carries it to the surface. As the mining advances, the pillars remain to support the openings. Roof bolts are placed in the ceiling to stabilize the roof. Two small mines in Colorado use this continuous mining method: King Coal in La Plata County, and McClane Canyon in Garfield County.

The larger underground mines use a large coal-cutting machine called a "longwall" miner (Fig. 10). This automated machine is 1,000 feet long and has moveable three-foot-wide cutting teeth that cut away at the face of the wall of coal. This 36-inch diameter rotating shearer cuts the coal, where it drops onto a conveyor which hauls to the surface. Because this machine cuts a continuous 1,000-foot-long swath into the coal seam, there are no pillars left to support the roof. So moveable metallic roof shields are installed all along the 1,000 foot zone that will be cut. This keeps the roof from collapsing near the cutting machine. After each 1,000-foot-long cut (each three feet deep), the metal shields are moved forward allowing the roof to collapse behind. The five longwall operations at coal mines in Colorado are the West Elk and Elk Creek mines (Gunnison County), Bowie Mine (Delta County), Deserado Mine (Rio Blanco County), and Twentymile Mine (Routt County). The deepest longwall machine in Colorado operates 2,300 feet below the surface at the West Elk Mine.

Surface Mining

If the coal beds are relatively close together and less than 200 feet from the surface, then surface mining is considered. The types of surface mining include area, mountaintop removal, and contour mining. In Colorado, only area mining is done and consists of removing shallow coal in a large, flat area.

Huge dragline shovels (12–27 cubic yard buckets) first remove rock overburden to get to the coal. These machines stockpile the overburden until it is time to reclaim the pit. The coal is excavated from the pit floor with truck shovels and front-end loaders and then hauled to the loading area with large trucks. As the pit

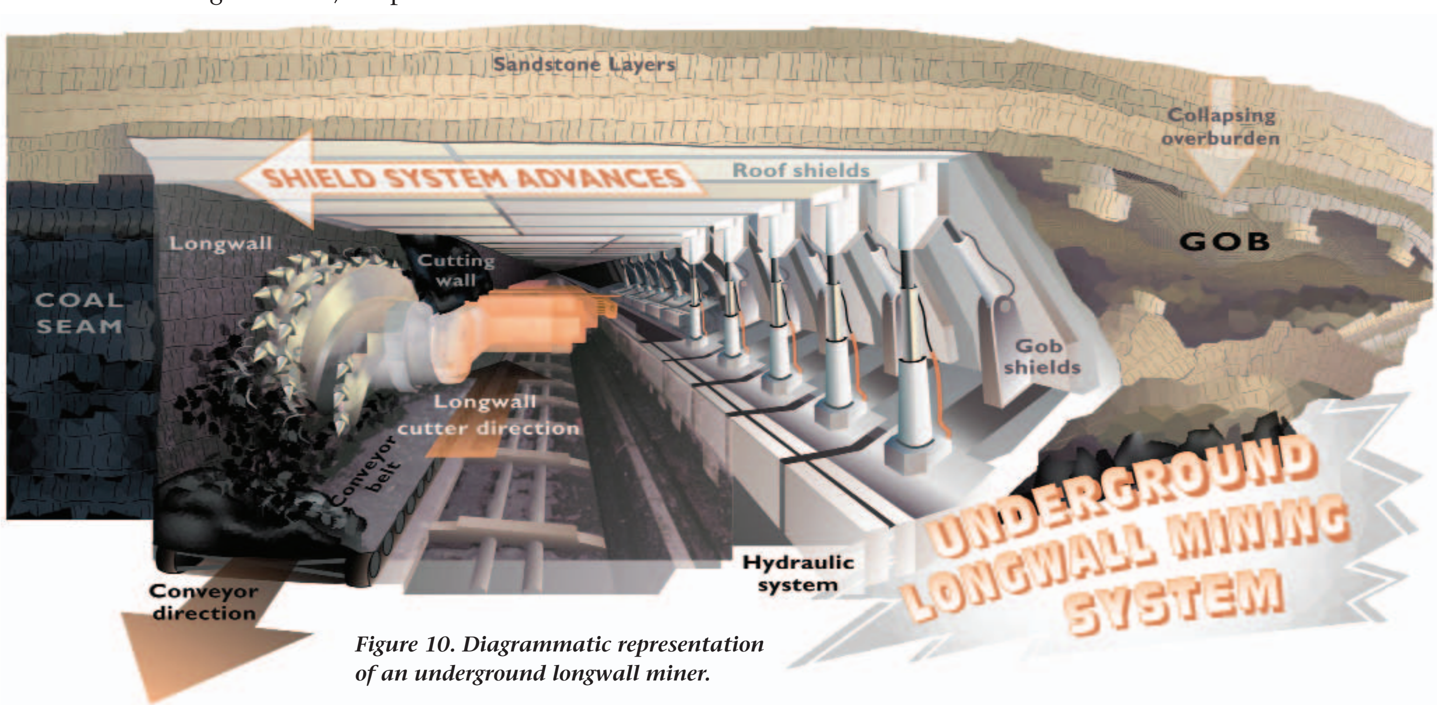


Figure 10. Diagrammatic representation of an underground longwall miner.

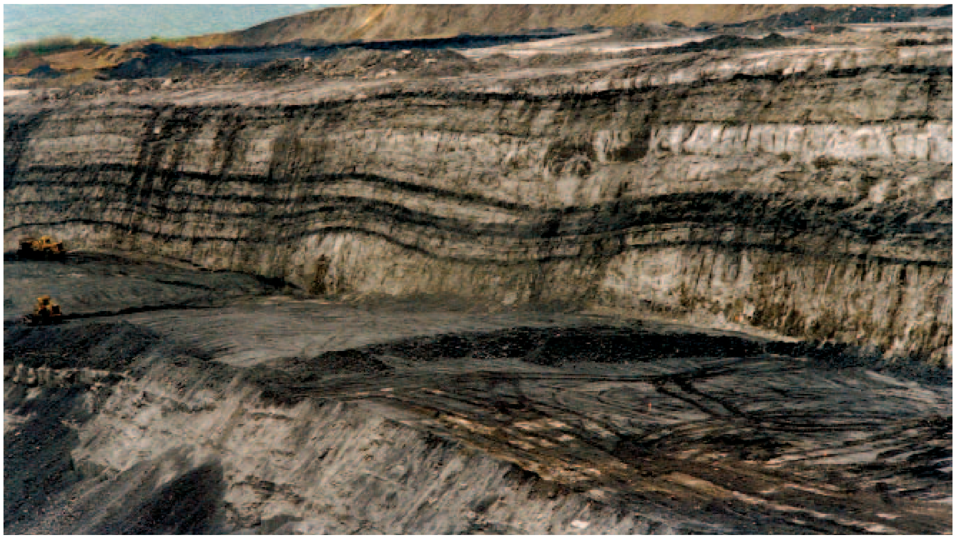


Figure 11. Cretaceous coal strata exposed in a bench cut of the Williams Fork Formation at the Kennecott Corp. Colowyo surface coal mine in Moffat County, Colorado. Note how the coal beds split and roll.

widens and deepens, the walls become steeper. The wall in the pit where the coal is mined is called the highwall. The back side of the pit is filled with waste rock. The highwall is benched (Fig. 11) to mine the upper coal beds, and then the underlying rock is blasted with explosives for easier removal. This type of coal mining is done today at the Seneca II-W and Yoast mines (Routt County), Trapper and Colowyo mines (Moffat County), and the New Horizon Mine (Montrose County). Colowyo Mine is the largest surface mine in the state with a highwall over 400 feet.

When the pit walls are too high and steep, surface miners try to remove coal remaining in the highwall without further excavation. Two methods of mining can achieve this feat, auger and highwall mining (Fig. 12). Auger mining employs a 6-foot diameter horizontal auger to drill out the remaining coal. This methods works well on flat-lying coal beds. When the coal beds dip or roll, the highwall miner is used. This new technology machine excavates a rectangular hole into the coal outcrop with a rotating continuous miner head. As the laser-guided machine extracts coal from the hole, conveyor belts transport the coal back to the surface while the mining machine advances. The remote-control machine can extract coal up to 1,200 feet into the highwall. This method can safely remove coal without using miners underground. In Colorado, one highwall machine is operated at the Colowyo Mine.

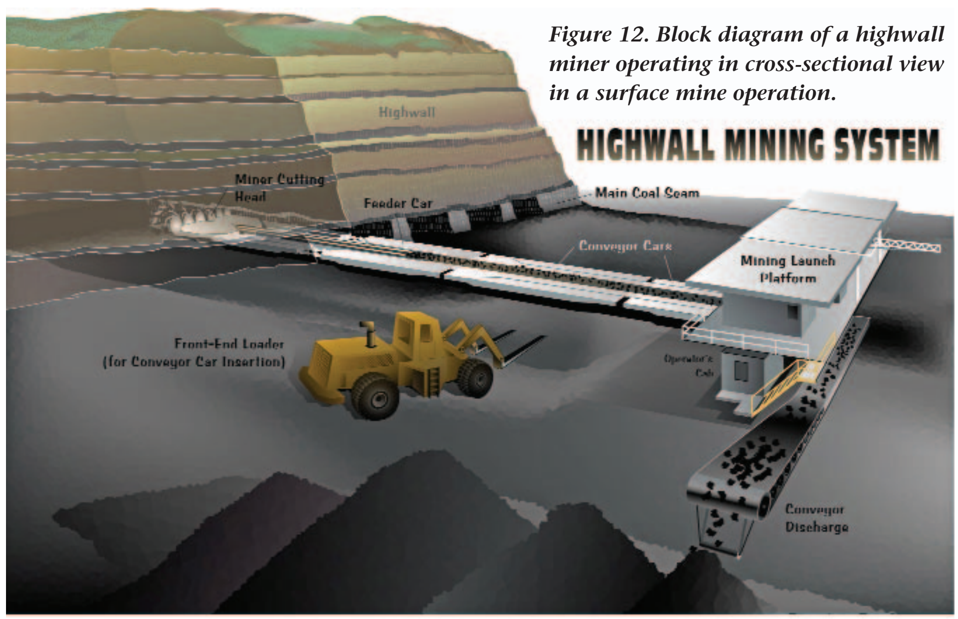


Figure 12. Block diagram of a highwall miner operating in cross-sectional view in a surface mine operation.

Coal Mine Subsidence

When coal is extracted underground, sometimes the weight of the overlying rock causes the layers to sink downward into the void left by removal of coal. Ultimately, this process can affect the surface, causing the ground to sag and crack and holes to form. Merely two inches of differential subsidence beneath a residential structure can cause several thousand dollars worth of damage. It is best to avoid building over abandoned coal mines.

Subsidence can happen suddenly and without warning. Detailed investigations of an undermined area are needed before development occurs to resolve the magnitude of the subsidence hazard and to determine if safe construction is possible. While investigations after development can determine the extent of undermining and potential subsidence, it is often too late to protect existing buildings against subsidence hazards. The cost of remedial measures can be high.

Inactive Coal Mines and Population Growth

Coal mining in Colorado started in the 1860s and is a continuing activity in many areas of the state. As of August 1977, Federal and State laws require that potential surface subsidence be taken into account in mining plans. Prior to that time, the effect of mining on the surface was not fully considered.

Many old mines are located near present urban areas. With Colorado's population growth in the last 25 years, not only have many homes been built over abandoned mines, but also many homeowners are unaware of previous mining or the extent of mining in an area. Subsidence over abandoned coal mines has occurred and is a potential hazard for thousands of homes along the Front Range urban corridor, and these numbers will continue to grow as more residential and commercial development takes place.

*See **Subsidence** on page 12*

Coal Mine Reclamation

Figure 13. Oblique aerial view of active surface operations at Kennecott's Colowyo coal mine, Moffat County, Colorado. Note the draglines for scale. Reclamation occurs simultaneously as the pit advances. Photo courtesy of D. Berry.

The Colorado coal mining industry continues to increase production while also maintaining outstanding environmental compliance and reclamation performance. The Colorado Division of Minerals and Geology (DMG) Coal Mine Regulatory Program within the Department of Natural Resources regulates Colorado's coal mines. The state Coal Program conducts permitting and inspection duties with state primacy delegated from the Department of the Interior, Office of Surface Mining Reclamation and Enforcement (OSM). Colorado's authority to permit and inspect mines was granted on December 15, 1980. Colorado's coal mine operators work closely with the Coal Program to ensure environmental compliance, and to implement ongoing reclamation. These activities continue to result in successful bond release, and both national and state reclamation award recognition. Other DMG mining-related programs include the Inactive Mines Program, the Minerals Regulatory Program and the Mine Safety and Training Program.

Information on the DMG mining-related programs can be found on the DMG Web site at www.mining.state.co.us. The site allows access to many DMG reports, and most recently provides the Inactive Mines Program "Report on the Status of Fires at Abandoned Underground Coal Mines in Colorado.

The Coal Program currently manages 50 mine sites that cover nearly 163,000 permit acres. These permit areas include approximately 19,300 acres involved in surface mining or surface facility activities (Fig. 13). Additionally, these permit areas include approximately 76,700 acres that overlie underground mine workings. The Coal Program conducted 190 permitting actions and 514 mine site inspections during 2004. A total of 14 coal mine permits were previously and completely bond released, and these released sites included a total of 18,018 permit acres. The Coal program currently holds approximately $137,700,000 in reclamation bonds. The Colorado Mined Land Reclamation Board (MLRB) provides program oversight to the Coal Program, and is the approving authority for any Coal Program regulation changes. The MLRB is a seven member governor-appointed board with members representing a broad range of interests.

Colorado's coal mines must manage many areas of compliance. The compliance process includes detailed permitting activities, and the mines are monitored on a monthly basis to ensure ground compliance. The Colorado mining industry has long exhibited a cooperative and proactive stance in meeting these obligations. Mine site personnel maintain close contact with the Coal Program to address both permitting and inspection issues. In addition, the mines and the Coal Program work closely with local community contacts and other agencies to implement an open and public regulatory process. All permitting actions are posted for public review and comment, and the public frequently provides input to the process.

Colorado's mine sites manage a complex suite of environmental provisions. These include surface and groundwater hydrology protection measures, erosion and sediment control, water quality protection, subsidence impact controls, blasting impact mitigation measures, topsoil resource management and protection, landslide prevention, and mine waste rock or processing waste management. In all cases, final reclamation must establish a specified beneficial post-mining land use such as agricultural production, rangeland and/or wildlife habitat. Concurrent reclamation requirements include establishment of the approximate original land configuration, topsoil redistribution and revegetation, including noxious weed control. Mine site permits require extensive baseline environmental data collection prior to permit issuance, and all operations conduct ongoing environmental monitoring and reporting.

The Coal Program, Colorado State University, Colowyo Coal Company, Seneca Coal Company and Trapper Mining are currently completing a five-year cooperative study to assess shrub establishment methods at Colorado surface coal mines. The study is intended to address, and hopefully resolve, challenges currently experienced by mine sites as they work to establish healthy shrub populations on reclaimed lands. Some sites have experienced difficulty in achieving extensive shrub establishment due to intense grazing by the large elk herds that frequent the reclaimed areas. Reclaimed Colorado mine sites

(continues next page)

continue to attract healthy wildlife populations that include elk, deer, antelope, and numerous small mammal species. Columbian Sharp-tail Grouse leks are now observed with frequency at various reclaimed surface coal mines in northwest Colorado.

Colorado coal mines continue to receive recognition at both the federal and state level. The Trapper Mine located in Moffat County recently received the Special 25th Anniversary Bronze Award from the OSM. Other OSM award winners include the Eckman Park and the Seneca II Mines in Routt County and the Deserado Mine located in Rio Blanco County. Last fall, the Trapper Mine received additional recognition from the OSM by receiving the national "Good Neighbor Gold Award." In addition, over twenty mines have received annual reclamation awards from the DMG and the Colorado Mining Association.

The Coal Program remains actively engaged in regional and national issues related to coal mining through participation with the Western Interstate Energy Board and the Interstate Mining Compact Commission. Issues currently being addressed through these groups include reclamation bonding, coal combustion waste management, OSM oversight policy and OSM grant funding.

Colorado enjoys an environment where coal mining occurs with record production, and where environmental compliance and reclamation are exemplary. These goals result from a positive relationship between the industry, the public and the regulatory agencies that focuses on problem resolution and achievement of mutual interests.

Coal Resources

How much coal do we have?

This is an important question asked by coal geologists. Using computers to model where the remaining coal beds are located, we can determine the depth, thickness, and quality of the coal beneath the ground. The result gives a huge number of 434 billion tons of coal. But only a small part of this can be actually recovered.

The Colorado Geological Survey and the U.S. Geological Survey are collaborating on a program entitled Coal Availability. This program is designed to determine the amount of coal available for mining after the exclusion of land-use and technological restrictions. Geologists use well logs, outcrop measurements, and other geologic information to determine the best locations for present and future coal mining. Coal geologists then subtract areas considered inappropriate for mining (beneath cities, roads, cemeteries, schools, bald eagle nesting sites, steeply dipping rocks, and wilderness areas). The result of this analysis is the Demonstrated Reserve Base which is only 12 percent of the total coal resources.

How long will our coal supply last?

Using this 16.4 billion ton Demonstrated Reserve Base (DRB) in Colorado today, and the current coal production rate, we can extrapolate how long the supply will last and estimate how much coal will be remaining in the future:

Year	Demonstrated Reserve Base (billion tons)	Annual rate of production (million tons)	100-year extraction total
2005	16.4	40	4 billion (2005–2105)
2105	12.4	80	8 billion (2105–2205)
2205	4.4	100	

- At the current rate of extraction of 40 million tons per year, over the next ten years, we will produce 400 million tons by 2015. Assuming that rate is constant over the next 100 years, we will mine a total of 4 billion tons. Subtracting that from the Demonstrated Reserve Base leaves 12.4 billion tons left by the year 2105.
- Assuming our needs will double by then, we will be mining 80 million tons per year in 2105. That rate will be 8 billion tons per 100 years, leaving 4.4 billion tons left by the year 2205.
- So the conclusion is that our known supply of 16 billion tons today will be exhausted in about 225 years from now, or the year 2230.

Hopefully there are other reserves to be found, either deeper, steeper, or shallower, that can be mined in the future with technology beyond today's means. This will extend the life of our coal supply well into the future.

Figure 14. Aerial view of the Arch Coal West Elk Mine, Gunnison County, Colorado. Visible on the surface are the long conveyor lines between the portal and the coal loadout facility. Photo courtesy of W. Koontz, West Elk Mine.

***Subsidence** from page 9*

When and How Much Subsidence Can Occur

Where longwall mining is active and subsidence is a well-documented and predictable consequence, surface response to ongoing mining can be accurately estimated. However most residential development in Colorado has occurred over room and pillar mines. In this case there can be inaccurate record keeping, and predictions of when subsidence will happen are not possible.

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THIS ISSUE
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How much subsidence will occur depends not only on the type of mining but on geology and several physical features of the voids left by mining. Some general rules of thumb are:

- The larger the mine opening height and width, and the shallower the mine, the larger the subsidence feature at the surface;
- Deep longwall mines can also show surface trough subsidence;
- The strength of the rock (including the number of fractures, faults, and joints) above the coal seam is a factor in whether subsidence extends to the surface and influences the kind of features that could appear.

Subsidence Hazard Area Identification

A residence or other structure may be subject to subsidence if it is located over or close to an undermined area. Therefore, the first step in determining the subsidence potential at a specific location is to discover if the area is undermined. Several published sources of information are available for the locations of inactive mines. Maps showing the extent of inactive coal mines and actual maps of coal mines are available for viewing from the Colorado Geological Survey.

Individual site-specific investigations involve examining the available data and drilling exploratory holes for information on the present condition of the mine. These investigations determine how the subsidence hazard can affect proposed development, whether safe building areas exist, and what unsafe areas should be avoided.

These studies, when available, are often on file with the builder, city, or county. They also may be available for inspection from the files of the Colorado Geological Survey. To determine if one of these studies is available for a specific subdivision, the subdivision name (as platted) and location should be known.

Mining Subsidence Damage

Where subsidence causes ground openings, a driveway or major structural member of a building can often bridge a hole, but only for a short time. However, the stresses produced by ground subsidence can damage buildings, even if surface openings do not appear. Damage can be manifested as cracks, broken pavement or floor slabs, sunken foundations, or doors and windows that stick. Because other hazards, such as swelling and collapsible soils, and limestone and evaporite sinkholes, can produce damage similar to mine subsidence, it is important to have a problem evaluated by a qualified professional.

New Resources

The CGS has updated the Annotated Bibliography of Subsidence Studies over Abandoned Coal Mines, IS-22. The new publication will be a database on CD-ROM, IS-72. Mine maps are now available in electronic format. The mines have also been categorized into coalfields, and disc-set collections of maps are available for purchase.

ROCKTALK

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