ChemHistory

Coal Mine Safety

PHOTODISC

By Harvey Black

For a few days in July 2002, the safety of nine Pennsylvania coal miners trapped 240 feet below the surface held a horrified nation riveted to the 24-hour television media coverage. When the nine Quecreek miners accidentally broke into a water-filled abandoned chamber, they were effectively cut off from their escape route.

Tension reached the breaking point when mining engineers and geologists armed with old maps, their knowledge of the mines, and their Global Positioning Satellite devices gave the word: "Dig here." There was no margin of error. Time loss and the risk of flooding the Quecreek miners' only place of refuge loomed as the deadly outcomes of digging the wrong shaft. They got it right. On July 28, nine exhausted miners were hoisted to the surface where they were embraced by their families. An entire nation breathed a collective sigh of relief.

For a time, public interest and the media lingered on the spectacle. Good questions arose about our national dependence on coal and the accompanying safety risks that go along with its use. Many of these questions are still waiting for answers.

Story of black diamonds

Let's start with one that is relatively easy to answer: What is coal? Most of us think of coal only in terms of deep mines or in terms of stripped-off mountaintops. We think of huge machines, hard labor, and all of the hazards that go along with an industry that

has figured heavily in our nation's history.

But the story really starts long before the first settlers arrived. It starts with land and plants that look nothing like coal and the underground seams where it is found today. Think of the Everglades in Florida or the Okefenokee Swamp in Georgia. Coal begins to form in swamps and bogs like these.

Geologist Glenn Stracher of East Georgia College defines coal as rock formed from the remains of plant materials. "Anything that comes from a plant can go into the process of making coal," he says. On a much smaller scale, animal remains are also included.

As the growing season passes, plants growing in swampy areas die and their remains fall into the water. There, they start to decompose, but do so very, very slowly. That's because in the still water of swamps and bogs, there is not enough dissolved oxygen to meet the requirements for most decomposers—bacteria and fungi.

"More material dies and falls in on top of that previous material, and more [organic remains] falls on top of that. So what you started out with initially gets buried deeper and deeper in the swamp as time goes by," explains Stratcher. He notes that coal in Pennsylvania can be between 200 and 300 million years old. The term *fossil fuel* is applied to fuels like coal that trace their origins to these long-dead plants and animals preserved in the earth.

Coal formation goes through a number of stages. The initial stage is peat—a loose brown collection of plant material. Over time, successive forms of coal are lignite, bituminous, and finally anthracite. Each successive form contains a higher percentage of carbon, releasing more heat for a given weight when burned.

Actually, each successive form represents organic material buried deeper in the earth over a longer period of time. As overlying sediments pile up, both the temperature and the pressure increase. About 3–7 feet of compacted organic matter transforms under temperatures ranging from 100 °C to 200 ˚C to yield about 1 foot of bituminous coal—the most common form in the United States.

Our dependence on coal

Worldwide, people have been digging coal out of the earth for more than 1,000 years. Coal mining in Pennsylvania dates back to colonial America, but both here and elsewhere, the demand for coal soared during the 19th century as the Industrial Revolution got under way.


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Coal may not be the first thing you think of as you hit a light switch or open your refrigerator, but more than half of the energy consumed in the United States today is traced to coal fuel. Today, coal is not often burned directly in furnaces to provide heat for buildings. But it remains the major source of energy for creating steam. Hot steam turns turbines in power plants, and electricity is the result.

Although residents of the northeastern states had an opportunity to ponder life without electricity when the power grid went down last June, few of us can imagine anything longer than a temporary blackout. Health, safety, transportation, manufacturing, entertainment—in short, life as we know it is dependent on a stable power supply. And underlying that power supply is coal.

As Barry Commoner, an environmental activist and author once put it, "There is no such thing as a free lunch." What is the real price of our dependence on coal? We've already noted how tragedy can strike in the mining industry. Are there other risks?

Coal is risky business

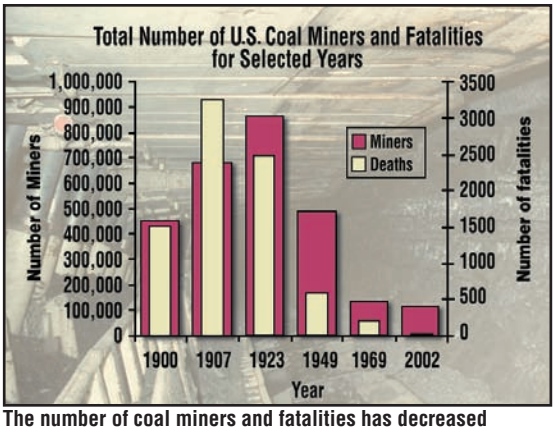
Burning coal releases a range of pollutants into both air and water. Most notable among these pollutants are oxides of sulfur and nitrogen—both causing air pollution and the production of acid rain. The burning of coal may also release mercury into the environment, which collects into waterways to be ingested by fish. Consuming mercury-contaminated fish puts humans at risk for kidney and nervous system damage.

Concentrated pollutants released into the air by burning coal can bring about tragic results. One such incidence was the infamous killer smog that settled on London in December 1952. A long cold spell kept coal fires burning longer than normal, and a weather condition called a "temperature inversion" kept the smoke at ground level. The result was thousands of deaths in four days.

Although no one was killed in 2000 when millions of gallons of gooey, sticky coal mine wastes broke through the walls of an impoundment, several streams in Kentucky were horribly polluted. The wildlife population that depended on the river for food was immediately devastated.

Sometimes the health effects of coal exposure take years to develop. Black lung disease, which is characterized by scarring and inflammation that make every breath a chore, results from years of inhalation of tiny coal particles. Today, one coal miner in 20 has some form of the disease, according to the American Lung Association. Although coal particles can cause a long-term illness, it is methane that can be responsible for more immediate and equally deadly effects.

Methane (CH_4) is the major part of natural gas, in itself a source of fuel. It is released by the lengthy processes that result in coal formation. In coal mines, this odorless, colorless, lighter-than-air gas, is a constant safety concern. With any spark to ignite the gas, methane in concentrations of between 5 and 15% in air readily explodes, explains Stephen Schatzel, a geologist in the National Institute of Occupational Safety and Health (NIOSH), a federal agency that works to make sure conditions on the job are safe.



SOURCE: DEPARTMENT OF LABOR

The number of coal miners and fatalities has decreased sharply over time. Coal mining is still dangerous. In 2002, there were 27 deaths.

To reduce the methane risk, current government mining regulations require that the maximum level of methane be even lower. "In

most of the mine workings, it has to be below 1 [percent]," says Schatzel. To keep methane levels at regulation level, fans are installed to move air out of ventilation shafts at very high rates of speed. There are also extensive and powerful ventilation systems to provide fresh air to areas where the miners are working. And three times per hour, mandatory checks are made to see that the methane concentration is no greater than 1%.

And that's not all. "The mining machinery is required to have detection devices called methanometers on them. The devices shut down the machinery [automatically] at 1%," he says.

Keeping methane low is critical given the risk of ignition in a mine. "You have a piece of mining equipment that is operating, and it strikes coal or the roof or floor rock, the rock immediately above or below the coal bed—and it produces a spark," explains Schatzel.

Explosions kill

In what was one of the worst accidents in nearly 20 years, a methane explosion in an Alabama coal mine killed 13 miners in 2001. In China, where thousands of mines are poorly ventilated, methane explosions still kill thousands of miners each year.

Explosions can occur even when methane levels are low. Tiny particles of coal dust suspended in oxygen-rich air can be another potential disaster just waiting for a spark. On April 26, 1942, 1549 people were killed by a coal-dust explosion at Honkeiko (Benxihu) Colliery, China. That was the worst single coal-mining disaster in history, according the *Guinness Book of World Records*. Today, coal dust continues to pose serious risks in China and elsewhere. In May of 2002, 18 miners were killed in an explosion at a coal mine in Wentang township in China's southern Hunan province.

Despite attempts to regulate gas and particle exposures, Schatzel is concerned that these hazards will increase as new mining methods are developed to dig out more coal in less time. "The more rapid the mining moves ahead, the more gas they [the miners] will encounter because the gas has not had an opportunity to bleed off from the coal. That presents an inherent challenge. The methane control technology really hasn't changed dramatically from the seventies. So we try at look at new methods," says Schatzel.

Schatzel and his colleagues are working on a mathematical model to predict the amount of methane that will be released as rapidly operating mining machines slice off huge chunks of coal from mine walls. Figuring this out, he says, is a complex process that takes into account the geologic formation, the depth of the coal bed, the rate of mining, and barriers to gas movement, such as veins of clay. "It's an ambitious project," he says.

Coal mines, even inactive ones, are by their very nature hazardous. Abandoned mines present their own set of threats. Certainly, the Quecreek miners found that out as they accidentally penetrated the walls of an abandoned water-filled mine. Abandoned mines can pose hazards above ground too, note professional geologists Robert Turka and Stan Michalski of the geology and engineering firm, GAI Consultants, Inc., of Monroeville, Pennsylvania.

COURTESY OF NIOSH, PITTSBURGH RESEARCH FACILITY

This controlled explosion at a NIOSH facility shows how dangerous methane gas can be if it exceeds safe levels in a mine.

"You create this enormous hole in the ground! Frequently in the old mines, you'll get a buildup of methane. It'll move through fractures," says Turka. There have been instances, though they are rare, in which lighter-than-air methane diffused into homes and exploded.

Mines can also threaten the safety of the environment by releasing acids that drain into streams and groundwater. Acids form when sulfide-rich minerals are exposed to air and water. Pyrite (FeS_2)— particularly common in coal mines—is readily oxidized to form sulfuric acid:

$$2FeS_2\,(s) + 7O_2 + 2H_2O \rightarrow 2FeSO_4 + 2H_2SO_4$$

The drainages containing these acids are in the range of pH 0–1 and may contain toxic heavy metals as well, thus posing a potentially lethal threat to aquatic life in ponds and rivers into which they drain.

Although acid mine drainage is a serious problem, it is not an inevitable outcome of coal mining. Ron Graham, a chemist with SGS, Inc., a Swiss-based testing and certification firm, notes that "some rock strata have inherent neutralizing potential." Calcium carbonate ($CaCO_3$), which is found in some coal mines, dissolves to form a basic solution that can neutralize the acid formed from coal mining.

As an example, he notes that in the major coal mining state of West Virginia, the southeastern part of the state has little problem with acid mine drainage. In this region, calcium carbonate is abundant where coal is mined. In more northern sections of the state, acid drainage is a problem because of the relative absence of neutralizing calcium carbonate.

Coal fuels modern life and the myriad conveniences, services, and devices on which we depend. But, at the same time, coal and its pollutants threaten the environment and even our global climate. On a local level, coal mining may provide not only the jobs on which people's livelihoods depend, but also the toxins that keep those life spans below the national average.

As the media analyzed the 2002 Quecreek Mine drama, someone speculated that the exhaustive coverage of the potential disaster may have single-handedly killed the future of an industry. They asked, "What kid could watch that drama unfold and still decide to become a miner?" Coal—mining it and consuming it—raises many questions about benefits and risks. These are important questions that will require some deep digging for answers.

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CHEMMATTERS

February 2004 Teacher's Guide

"Coal Mine Safety"

Puzzle: Missing Numbers

In a year of chemistry, one deals with lots of numbers. This puzzle challenges you to come up with some important ones, perhaps from memory. We give below ten values that you likely have (or will) encounter. Each is a familiar constant or a conversion factor, and we'll give you appropriate units and labels to help you recognize it.
But in each one there's a digit missing. Can you find/recall that missing number? Try to do as many as you can before consulting any tables of physical constants. Finally, there's one more hint. Each digit (0 – 9) is used exactly once in our ten terms.

Happy hunting !

6. _ 2 x 10^{23} particles per mol Avogadro's number

0.08_ liter-atm/mol-K universal gas constant

_60 mmHg standard pressure in STP

2._98x10^{8} m/s speed of light

-1. _ 6 ^{o}C/molal k_{fp} of water

1._6 x10^{-24} g/amu conversion of mass units to atomic scale

27_.2 K standard temperature in STP

96_00 C/mole of electrons Faraday's constant

10_ . 3 kPa/atm conversion of pressure units

_.18 J/cal conversion of heat units; the mechanical equivalent of heat

Puzzle Answers

In order

0, 2, 7, 9, 8, 6, 3, 5, 1, 4

Student Questions

Coal Mine Safety

1. Describe the general process by which coal is formed.

2. What are some of the environmental problems associated with the burning of coal?

3. What is Black Lung disease and what is its cause? How prevalent is Black Lung disease today?

4. Why does the presence of methane, CH_4, in a coal mine constitute a safety hazard? Describe some techniques that are used to prevent methane accidents.

5. Write a chemical equation that illustrates how sulfide-rich minerals containing pyrite can result in highly acidic drainage from mines.

6. Explain how the presence of calcium carbonate, $CaCO_3$, can lessen the environmental danger posed by acid mine drainage

Answers to Student Questions

Coal Mine Safety

1. Coal is formed over a period of millions of years from plants (and to a small extent, animals) that died in swampy areas. Their remains fall into the water and begin to decompose. However, since swamp water is very stagnant, there is little dissolved oxygen to meet the requirements for most decomposers—bacteria and fungi. As more material falls on top of the previous material, it is buried deeper and deeper. As these sediments pile up, temperature and pressure rise. Over a period of several million years, this temperature and pressure convert this plant material into coal.

2. When coal is burned a number of pollutants can be released into both the air and water. The most noteworthy are oxides of nitrogen and sulfur, which contribute to air pollution and acid rain. Mercury may also be released. It can accumulate in fish and cause health problems for anyone who consumes the fish.

3. Black Lung disease is a disease characterized by scarring and inflammation of lung tissue. It is caused by breathing coal dust over a period of several years. It is estimated that even today about one coal miner in twenty has some form of the disease.

4. Methane forms an explosive mixture when mixed with oxygen gas at a concentration of between 5-15%. To prevent these explosions from occurring, current government mining regulations require that the maximum concentration of methane in a mine must be kept below 1%. To achieve this, fans are installed to move air out of ventilation shafts at a very high rate and other ventilation systems provide fresh air to areas where miners are working. Three times each hour there are mandatory checks made to see that the methane is at or below acceptable levels. In addition, the mining machinery is required to have detection devices called methanometers. These devices automatically shut down the mining equipment if methane levels reach 1%.

5. $2\ FeS_2(s) + 7\ O_2(g) + 2\ H_2O \text{ -----> } 2\ FeSO_4 + 2\ H_2SO_4$

6. Calcium carbonate dissolves to form a basic solution. Since bases neutralize acids, the presence of calcium carbonate can neutralize the acidity present in acid mine drainage.

Content Reading Materials

National Science Education Content Standard Addressed As a result of activities in grades 9-12, all students should develop understanding.	**Cryogenics**	**You're Getting Sleepy**	**Project Yukon**	**The Aspirin Effect**	**Coal Mine Safety**
Science as Inquiry Standard A: about scientific inquiry.	✔	✔	✔	✔	✔
Physical Science Standard B: of the structure and properties of matter.	✔	✔		✔	✔
Physical Science Standard B: of chemical reactions.		✔	✔	✔	✔
Physical Science Standard B: of conservation of energy and increase in disorder.	✔				✔
Life Science Standard C: of the cell.		✔		✔	
Life Science Standard C: of the interdependence of organisms.			✔		✔
Life Science Standard C: of matter, energy, and organization in living systems.			✔		✔
Life Science Standard C: of the behavior of organisms.			✔		
Earth and Space Standard D: of geochemical cycles.			✔		✔
Science and Technology Standard E: about science and technology.	✔	✔	✔	✔	✔
Science in Personal and Social Perspectives Standard F: of personal and community health.	✔	✔	✔	✔	✔
Science in Personal and Social Perspectives Standard F: of natural resources.			✔		✔
Science in Personal and Social Perspectives Standard F: of environmental quality.			✔		✔
Science in Personal and Social Perspectives Standard F: of natural and human-induced hazards.		✔	✔	✔	✔
Science in Personal and Social Perspectives Standard F: of science and technology in local, national, and global challenges.	✔	✔	✔	✔	✔
History and Nature of Science Standard G: of science as a human endeavor.	✔	✔	✔	✔	✔
History and Nature of Science Standard G: of the nature of scientific knowledge.	✔	✔	✔	✔	✔
History and Nature of Science Standard G: of historical perspectives.	✔	✔	✔	✔	✔

Anticipation Guides

help engage students by activating prior knowledge and stimulating student interest. If you have time, discuss their responses to each statement before reading each article. Students should read each selection and look for evidence supporting or refuting their responses. Evaluate student learning by reviewing the anticipation guides after student reading.

Directions for all Anticipation Guides: In the first column, write "A" or "D" indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. Cite information from the article that supports or refutes your original ideas.

Coal Mine Safety

Me	Text	Statement
		1. Coal was formed mostly from animal remains.
		2. Coal formation begins with the formation of peat.
		3. People have been using coal for fuel for more than 1000 years.
		4. Coal supplies only 25% of the electricity consumed in the United States.
		5. Burning coal contributes to acid rain.
		6. Methane is odorless, colorless, lighter than air, and very flammable.
		7. Abandoned coal mines pose few hazards to the environment.

Reading Strategies

These content frames and organizers are provided to help students locate and analyze information from the articles. Student understanding will be enhanced when they explore and evaluate the information themselves, with input from the teacher if students are struggling. If you use these reading strategies to evaluate student performance, you may want to develop a grading rubric such as the one below.

Score	Description	Evidence
4	Excellent	Complete; details provided; demonstrates deep understanding.
3	Good	Complete; few details provided; demonstrates some understanding.
2	Fair	Incomplete; few details provided; some misconceptions evident.
1	Poor	Very incomplete; no details provided; many misconceptions evident.
0	Not acceptable	So incomplete that no judgment can be made about student understanding.

Coal Mine Safety

Complete the table below, describing the risks of using and mining coal. Include descriptions and chemical reactions.

	Coal Mining Risks	**Possible Solutions**
Pollution		
Explosions		
Long-term hazards		

Coal Mine Safety

Background Information

More About the Quecreek Mining Accident

Saxman Mine was the name of the mine that was breached. It was incorrectly thought that this mine was 300 feet from where it actually was located. Breaching an abandoned mine does not usually result in any serious problems, but in this case it did, since the Saxman Mine had been abandoned decades earlier, and as a consequence had filled with water. It is estimated that the nine miners trapped in the Quecreek Mine were trapped by between 50-60 million gallons of water that poured in from the Saxman Mine.

Fortunately, one of the trapped miners was able to phone another group of miners to warn them that the mine was flooding. This other group of nine miners was able to escape and alert officials.

Initial efforts were directed towards helping the miners survive until a rescue could be attempted. A hole was drilled into the pocket were the trapped miners had gone in order to escape the water. Warm air was pumped into this pocket to push back the cold water threatening to engulf them.

Then the drilling of a rescue shaft was begun. It was originally estimated that this could be accomplished in about eighteen hours, but when the drill bit broke, a delay ensued as everyone had to wait for a replacement to be brought in. For a time things did not look good, as no sounds could be heard coming from the trapped miners. But more sensitive seismic equipment later determined that sounds were still emanating from the location where the miners were trapped.

At 10:15 pm on Sat., July 27th the drill broke through to the mine. Food and a telephone were lowered to the miners. The drill bit was removed and a rescue capsule lowered. At 12:50 am the first miner was rescued. The miners selected the order in which they would be removed, one at a time, in intervals of about 10-15 minutes. By 2:44 am the last had been rescued. The rescuers had been spurred on during their exhausting effort by the slogan “Nine for nine.”

As would be expected, an extensive twelve-month investigation into the causes of the July, 2002 Quecreek mining accident was undertaken by the Pennsylvania Department of Environmental Protection. The accident highlighted some of the shortcomings that existed in the state’s mining policies and procedures related to underground mine safety. The final report made twenty-six recommendations.

Perhaps the key finding, as pointed out in the article, was the following. In order to open a mine, a permit must be granted. Unfortunately, the maps provided to the DEP as part of the application process were inaccurate. But because there was no requirement that maps be certified, a permit was granted in 1998.

The investigation uncovered maps that were more recent than the ones submitted with the application, but even these maps did not appear to accurately reveal the full extent and location of the abandoned mine that was accidentally breached. No evidence was ever found indicating that the mine operator or superintendent knew that the maps used were inaccurate.

To help prevent similar accidents from occurring in the future, an administrative order was issued to all mines operating near any known abandoned mine that credible evidence be provided, either in the form of accurate maps, drilling, or other means, of the location of any abandoned mines. In addition, the DEP embarked on an intense and widespread effort to catalogue and electronically scan thousands of maps to produce a database that would help locate any mine voids.

Extensive information regarding the investigation and recommendations can be found at:
http://www.dep.state.pa.us/dep/deputate/minres/dms/website/accidents/quecreek/

and an excellent site for additional information about the rescue efforts, individual miners and rescuers and photos is:

http://www.pahighways.com/features/quecreek.html

A bit about the history and significance of coal

Coal represents one of man's earliest sources of both light and heat. We know that coal was dug from the earth by the Chinese at least 3,000 years ago.

The first recorded discovery of coal in the United States dates back to 1674 and French explorers on the Illinois River, who reported the discovery of *charbon de terra*. Coal was discovered in 1701 near Richmond, Virginia, and the first recorded commercial mining took place there in 1750. Soon afterward coal was reported in Pennsylvania, Ohio, Kentucky, and West Virginia. The importance of coal quickly grew, and for the hundred year period from 1850-1950 it was the most important fuel in the United States. Without coal, the rapid industrial growth in the United States would not have been possible. Railroad cars powered by coal moved raw materials, goods, and people.

But other sources of energy such as oil and natural gas are easier to store and move. As the price of these fuels decreased, they began to replace coal in railroad transportation, home heating, and some industrial applications. In addition, nuclear power began to emerge as a source of energy with which to produce electricity.

But these sources of energy also carried problems. The oil embargoes that occurred during the 1970s caused prices to surge and exposed the difficulties connected to foreign energy dependence. The costs associated with nuclear power also rose, as did problems associated with the disposal of the nuclear waste produced by these power plants. So rather than fading into oblivion, coal continues to represent a significant energy source.

It is estimated that coal represents about 80% of the recoverable fossil fuels in the United States, and at the current rate of use there remains a 250-300 year supply. Today coal still is used to generate more than half of the electric power produced in the United States.

How coal is formed

Like oil and natural gas, coal is called a "fossil fuel" because it was formed from the remains of vegetation over a period of a few hundred million years. The oldest coal is perhaps about 400 million years old, the youngest perhaps only about one million, but the majority of coal dates back to plants that died about 300 million years ago, when much of the earth was covered by steamy swamps.

As plants died, they sank to the bottom of these swamps. Layer after layer were deposited, forming a material called peat. Later, seas and rivers deposited sand, clay and other materials on top of this peat. Even later sandstone and other sedimentary rocks were formed. These rocks exerted great pressure on the peat, squeezing out water. As this peat underwent even deeper burial and was subjected to great pressure and heat, it changed into the material we call coal. It is estimated that it took between 3-7 ft. of compacted plant material to produce 1 foot of bituminous coal.

Types of coal

There are four basic types of coal.

Anthracite: This has the highest carbon content, between 86%-98%, and thus is considered to be the highest quality of coal. It produces the greatest amount of heat, about 15,000 BTU/lb. It is found primarily in eleven northeastern counties

in Pennsylvania. Most often used to heat homes, it now represents a very small segment of the U.S. coal market. There are bout 7.3 billion tons of anthracite reserves in the United States.

Bituminous: This is the most plentiful type of coal. It has a carbon content of between 46%-86%, and produces about 10,500-15,500 BTU/lb. Its primary uses are to produce electricity and make coke for steel.

Subbituminous: About 35%-45% carbon, producing between 8,300-13,000 BTUs/lb. Because it generally contains less sulfur, it is considered cleaner burning. It is found mainly in Western states and Alaska.

Lignite: This is sometimes called "brown coal," since it contains the lowest amount of carbon, between 25%-35%, and has a heat content of between 4,000-8,000 BTUs/lb. It is primarily used to generate electricity.

Some history and statistics about coal mining

Coal is actually mined in twenty-seven different states, and found in even more. Perhaps surprisingly, Montana actually contains the greatest amount of coal reserves, about 120 billion tons, representing a bit over one-fourth of known reserves. Illinois is second, with 78 billion tons and 16.5% of known reserves. Although Wyoming ranks third in known reserves, it actually ranks 1st in production, accounting for about 18% of annual production.

Coal reserves in the United States are estimated to contain about twelve times as much total energy as the oil reserves of Saudi Arabia. There are about 1.7 trillion tons of identified coal resources. Because it is assumed that more coal deposits will be discovered in the future, geologists estimate that the total amount of reserves may be about 4 trillion tons. Because of quality considerations and mining difficulties, perhaps 470 billion tons of coal are potentially recoverable with current techniques and at the current market.

The United States exports about 10% of the coal that is mined.

More about coal mining

Although most of us probably think of deep mines when we think of coal mining, in fact, about 60% of coal mined in the United States today comes from surface mines. Most deep mining is done east of the Mississippi, especially in the Appalachian mountain states. Surface mining is most prominent in the western United States.

A fairly thorough description of different mining techniques can be found at:

http://www.ket.org/Trips/Coal/AGSMM/agsmmproduced.html

What was it like to be a coal miner in the early 20th century?

There is an excellent description at:

http://www.history.ohio-state.edu/projects/coal/LifeOfCoalMiner/LifeofaCoalMiner.htm

Here is one small excerpt. The date is 1902.

> *His dangers are many. He may be crushed to death at any time by the falling roof, burned to death by the exploding gas, or blown to pieces by a premature blast. So dangerous is his work that he is disbarred from all ordinary life insurance. In no part of the country will you find so many crippled boys and broken down men. During the last thirty years over 20,000 men and boys have*

been killed and 25,000 have been injured in this industry. Not many old men are found in the mines. The average age of those killed is 32.

A few statistics about current coal demand and usage

During 2000, 1.08 billion tons of coal were consumed in the United States, of which 91.0% were used to generate 51.8% of the electricity used. Each ton of coal produces about 2,000 kilowatt-hours of electricity. A pound of coal supplies enough electricity to light ten 100-watt bulbs for about an hour.

The second largest use of coal was for industrial purposes—about 65.52 million tons.

The United States actually imports about 12.5 million tons of coal even though we export about three times as much. Imports represent less than 1% of U.S. consumption and primarily consist of low-sulfur coal.

More about "black lung" disease

"Black lung" is actually more of a legal term referring to any man-made occupational disease caused by the prolonged breathing of coal mine dust. It sometimes is called miner's asthma, silicosis, coal workers' pneumoconiosis or even *pneumonoultramicroscopicsilicovolcanoconiosis*. When mine dust is breathed, only the smallest particles make it past the protective defenses of the nose, mouth, and throat and reach the alveoli deep in the lungs. There they are picked up by a type of blood cell called a microphage. These microphages carry them to where they can be coughed out or swallowed. This is a good defense, but if too much dust is inhaled over too long a period of time, some particles and dust-laden microphages collect permanently in the lungs. Although the disease was observed in miners for years, and first referred to as asthma, it wasn't until 1831 that the term "black lung" was coined.

Although there were efforts to publicize the problem, and despite the widespread incidence of this devastating disease amongst coal miners, little was done to prevent its occurrence. Indeed, some medical representatives from the coal industry claimed that it was actually beneficial, since inducing coughing would dislodge silica from the lungs. The United Mine Workers sought to secure corrective legislation, but achieved little success. It wasn't until 1952 that Alabama became the first state to provide compensation for coal workers' pneumoconiosis. A few years later Virginia recognized the disease as one meriting compensation, but within a year the amendment was repealed. Pennsylvania enacted legislation requiring compensation in 1965.

Sometimes it takes a tragedy to move things, and that tragedy occurred on November 20, 1968 in the form of a terrible coal mine explosion at Farmington, West Virginia that resulted in the deaths of 78 coal miners. The resulting public outrage at mine conditions spread to include the problem of black lung disease, and in 1969 the United States Congress ordered that it should be eradicated from the industry. Nevertheless, it is estimated that several hundred coal miners still die from the diseases each year. There are widespread reports of cheating on inspections and other failures to enforce the existing laws. It is still an issue. In 1997, the U.S. Department of Labor issued proposed regulations that would amend the process by which miners stricken with black lung disease could apply for benefits. So much debate ensued that the final rules weren't published until Dec. 20, 2000. They were scheduled to go into effect on Jan. 19, 2001. On Dec. 22, 2000, the National Mining Association filed a lawsuit challenging the new regulations.

Methane emissions from coal mines

When vegetation is converted to coal, it is always accompanied by the production of methane, CH_4. When this coal is mined, this entrapped methane is released. The United States Environmental Protection Agency (EPA) estimates that emissions of methane from coal mines amounts to about 185-325 billion cubic feet every year, and emissions from other parts of the world are thought to be several times this amount. Many experts consider this to be a significant source of greenhouse gases.

Methane forms an explosive mixture with air when it ranges in concentration from about 5%-15%. It therefore must be removed from a mine to prevent such explosions. The most common method of doing this is to force very large quantities of ventilation air into the mine to keep the concentration below the 5% level—typically a level of 2% or less is sought. Another technique sometimes employed is to drill wells into the coal seam even before mining is begun to extract much of the methane in advance. The extracted methane is often of high enough quality that it can be sold if there is an existing pipeline located near the mine. Sometimes it can be used as fuel.

Connections to Chemistry Concepts

The energy content of coal is often expressed in BTU/lb. BTU stands for "British Thermal Unit." Conceptually, it is a unit similar to the calorie. It is the amount of energy needed to raise the temperature of one pound of water by one Fahrenheit degree. Since one pound represents 453.6 grams and one Fahrenheit degree is 5/9 of a Celsius degree,

1 BTU = (453.6)(5/9) = 252 calories, or

1 BTU = 1 lb. $H_2O \cdot {}^{o}F$ (453.6 g H_2O/lb. H_2O) (5 ${}^{o}C$/9 ${}^{o}F$) = 252 g $H_2O \cdot {}^{o}C$ = 252 calories

The article mentions that acid mine drainage can cause environmental problems due to its high acidity, and this acidity is often linked to the presence of pyrite, FeS_2. Pyrite is often referred to as "fools gold," because it is a brassy yellow mineral that can easily be mistaken for a mineral that contains gold. When pyrite deposits are exposed to the atmosphere they can undergo oxidation and interaction with moisture to produce the acidity associated with acid mine drainage, as illustrated by the following equation:

$$2\ FeS_2(s) + 7\ O_2(g) + 2\ H_2O \text{ -----> } 2\ FeSO_4 + 2\ H_2SO_4$$

Possible Student Misconceptions

There are a number of very understandable misconceptions that students may have about coal and issues connected to it. Among them might be included:

All coal is mined deep underground.
In fact, about 60% of coal mined in the United States comes from surface mines.

Black Lung disease has been eradicated.
It is estimated that even today several hundred miners die as a result of these diseases.

Most mined coal comes from Appalachia.
Actually Wyoming produces the greatest amount of coal and Montana contains the greatest reserves.

Like oil, coal is a dwindling resource.
It is estimated that there are enough coal reserves in the United States to last 250-300 years at the current rate of usage. Additional discoveries could extend that even further.

Coal is an outdated resource rarely used today.
During 2000, 1.08 billion tons of coal were consumed in the United States, of which 91.0% were used to generate 51.8% of the electricity used.

Demonstrations and Lessons

1. What should be the future role of coal in providing energy to fuel our economy? This is a highly debatable and often emotional issue. On the one hand, coal is our most abundant energy resource. Increasing the use of coal could relieve the United States from some of its dependence on foreign sources of oil. On the other hand, coal has been associated with environmental issues such as global warming, air pollution, and acid rain. But there are problems with the use of nuclear power as well, and modern technology can help reduce some coal-connected environmental issues. But can they reduce them enough, and can we count on industry or government to actually do what may be possible?

Properly done, with an emphasis on good preparation as opposed to "opinion before knowledge," a debate could make for a highly valuable educational experience if time permits. After an initial polling of student opinion (based, perhaps on limited knowledge), students could either be allowed to choose their position (best) or assigned a position (if necessary) and then the debate held at some future date with points being assigned to the amount and quality of science and other information that is brought to the floor. Videotaping the debate might produce a truly outstanding example of what good education is all about.

2. Since the major use of coal is to produce energy by burning, this would tie in nicely with a heat of combustion lab experiment, perhaps of a candle or a food snack. Directions for running either of these labs can be found in the fourth edition of *Chemistry in the Community*.

Connections to the Chemistry Curriculum

This article connects nicely into the general topic of energy, and also to several environmental issues. As such, it could provide the base for a discussion of any or all of the following topics:

Energy and everything connected to it
Acid rain
Air Pollution
Global warming and the greenhouse effect
Renewable and nonrenewable resources
The "hydrogen economy"
Wind power
Nuclear power—promise and problems

Suggestions for Student Projects

1. Since the use of coal is associated with environmental issues such as air pollution, acid rain and the greenhouse effect, this article can provide a link to several possible reports that students might prepare. Some of these possibilities include:

   Air pollution. To what extent is the burning of coal responsible? Can modern technology reduce or eliminate this problem so that coal can (and perhaps should) assume a larger role in satisfying our nation's energy needs?

   The greenhouse effect. Is this effect real, and if so, how much can be linked to the burning of coal? Is it something that we should really be concerned about, and if so, how should the problem be addressed?

   Acid rain. What is it? How does it arise? What damage does it cause? It is a serious problem? To what extent is the burning of coal responsible? What can be done to reduce or eliminate it?

   Alternative energy sources—renewable, wind, solar, etc. Is a switch to a "hydrogen economy" a practical solution?

2. “Black lung” disease refers to any disease caused by inhaling coal dust (see *Background Information*). Students could report on this disease, what it is, what causes it, what is being done to prevent it, and the current state of both legislation and its enforcement. Black lung still kills miners every year. How and why does this occur?

3. Sir Humphrey Davy is mentioned in another article contained in this issue in connection with the discovery of nitrous oxide, “laughing gas,” as an anesthesia. Davy was also the inventor of the Flame Safety Lamp in 1816. This ingenious device allowed miners to carry a flame into a mine without fearing that the flame might ignite any methane present in the mine’s atmosphere. How did this work? Students could prepare a report on the design of this lamp and the relatively simple scientific principles that underlie its operation.

Anticipating Student Questions

1. Is coal still used much?

   Absolutely. While its use to heat homes has clearly declined to almost nothing, it is still widely used to generate electricity. In fact, more than half the electricity generated in the United States is produced by burning coal.

2. Are there still cases of black lung disease?

   Yes. Despite legislation and improved conditions in the mines, it is estimated that black lung disease still causes several hundred deaths of miners every year.

3. How does iron pyrite cause mine drainage to become acidic?

   See *Connections to Chemistry Concepts*.

Websites for Additional Information and Ideas

The American Coal Foundation provides free educational materials to teachers and students about coal, electricity and other issues associated with the coal industry. It will also send, free of charge, samples of peat, lignite, bituminous, and anthracite coal.

http://www.ket.org/trips/coal/acf.html

A nice time-line of Coal Milestones can be found at:
http://www.eia.doe.gov/kids/milestones/coal.html

Some images of early coal miners can be found at:
http://www.history.ohio-state.edu/projects/coal/LifeOfCoalMiner/coalpics.htm

More information about methanometers can be found at:
http://www.methanometer.com