2. *Coal's Life Cycle*

Although people have burned coal for hundreds of years, the demand for coal exploded during the industrial revolution. Initially, coal powered the steam engine and therefore became the essential fuel for transportation during the nineteenth century, when steamships and railroads flourished. By fueling the steam shovel, coal became the vehicle for its own excavation. By the middle of the 1800s, coal replaced charcoal in the production of iron and steel, thus filling another key role in driving industrialization. Coal became a source of energy for the generation of electricity at the end of the 1800s.

Oil eventually replaced coal as the fuel of choice in the transportation industry. However, coal has once again become the dominant source of energy for the generation of electricity. Because more than 25% of the world's recoverable coal reserves are in the U.S. and because it is cheap, there has been a recent resurgence of coal as an energy source among utilities.[1] This modern coal boom is exemplified by the dozens of new coal plants currently in the planning or construction stage.

Today coal is the predominant source of energy used to produce electricity. Almost half of the energy used to generate electricity in the U.S. in 2007 came from coal, mined in such states as Wyoming, West Virginia, Kentucky, and Pennsylvania.[2] In addition to its major role in the generation of electricity, large amounts of coal are used by the steel industry. According to the World Coal Institute,

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almost 70% of global steel production is dependent on coal.[3]

Coal is formed from fossilized prehistoric plants subjected to heat and pressure over millions of years. Coal is classified into four main types, or ranks, based on moisture and carbon content: lignite, sub-bituminous, bituminous, and anthracite (see Table 2.1). High-carbon coals produce the most energy when burned and low-carbon coals produce the least. Lignite is the lowest rank of coal, having the highest moisture content and the lowest energy content. Sub-bituminous coal is the next highest rank, with a lower moisture content and higher carbon content than lignite. Harder, black coals are higher in rank and include bituminous coal, the most abundant form of coal in the U.S., and anthracite, the hardest, richest in carbon and the rarest. Impurities such as sulfur and heavy

Table 2.1: The ranks of coal

Rank	Appearance	Percent carbon content	Uses	Percent of world reserves	Percent of U.S. production	Largest U.S. producers
Lignite	Brown, soft, flaky	25–35	Power generation	17	7	Texas, North Dakota
Sub-bituminous	Brownish-black, soft	35–45	Power generation, cement manufacture, industrial uses	30	44	Wyoming (Powder River Basin)
Bituminous	Black, hard	45–86	Power generation, cement manufacture, industrial uses	52	49	West Virginia, Kentucky, Pennsylvania
Anthracite	Black, hard, glossy	86–97	Domestic/industrial uses	1	Less than 0.5	Pennsylvania

metals are incorporated into coals as they are formed and are released when coals are burned or cleaned.

Electricity generation provides many benefits worldwide, and is synonymous with economic development, higher standards of living, and increased life expectancy.[4] However there are major health costs associated with the use of coal. Detrimental health effects are associated with every aspect of its life cycle, including mining, hauling, preparation at the power plant, combustion, and the disposition of post-combustion wastes. This section reviews in brief the human health effects of coal's life cycle.

MINING

Coal is extracted from underground and surface mines. The two main types of underground mines in the U.S. are longwall mines and room-and-pillar mines. In longwall mines, long sections of coal are removed without the use of supporting structures. This may lead to the subsidence of the land above. In room-and-pillar mines, sections of rock are not excavated (the "pillars") in order to provide structural support for the adjoining areas where all the coal is removed (the "rooms"). Both types of mines involve excavating shafts hundreds of feet deep, the installation of elevators, massive conveyance machinery, and air circulation technology.

Surface mining accounts for 69% of the coal mined in the U.S.[5] Used when the coal seam is close to the surface (less than 200 feet deep), it is cheaper than underground mining and often high-yield. In this method, vegetation, topsoil, and rock are blasted and removed down to the level of the coal seam, which is then mined. The top ten coal-producing mines in the U.S. are surface mines in the Powder River Basin of Wyoming.[6] "Mountaintop removal" is the name given to another type of surface mining, used to reach coal seams in mountainous terrain. It involves blasting down to the level of the coal seam—often hundreds of feet below the surface—and depositing the resulting rubble in adjoining valleys.

Coal mining leads U.S. industries in fatal injuries.[7] According to the National Institute for Occupational Safety and Health, the 2006 fatality rate in coal mining was 49.5 per 100,000 workers, more than 11 times greater than that in all private industry (4.2 per 100,000).[8] There were 47 occupational fatalities in coal mining in 2006, 34 in 2007, and 30 in 2008.[9] Underground coal mining is more dangerous than surface mining. Of 47 coal mining fatalities in 2006, 37 occurred in underground mining operations. The nonfatal injury rate in mining, of 3.9 per 100 full time workers in 2001, compares favorably to other private sector workers, where the average incidence rate of nonfatal injury was 5.4 in 2001.[10]

Coal mining is also associated with chronic health problems among miners. Black lung disease is caused by inhalation of respirable coal mine dust, which causes lung tissue scarring.

Although technology and prevention strategies have improved incidence and mortality rates in the past century, black lung disease still disables large numbers of ex-miners and claims many lives each year.[11] According to the National Institute of Occupational Safety and Health, black lung disease has been responsible for approximately 10,000 deaths in the past 10 years.

In addition to the miners themselves, communities proximate to coal mines may be adversely affected by mining operations. Injuries and even deaths may result from physical damage to surrounding communities due to blasting at surface mines and subsidence of underground mines. Surface mining also destroys forests and groundcover, leading to flood-related injury and mortality, as well as soil erosion and the contamination of water supplies. Rubble, or "overburden," is deposited on the surface, destroying plants and animals and introducing into the food web trace minerals and metals once deeply buried. One study of West Virginians found that people living in high coal-producing counties had higher rates of cardiopulmonary disease, chronic obstructive pulmonary disease, hypertension, lung disease, and kidney disease compared to people living in low coal-producing counties,[12] raising the possibility that coal mining operations may exacerbate a range of chronic health conditions among people living in nearby communities.

Coal mining operations may exacerbate a range of chronic health conditions among people living in nearby communities.

Flooding and contamination of water supplies are of particular concern in Appalachia, where mountaintop removal mining is widespread. The Environmental Protection Agency estimated in 2005 that mountaintop removal mining had adversely impacted 1,200 miles of streams in a study area that included parts of Kentucky, West Virginia, Virginia, and Tennessee. These 1,200 miles represented 2% of streams in the study area. The study further concluded that 724 miles of streams had been directly buried by valley fill related to mountaintop removal mining through 2001.[13] There are no official current estimates of the extent of the practice, but one advocacy organization estimated that by 2005, more than 450 mountain summits had been destroyed by mountaintop removal mining.[14] The human health effects of burying streams under piles of rubble have not been quantified, but include flood-related injury and mortality and contamination of drinking water and surface water resources with arsenic and other pollutants.[15]

After removal of coal from a mine, threats to public health persist. When mines are abandoned, rainwater reacts with exposed rock to cause the oxidation of metal sulfide minerals. These reactions generate acid and release contaminants such as heavy metals into the surrounding water system.[16] Red, orange, or yellow sediments in streams near abandoned mines are markers for this acidic mine drainage. The degraded water resulting from acid mine drainage renders the water undrinkable, and can corrode culverts and bridges.[17]

WASHING AND TRANSPORT

Coal is usually washed before it is transported to power plants to separate it from soil and rock impurities. Washing uses polymer chemicals and large quantities of water, and creates a liquid waste called slurry or sludge that must be stored. The slurry is the consistency of cement, and in addition to water, mud, and polymer chemicals, it contains heavy metals such as arsenic and mercury that are common in mined rock. Mine operators construct dams to impound the slurry in ponds, or inject it back into closed mines. Both slurry disposal strategies—the construction of surface impoundments and underground injection into closed mines—may leach chemicals into groundwater supplies. This is an aspect of mining that has not been examined closely.[18] In addition, both of these waste storage strategies can leak or break. Impoundment failures in the past have caused death and injury, including the 1972 Buffalo Creek, West Virginia, impoundment failure that killed 125 people and injured 1,000. More recently, an impoundment breach in 2000 of about 250 million gallons of slurry near Inez, Kentucky, disrupted local water supplies but did not cause injuries or deaths.[19] Slurry injected underground into old mine shafts has the potential to release arsenic, barium, lead, and manganese into nearby wells, contaminating local water supplies.

Once coal is mined and washed, it must be transported to power plants. Coal is hauled to plants by train, truck, barge, and conveyor. Trains are the most economical way to move coal long distances and play the largest role in coal transport. In 2005, railroads accounted for 70% of coal shipments to power plants.[20] Together, railroad engines and trucks release over 600,000 tons of nitrogen oxide and 50,000 tons of particulate matter into the air every year in the process of hauling coal,[21] largely through diesel exhaust. Diesel engines currently produce approximately 1.8 million tons of NOx and 63,000 tons of small particles (less than 2.5 microns in diameter) each year.[22] These emissions adversely impact many organ systems, as this report will detail. Coal trains and trucks also release coal dust into the air as they move, degrading air quality and exposing nearby communities to dust inhalation.[23]

COMBUSTION

It is during the combustion phase of coal's lifecycle that our dependence on coal energy exacts the greatest toll on human health. Coal combustion releases over 70 harmful chemicals into the environment and contributes significantly to global warming (see Table 2.2). This section describes the pollutants emitted by coal combustion.

Coal combustion creates both solid and gaseous byproducts. Gas byproducts are emitted into the atmosphere through smokestacks. Some solids go into the atmosphere as well. Other solids are left behind at the plant as solid waste, also called coal ash. Some of the pollutants entering the air stay in the atmosphere for long periods; others fall to the earth and in turn pollute soil and water bodies. Some substances are not directly harmful but undergo chemical reactions in the atmosphere that create harmful secondary pollutants.

The pollutant composition of coal varies according to the geologic conditions of its formation. For example, plants that once lived and died in sea water formed coal with high sulfur content, while plants buried under fresh water formed low-sulfur coal. Thus, coals from different ranks and even from different mines differ not only in heat production and carbon content but also in pollutant composition. Such differences may affect local air quality concerns, as power plants may produce different pollution emissions depending on which coals are being burned.[24]

Notwithstanding local differences in pollutant composition, coal combustion causes pollution nationwide. Though coal supplies roughly 50% of the nation's electricity, it produces a disproportionate share of electric utility-related pollution. Coal plants emit approximately 87% of total utility-related nitrogen oxide pollution, 94% of utility-related sulfur dioxide pollution, and 98% of all utility-related mercury pollution.[25] Even across economic sectors, coal plants are responsible for a large share of human-caused air pollution: they are the single largest source of sulfur dioxide, mercury, and air toxic emissions and the second largest source of nitrogen oxide pollution.[26,27] Coal combustion is also responsible for more than 30% of total U.S. carbon dioxide pollution, contributing significantly to global warming.

Criteria air pollutants are a class of ubiquitous, harmful pollutants designated under the Clean Air Act. They are the only pollutants for which the EPA sets legal limits, called the National Ambient Air Quality Standards, on the amounts allowed in ambient air. These standards are based on health risk considerations. There are six criteria pollutants: nitrogen oxides, ozone, sulfur oxides, particulate matter, lead, and carbon monoxide. Coal combustion produces significant quantities of nitrogen oxides, sulfur oxides, and particulate matter, and contributes to the production of ground-level ozone.

Coal-fired power plants are second only to automobiles as the largest source of nitrogen oxide

Table 2.2: The health effects of power plant pollutants

Pollutant	What is it?	How is it produced?	Health effects	Most vulnerable populations
Ozone	Ozone is a highly corrosive, invisible gas	Ozone is formed when nitrogen oxides (NOx) react with other pollutants in the presence of sunlight.	Rapid shallow breathing, airway irritation, coughing, wheezing, shortness of breath. Makes asthma worse. May be related to premature birth, cardiac birth defects, low birth weight, and stunted lung growth.	Children, elderly, people with asthma or other respiratory disease. People who exercise outdoors.
Sulfur Dioxide (SO_2)	SO_2 is a highly corrosive, invisible gas. Sulfur occurs naturally in coal.	SO_2 is formed in the gases when coal is burned. SO_2 reacts in the air to form sulfuric acid, sulfates, and in combination with NO_x, acidic particles.	Coughing, wheezing, shortness of breath, nasal congestion and inflammation. Makes asthma worse. SO_2 gas can destabilize heart rhythms. Low birth weight, increased risk of infant death.	Children and adults with asthma or other respiratory disease.
Particulate Matter (PM)	A mixture of small solid particles (soot) and tiny sulfuric acid droplets. Small particles are complex and harmful mixtures of sulfur, nitrogen, carbon, acids, metals, and airborne toxics.	Directly emitted from coal burning. Formed from SO_2 and NO_x in the atmosphere.	PM crosses from the lung into the bloodstream resulting in inflammation of the cardiac system, a root cause of cardiac disease including heart attack and stroke leading to premature death. PM exposure is also linked to low birth weight, premature birth, chronic airway obstruction and remodeling, and sudden infant death.	Elderly, children, people with asthma.
Nitrogen Oxides (NO_x)	A family of chemical compounds including nitrogen oxide and nitrogen dioxide. Nitrogen occurs naturally in coal.	NO_x is formed when coal is burned. In the atmosphere can convert to nitrates and form fine acidic particles. Reacts in the presence of sunlight to form ozone smog.	NO_x decreases lung function and is associated with respiratory disease in children. Converts to ozone and acidic PM particles in the atmosphere.	Elderly, children, people with asthma.
Mercury	A metal that occurs naturally in coal.	Mercury is released when coal is burned.	Developmental effects in babies that are born to mothers who ate contaminated fish while pregnant. Poor performance on tests of the nervous system and learning. In adults, may affect blood pressure regulation and heart rate.	Fetuses and children are directly at risk. Pregnant women, children, and women of childbearing age need to avoid mercury exposure.
Carbon Dioxide	Coal has the highest carbon content of any fossil fuel.	Carbon dioxide is formed when coal is burned.	Indirect health effects associate with climate change including the spread of infectious disease, higher atmospheric ozone levels, and increased heat- and cold-related illnesses.	People of color, children, people with asthma.

Source: Clean Air Task Force. Cradle to grave: the environmental impacts of coal. June 2006.

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pollution, producing 18% of total U.S. nitrogen oxide emissions.[28] Nitrogen oxides are respiratory irritants.[29] They also pose a serious health risk as ozone precursors. Ground level ozone, also known as smog, is formed when nitrogen oxides react with volatile organic compounds in the presence of heat and sunlight. According to the American Lung Association, 175.4 million Americans live in counties with unhealthy ozone levels, representing more than half of the total U.S. population.[30] Ground level ozone is one of the nation's most pervasive air pollutants, and is particularly harmful to children and the elderly.

Sulfur occurs naturally in coal. Upon combustion, sulfur dioxide, a respiratory irritant, is emitted from coal plants and once in ambient air forms acid rain and particulate pollution. Coal-fired power plants are responsible for two thirds of the nation's sulfur dioxide emissions.[31]

Particle pollution is a complex combination of solids and aerosols suspended in the ambient air. It is categorized by researchers by size: PM_{10}, less than 10 microns in diameter, and $PM_{2.5}$, less than 2.5 microns in diameter. (By comparison, a human hair is about 70 microns in diameter.) Particle pollution is linked to asthma attacks as well as cellular inflammation, a risk factor for a range of chronic diseases. It has been estimated that coal plants in the U.S. will release 217,000 tons of PM_{10} and 110,000 tons of $PM_{2.5}$ in 2010.[32] These emissions estimates do not include secondary particle pollution, formed by the condensation of atmospheric gases such as oxides of nitrogen and sulfur with other pollutants, many of which are also released by coal plants.

The criteria pollutants produced by coal combustion carry large costs to society. The National Research Council has estimated the external costs associated with emissions of nitrogen oxides, sulfur dioxide, and PM from coal-fired power plants in the U.S. at $62 billion in 2005.[33]

In addition to the emissions of criteria pollutants, coal combustion is also a major source of Hazardous Air Pollutants (HAPs), a class of harmful pollutants for which emissions limits, as opposed to allowable ambient air levels, are set by the EPA. These emissions limits are dictated by the technologies available to control pollution instead of by health risk considerations. There are 189 HAPs designated under the Clean Air Act.

In EPA smokestack tests released in 1998, coal plants were found to emit 67 different HAPs, many of which are known or probable human carcinogens, neurotoxins that can harm brain development, and reproductive toxins. These 67 HAPs include arsenic, beryllium, cadmium, chromium, lead, manganese, mercury, nickel, hydrogen chloride, hydrogen fluoride, acrolein, dioxins, formaldehyde, and radionuclides.[34] Based on exposure and risk estimates, the EPA identified four coal-related HAPs as posing potential risks to human health: mercury, dioxins, arsenic, and nickel. Mercury is the HAP of greatest concern emitted through coal combustion, due to its impacts on the nervous system. In 2007, electric utilities were responsible for more than 70% of all mercury air emissions.[35] Almost all of this mercury came from coal combustion.

Table ES.1 (see pages x–xi) describes the major health effects linked to coal combustion emissions. These health effects damage the respiratory, cardiovascular, and nervous systems and contribute to four of the top five leading causes of death in the U.S.: heart disease, cancer, stroke, and chronic lower respiratory diseases. These health effects are discussed further in subsequent sections. Although it is difficult to ascertain the proportion of this disease burden that is attributable to coal pollutants, even very modest contributions to these major causes of death are likely to have large effects at the population level, given high incidence rates.

POST-COMBUSTION WASTES

Coal's health effects extend beyond combustion. The potential hazards posed by post-combustion wastes are not a new problem, but one that has received little attention. In 2007, in response to complaints by interest groups, the EPA surveyed a number of sites where coal ash slurry, the residue left after burning coal, is stored. It found that damage to human health or the environment was inflicted at nine of the sites and potential damage was present at another 25.[36] A subsequent risk assessment showed that toxic residues from coal ash storage sites had migrated into water supplies and threatened human health at approximately 24 sites.[37] Then in December, 2008, a spill of approximately one billion gallons of coal ash slurry in Tennessee inundated hundreds of acres and threatened to contaminate drinking water and waterways with toxic metals, including lead and arsenic. Thus, coal poses risks to health from the point it is extracted from the ground, through combustion, and even afterwards as a toxic waste.

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