



Scientific Evidence of Health Effects from Coal Use in Energy Generation

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APRIL 2013



The Health Care Research Collaborative was developed to meet a need expressed by hospital and health system executives for more research and data to assist them in their efforts to make more sustainable choices in health care design, construction, operations and organization. To fund this initiative, HCWH applied for and received seed funding from the Robert Wood Johnson Foundation. The Health Care Research Collaborative is based at the University of Illinois at Chicago School of Public Health with a mission to stimulate the development, coordination and dissemination of research focused on the impact of the health care built environment, operations and organization on patient, worker and environmental safety and sustainability. This interdisciplinary approach reflects the growing understanding among the leadership of health care providers that patient, provider, and community health and safety are profoundly interrelated.

The Research Collaborative has published a series of white papers that explore existing research and identify research gaps in a number of areas of health care safety and sustainability. It also develops original research projects and works closely with both the Healthier Hospitals Initiative, a group of hospitals that are leading the way on sustainability, and with Practice Greenhealth, a membership and networking organization engaged in sustainable health care.

More recently, the Research Collaborative has taken on a second field of inquiry -- that of evaluating the health impacts and healthcare costs of various energy generation choices in a diversity of countries. The Collaborative's Energy and Health Initiative has begun with a brief literature review of the health impacts of coal combustion. It will expand over time to explore this issue in depth and to address a series of other energy sources and engage a number of other academic and institutional partners.

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INTRODUCTION

Access to electricity has a positive effect on the health and well-being of people worldwide. However, the use of coal to generate energy has negative health consequences. There is evidence of coal's impact on human health during every stage of its use for electricity generation -- from mining to post-combustion disposal. In particular, the combustion of coal has been well-studied, with compelling evidence of widespread health effects on the population. Air pollution produced by coal combustion in power plants can affect the respiratory and cardiovascular systems as well as cause abnormal neurological development in children, poor growth of the fetus before birth, and can cause cancer. Coal used for heating and cooking indoors, generates pollutants in indoor air that are known to cause respiratory ailments and cancer. Moreover, coal combustion contributes to climate change, which can harm human health on a global scale.

This document includes scientific evidence of health effects from the use of coal for energy generation. Its aim is to serve as a resource for those interested in the evidence from the health research literature addressing the health effects of the use of coal, focusing primarily on air emissions from coal combustion. Biomedical research databases (Ovid Medline and PubMed) were searched for all articles using the search terms "coal or solid



fuel" and "health or burden or economic or cost". English language articles published in the last 10 years were exclusively included unless the article was of unique value. Articles examining coal use in power plants were prioritized for review, and exposures produced by alternative uses of coal were in general excluded. Background readings found on the Internet along with resources from industry and environmental non-governmental organizations were also reviewed, but were not used in this document. They are provided in the accompanying Additional Resources section. Citations are provided using a standard scientific format to aid those who may be interested in accessing full-text articles.

BACKGROUND

The use of coal to produce electricity has been shown to increase illness and death in the general population through air pollution. When coal is burned in power-plants -- to generate steam which spins turbines and creates electricity -- it produces air-borne pollutants of particulate matter, sulfur dioxide, oxides of nitrogen, carbon dioxide, mercury, arsenic, chromium, nickel, other heavy metals, acid gases (HCL, HF), hydrocarbons (PAHs) and varying levels of uranium and thorium in flyash.

In 2011 the World Health Organization (WHO) compiled air quality data from 1,100 cities in 91 countries and found that residents living in many urban areas are exposed to persistently elevated levels of fine particle pollution.⁽¹⁾ The report states, "In both developed and developing countries, the largest contributors to urban outdoor air pollution include motor transport, small-scale manufacturers and other industries, burning of biomass and coal for cooking and heating, as well as coal-fired power plants. Residential wood and coal burning for space heating is an important contributor to air pollution, especially in rural areas during colder months."⁽¹⁾

Before coal can be used in power plants, it first must be mined, washed, and transported. After being burned in power plants, the remaining ash must be stored or disposed

of. Each of these steps in the coal life cycle, in addition to coal combustion, generates pollution. In the mining of coal, excess oil and slurry from the washing process contains hazardous substances such as heavy metals that can leach out of storage containers or in-fill, contaminating surface and ground water. After being washed, coal is transported from mines to power-plants via train, truck, ship, or barge. Diesel emissions from coal transport can be a significant contribution to local air pollution. After combustion, some coal ash is recycled into cement and other engineering products, but most of it is disposed of in dry or wet landfills. Landfills that leak flyash waste can contaminate ground and surface water with arsenic, cadmium, barium, thallium, selenium, and lead.

In the vicinity of coal fired power plants, exposure to emissions depends on factors such as weather (temperature, precipitation, wind-direction and speed) and topographical features of the local area. Emissions can also be transported long distances, even globally, causing health effects to those living far from power plants. Individual susceptibility to the health effects of coal emissions depends on age, underlying medical conditions, and use of medications. Populations that are especially vulnerable to health effects from air pollution include children, the elderly, pregnant women, and people with lung conditions like asthma and chronic obstructive pulmonary disease.

HEALTH EFFECTS FROM COAL-FIRED POWER PLANTS

Forty percent of the electricity produced in the world is generated from the combustion of coal, and the number of power plants burning coal is likely to rise in the next two decades as world-wide energy demand increases.^(2,3) The World Resources Institute estimates that, globally, approximately 1,200 new power plants are currently proposed, with 76 percent of the new capacity proposed in China and India.⁽⁴⁾

The 'external costs' of electricity generation from coal are the burdens to society that are not included in the electricity's monetary price. Estimates of the external costs of electricity generation from coal suggest that 95% of the external cost consists of the adverse health effects on the population.^(5,6) Most of coal's health burden results from its combustion in power plants, with the rest of

the health burden consisting of the effects caused from the other steps of coal's life cycle.^(5,6)

A 2007 article published in the medical journal, *The Lancet*, summarizes the burden of the health effects of generating electricity from coal and lignite (a type of coal). The authors estimate that for every TWh (Terawatt-hour) of electricity produced from coal in Europe, there are 24.5 deaths, 225 serious illnesses including hospital admissions, congestive heart failure and chronic bronchitis, and 13,288 minor illnesses.⁽⁷⁾ When lignite, the softest and most polluting form of coal, is used, each TWh of electricity produced results in 32.6 deaths, 298 serious illnesses, and 17,676 minor illnesses.⁽⁷⁾ The table below summarizes this information.



Forty percent of world electricity comes from coal combustion.



AIR POLLUTION-RELATED EFFECTS OF COAL AND LIGNITE COMBUSTION IN EUROPE Deaths/Cases per TWh

	DEATHS	SERIOUS ILLNESS	MINOR ILLNESS
Lignite	32.6 (8.2-130)	298 (74.6-1193)	17,676 (4,419-70,704)
Coal	24.5 (6.1-98.0)	225 (56.2-899)	13,288 (3,322-53,150)

Extracted from Markandya, Wilkinson; "Electricity generation and health", published in *The Lancet* September 15, 2007.⁽⁷⁾ Figures do not include the contribution to death and illness from climate change.

() is 95% Confidence Interval. Serious Illness column includes: "respiratory and cerebrovascular hospital admissions, congestive heart failure, and chronic bronchitis." Minor Illnesses column includes: "restricted activity days, bronchodilator use cases, cough, and lower-respiratory symptoms days in patients with asthma."⁽⁷⁾

According to a report from the International Energy Agency⁽³⁾, world-wide coal-based energy production was 8,572 TWh in 2010. Using the health effects per TWh estimates in *The Lancet* article, the worldwide health toll from air pollution due to coal combustion is 210,000 deaths, almost 2 million serious illnesses, and over 151 million minor illnesses per year, not including the effects of climate change. This calculation is based on European pollution standards and population density. In countries with fewer air pollution standards, higher use of coal, or poorer quality coal, the health burden is even greater. For example, a study in China, the results of which were reported in Markandya in 2007⁽⁷⁾, estimated 77 deaths per TWh from a coal-fired power plant that met Chinese environmental standards.⁽⁷⁾ This is over three times the estimate of deaths per TWh of coal combustion in Europe, and would result in an estimated 250,000 deaths per year in China, based on estimates of coal combustion in China.⁽³⁾

Respiratory Effects

Specific pollutants from burning coal that cause a negative health effect on the respiratory system include particulate matter (PM), sulfur dioxide (SO₂), and oxides of nitrogen such as NO₂. The mechanism injury to the airways and lungs via damage to cells caused by oxidizing molecules in pollutants. This leads to inflammation, cytotoxicity, and cell death.

Particulate Matter

Particulate matter is generated from the combustion of coal and is characterized by size -- small particles less than 2.5 micrometers (PM_{2.5}) and larger particles up to 10 micrometers (PM₁₀). PM_{2.5} travels deeper into the airways than PM₁₀ and is therefore

Coal combustion in China's power plants causes an estimated 250,000 deaths per year



generally believed to cause a greater threat to human health. A study of various powerplant emissions in China found that of total particulate matter emitted, PM₁₀ comprised 62-84% and PM_{2.5} comprised 8-44%.⁽⁸⁾

In a report evaluating over 40 studies on the health effects of exposure to small particulate matter (PM_{2.5}), the U.S. Environmental Protection Agency concluded that PM_{2.5} likely causes respiratory symptoms, the development of asthma, and decrements in lung function in children.⁽⁹⁾ Findings from the review conclude that a 10 µg/m³ increase in PM_{2.5} is associated with a 1% to 3.4% decrease in FEV₁, a measure of lung function, in asthmatic children.⁽⁹⁾

It also concluded that exposure to PM_{2.5} increases emergency department visits and hospital admissions for respiratory related symptoms such as infections and chronic obstructive pulmonary disease. Epidemiological evidence from Australia and New Zealand⁽¹⁰⁾, Mexico⁽¹¹⁾, Canada⁽¹²⁾, and Europe⁽¹³⁾ confirm that these health effects on the respiratory system are seen around the globe among communities exposed to PM_{2.5}. In addition to respiratory illnesses, long-term exposure to PM_{2.5} is causally linked to the development of lung-cancer.⁽⁹⁾

Sulfur Dioxide

Exposure to sulfur dioxide (SO₂) emitted by coal burning power plants increases the severity and incidence of respiratory symptoms of those living nearby, particularly children with asthma. For adults and children who are susceptible, inhalation of SO₂ causes inflammation and hyper-responsiveness of the airways, aggravates bronchitis, and decreases lung function.⁽¹⁴⁾ There is a significant association between community-level SO₂ concentration and hospitalizations for asthma and other respiratory conditions, and asthma

emergency department visits particularly among children and adults over 65.⁽¹⁴⁾ A review of epidemiological studies in European cities, in Italy, Spain, France, and the Netherlands found that low concentrations of SO₂ (less than 10 ppb 24-hr average) are associated with increased risk of death from heart and lung conditions.⁽¹⁴⁾ For every 10 ppb increase in SO₂ concentration there is a 0.4 - 2% increased risk of death.⁽¹⁴⁾ Fortunately, ambient concentrations of SO₂ in many countries have declined over the last few decades due to the addition of pollution control technologies at coal-burning power-plants. Countries with lower pollution standards put their populations at risk of health effects from SO₂. The ambient concentrations of SO₂ in China, for example, increased from 2000 to 2006 at an annual rate of 7.3%, mainly due to emissions from power plants. But in 2005, new policy in China increased the use of flue-gas desulfurization (FGD) technologies, and SO₂ concentrations have since been on the decline.⁽¹⁵⁾

Oxides of Nitrogen

Oxides of nitrogen (NO_x) are by-products of fossil fuel combustion from automobiles and coal-fired power plants, among many other sources. Oxides of nitrogen react with chemicals in the atmosphere to create pollution products such as ozone (smog), nitrous oxide (N₂O), and nitrogen dioxide (NO₂). NO₂ and ozone are pollutants of particular concern. When asthmatic children are exposed to NO₂ they can experience increases in wheezing and cough.⁽¹⁶⁾ Exposure to NO₂ also increases susceptibility to viral and bacterial infections, and at high concentrations (1-2 ppm), it can cause airway inflammation.⁽¹⁶⁾ At low concentrations (0.2 - 0.5 ppm) NO₂ causes decrements in lung function in asthmatics.⁽¹⁶⁾ Increases in ambient NO₂ levels (3-50 ppb) cause increases in hospital admissions and emergency department visits for respiratory causes, particularly asthma.⁽¹⁶⁾

Air pollution from coal plants affects respiratory and cardiovascular systems, causes abnormal neurological development in children, poor growth of the fetus before birth, and cancer.



Cardiovascular Effects

Coal-fired power plants contribute to the global burden of cardiovascular disease primarily through the emission of particulate matter. Particles less than 2.5 microns in diameter (PM_{2.5}) have been causally linked to cardiovascular disease and death.⁽⁹⁾ The mechanism of cardiovascular injury is the same as for the respiratory system: oxidative stress from oxidizing molecules in pollutants leads to inflammation and cytotoxicity.

The World Health Organization (WHO) estimates that worldwide, 5% of cardiopulmonary deaths are due to particulate matter pollution.⁽¹⁷⁾ Long term exposure to PM_{2.5} has been shown to accelerate the development of atherosclerosis and increase emergency department visits and hospital admissions for ischemic heart disease and congestive heart failure. The United States Environmental Protection Agency (USEPA) reports that a majority of the studies it reviewed found a 0.5-2.4% increase in emergency department visits and hospital admissions for cardiovascular diseases per each 10 µg/m³ increase in PM_{2.5} concentrations.⁽⁹⁾ A 2007 scientific review of the health effects of combustion emissions

reported an 8-18% increase in cardiovascular deaths per 10 µg/m³ increase in PM_{2.5} concentration in the United States.⁽¹⁸⁾ In addition, recent studies conducted in China and Latin America confirm the significant link between outdoor air pollution and cardiovascular events.^(19,20)

Reproductive Health

A literature review of air pollution's effects on pregnancy outcomes suggests that the evidence is sufficient to conclude that exposure to air pollution during pregnancy can cause low birthweight. The review included studies that investigated the effects of SO₂, PM (China, South Korea) NO₂, CO, and ozone (South Korea), concluding that all of the pollutants studied were associated with low birthweight.⁽²¹⁾

Researchers have studied the association between electricity generation from coal-fired power plants and infant mortality.⁽²²⁾ Infant mortality was shown to increase with increased coal consumption in countries that had mid to low infant mortality rate at baseline (1965) such as Chile, China, Mexico, Thailand, Germany, and Australia.⁽²²⁾

Neurologic Effects

Mercury

Coal contains many naturally-occurring heavy metals, including mercury. When coal is burned, mercury is emitted into the atmosphere in gaseous form. The United Nations estimates that 26% of global mercury emissions (339-657 metric tons/year) come from the combustion of coal in power plants.⁽²³⁾ The mercury emitted into the atmosphere from coal-burning power plants is deposited into waterways, converted to methylmercury, and passed up the aquatic food chain.^(24,25) Consumption of methylmercury-contaminated fish, from mercury emissions locally, regionally, and internationally, by pregnant women can cause developmental effects in their offspring such as lower intelligence levels, delayed neurodevelopment, and subtle changes in vision, memory, and language.⁽²⁶⁾ Large-scale epidemiologic studies in Spain, Hong Kong, and the United States have shown that many women have blood mercury levels that are above acceptable levels due to consumption of mercury-contaminated fish, putting their offspring at risk.⁽²⁷⁻²⁹⁾

Life Expectancy

A study modeling the effect of coal use for power generation on life expectancy found that the use of coal predicted a decrease in life expectancy in countries with moderate life expectancy at the baseline year (1965) including Poland, China, Mexico, and Thailand. In India and China, years of life lost were estimated up to 2.5 years and 3.5 years, respectively.⁽²²⁾

Climate Change

Global climate change is caused by the accumulation of greenhouse gases in the Earth's atmosphere. Two of the major greenhouse gases contributing to climate change are products of coal combustion: carbon dioxide (CO₂) and nitrous oxide (N₂O). As the concentrations of these gases in the atmosphere increase, the average global temperature slowly increases, setting in motion a host of consequences that further promote climate change such as melting of polar ice and thawing of the arctic permafrost.

Infant mortality was shown to increase with increased coal consumption in countries such as Chile, China, Mexico, Thailand, Germany, and Australia.



As the average global temperature increases, it is predicted there will be an increase in public health burden, particularly in low-income countries which have fewer resources to respond and adapt to the changes brought on by warmer global temperatures.⁽³⁰⁾ A higher average global temperature and warmer oceans are already increasing the incidence of extreme weather events such as floods, hurricanes, and droughts that in-turn, increase disease and injury, and adversely affect water quality and food security.^(31,32)

Warmer average temperatures alter ecosystems, causing a decrease in some key food-chain supporting species such as corals, and causing an increase in the growing ranges of some weeds, grasses, and trees that may increase the severity and prevalence of allergies.^(31,32) Other consequences include: the spread of climate-sensitive diseases such as tick-and mosquito-borne diseases and food-and water-borne pathogens, an increase in ground-level ozone and smog which aggravate asthmas and increase hospital visits; and an increase in the number of extremely hot days which can cause heat-related mortality.⁽³⁰⁻³⁴⁾ The mass migration of people to avoid these climate-related consequences may cause conflict and further stress on water, food, shelter, sanitation, and healthcare resources.⁽³⁰⁾

Other Health Effects

While this review focuses primarily on the health effects from the combustion of coal for electricity, it should be noted that other health burdens arise from the use of coal, two of which are reviewed below.

Indoor Coal-Combustion

Using solid-fuels such as coal for heating and cooking is estimated to cause almost 1 million deaths from pneumonia in children under 5 years old and one million deaths from chronic obstructive pulmonary disease per year world-wide.⁽³⁵⁾ While the use of coal for indoor fuel is relatively unusual, in China it is still in common use. In 2000, the World Health Organization conducted a meta-study on the use of solid fuels for heating and cooking in which they reported that about 158 million adults in East Asia and about 20 million adults in South Asia are exposed to coal smoke from cooking, causing over 16,000 deaths from lung cancer per year.⁽³⁶⁾

Coal Miners

The occupational health impacts of mining coal are well known and must be considered when reviewing the effects of electricity generation with coal. In a 2002 review of 250 studies on coal mining, Stephens and Ahern⁽³⁷⁾ calculated that up to 12% of coal



of global mercury emissions come from the combustion of coal in power plants.

miners develop the potentially fatal lung conditions coal workers' pneumoconiosis and silicosis due to the inhalation of dust during mining operations.⁽³⁷⁾ Miners are also at higher risk for chronic bronchitis and accelerated loss of lung function. Most of the research on the health effects of coal mining have been performed among miners in large scale mines in Europe and North America.⁽³⁷⁾ Small scale mines, many of which are found in developing countries, are often more hazardous, resulting in higher rates of accidents and injuries. They often employ less experienced workers and children, both of which are populations with increased vulnerability to occupational disease and injury.⁽³⁷⁾

The Cost of the Health Burden From Use of Coal for Energy Production

The impacts of coal combustion can be described in economic terms, and several papers have attempted to estimate the cost of using coal by assigning value to the environmental and public health damage caused during each stage of

coal's extraction, transportation, combustion, and disposal. One such study by Epstein et al.⁽³⁸⁾ estimated that the external costs of coal-fired electricity in the U.S. add an extra 17.8 cents to each kWh of electricity produced; an amount that would triple its cost to consumers.⁽³⁸⁾ Another U.S. report by Machol et al.⁽³⁹⁾ estimates 45 cents per kWh as the cost of the health burden and environmental damages from coal combustion. As part of an analysis for the European Commission in 2005, Rabl et al. estimated the external life cycle costs of fossil fuels (the most expensive of which was coal) to be 1.6 - 5.8 c€/kWh.⁽⁴⁾

In 2011 the US EPA estimated the benefits and costs of the Clean Air Act, a law which regulates emissions of sulfur dioxide, oxides of nitrogen, carbon monoxide, and particulate matter in the United States. The EPA calculated that the ratio of health care cost savings to compliance costs was 25:1 in 2010.⁽⁴⁰⁾ This means that for every dollar spent complying with the Clean Air Act, twenty-five dollars were saved in health care costs due to lower disease burden, including a reduction in premature deaths, and cases of bronchitis, asthma, and myocardial infarction.⁽⁴⁰⁾



If health and other external costs of coal-fired electricity in the U.S. are included, they triple its cost to consumers



SUMMARY AND RESEARCH NEEDS

This document has presented scientific evidence for the health effects from the use of coal for the generation of electricity. Recent research findings have been summarized, and we have provided references and additional resources for further information. It is clear that scientific research has shown that the pollutants generated by coal combustion can have profound effects on the health of local communities, especially vulnerable individuals including children, the elderly, pregnant women, and those suffering from asthma and lung disease in urban settings. On a global scale, coal emissions can travel long distances affecting populations living remote from power plants. Moreover, coal combustion contributes to climate change, whose health impacts are already significant and growing.

The use of coal results in health consequences throughout the span of its use --

from mining to combustion waste disposal. However, in order to keep this document brief, as an accessible resource on the topic, the health effects from exposure to fly ash and pollutants resulting from coal transport, or noise from blasting in coal mines were not included. Top quality, peer-reviewed global research and documentation on the health impacts of coal is needed. Future research should evaluate the global public health effects, including cancer, that are specific to the use of coal for indoor heating and cooking. In addition, effects on the local population from noise from blasting during mining, and local population-based health effects from coal-fired power plant emissions not discussed in this paper need to be further evaluated. Furthermore, a comparative study of the health impacts of various power generation options would help provide a scientific basis for energy policy choices.

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Local Resources