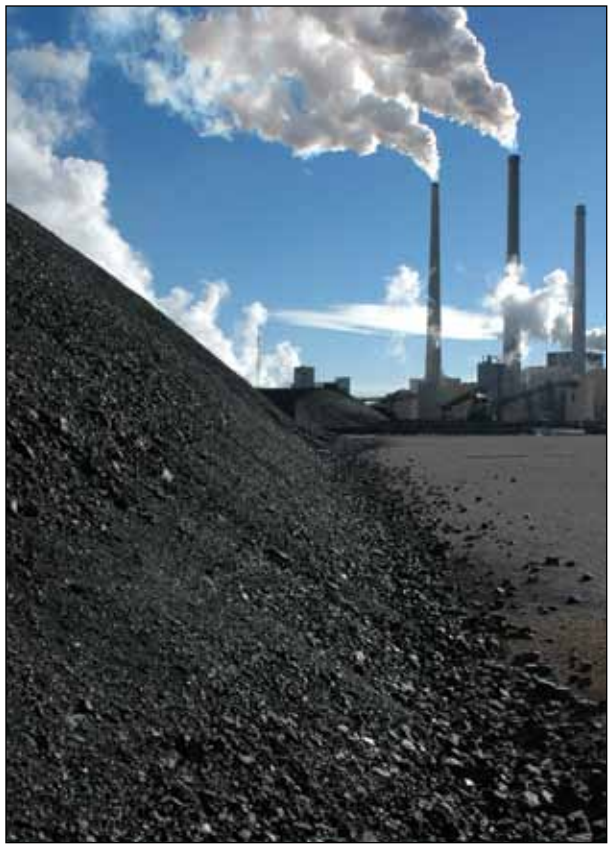
1. *Introduction*

Almost half of the energy used to generate electricity in the United States comes from burning coal, as shown in Figure 1.1. Coal is a major component of the economy and forms the center around which political, economic, health, and environmental considerations coalesce. The U.S. holds extensive coal reserves, although how much of that coal is accessible at a commercially viable cost is subject to debate. The high-end estimate 491 billion tons, which would be enough to last as much as 250 years at the current rate of consumption, earned the U.S. the title of the "Saudi Arabia of Coal."[1] In 2006, the electric power industry burned 1.026 billion tons of coal (see Figure 1.2). The electric industry currently plans to build as many as 100 new coal plants, adding to the approximately 600 large coal-burning power plants already in existence.

Using coal has a variety of major adverse impacts on health. Mining, transporting, burning, and disposing of the products of coal combustion all place human health at risk. With the passage of time, more and more adverse health effects have been attributed to the increasing reliance on coal. Studies of the health effects of hazardous air pollutants date clearly to 1872 with the publication of *Air and Rain: the Beginning of Chemical Climatology* by Robert Angus Smith. Since then, there have been a number of sentinel events that link episodes of severe air pollution to a variety of illnesses.[2] In October, 1948, almost half of the 14,000 residents of Donora, Pennsylvania were sickened when



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atmospheric conditions trapped toxic emissions from a nearby smelter: 20 died and 400 required hospitalization. In 1952, the infamous "killer fog" in London, lasting four days, sent death rates and hospital admissions soaring. Overall hospital admissions increased by 43%; those due to respiratory diseases rose by 163%. Almost 12,000 deaths

were attributed to this environmental disaster caused, in part, by burning coal.

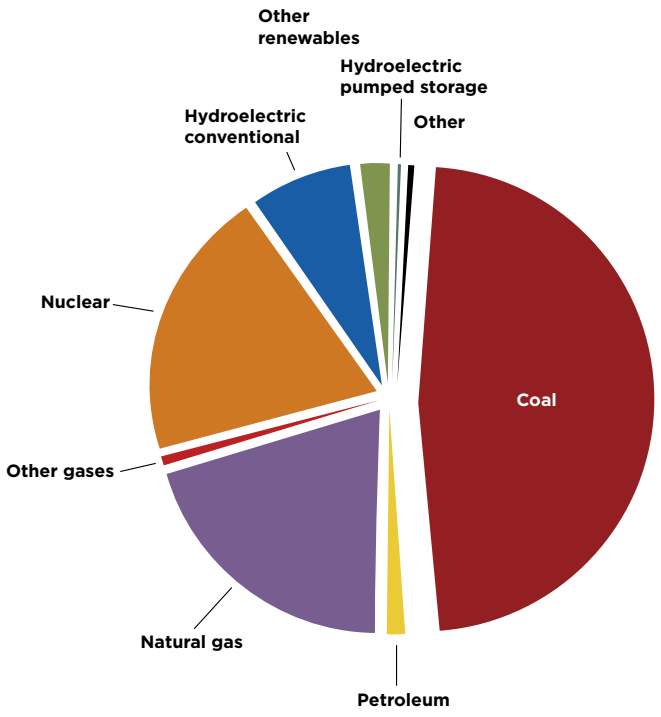
The link between burning coal and adverse health was made strikingly clear in Dublin, Ireland in the 1990s.[3] Because of increases in the cost of fuel oil in the 1980s, Dubliners switched from oil to bituminous coal to heat their homes and provide hot water. Subsequent increases in air pollution were associated with an increase in in-hospital deaths due to respiratory diseases. This led the Irish government to ban the marketing, sale, and distribution of bituminous coal on September 1, 1990. In the year that followed, black smoke concentrations declined by 70% (35.6 μg/m^3), respiratory deaths fell by 15.5%, and cardiovascular deaths fell by 10.3%. Approximately 450 lives were calculated to be saved that year by this measure, and hundreds of acute illnesses were prevented. Although burning coal was not the only cause of these illnesses, burning coal was clearly a major factor in the production of the complex mixture of airborne pollutants that had protean adverse effects on human health.

For each TerraWatt hour of electricity generated by coal, 24.5 deaths are expected in addition to 225 serious illnesses and 13,288 minor illnesses.

Many of coal's pollutants were identified by the U.S. Environmental Protection Agency in its 1998 report Report to Congress.[4] This report identified as many as 67 different hazardous air pollutants (HAPS) emitted from coal plants, but did not address particulates or oxides of nitrogen and sulfur (NO_X and SO_X), now referred to as criteria pollutants. Particulates, mercury, NO_X, SO_X, and the pollutants they give rise to, such as ozone, are now recognized as posing the greatest threats to health, and are the focus of much of this report.

Recent peer-reviewed reports provide estimates of the morbidity and mortality associated with burning coal. European data reported by Markandaya and Wilkinson show that for each TerraWatt hour of electricity generated (1 TWh = 10^{12} Watt hours), 24.5 deaths are expected (95% CI = 6.1–98) in addition to 225 serious illnesses (95% CI = 56.2–899) and 13,288 minor illnesses (95% CI = 3,322–53,150).[5] Burning lignite, a softer form of coal that yields more pollutants than bituminous coal, raises these numbers to 32.6 deaths (95% CI = 8.2–130), 298 serious illnesses (95% CI = 74.6–1,193), and 17,676 minor illnesses (95% CI = 4,419–70,704). To give these data perspective, consider the fact that nearly half of the 4,160 TWh of electricity generated in the United States in 2007 came from coal-fired power plants.[6] If these estimates are applied to the U.S., as many as 50,000 deaths per year may be attributable to burning coal. Although differences in population density between Europe and the U.S. are substantial and there are large boundaries on the 95% con-

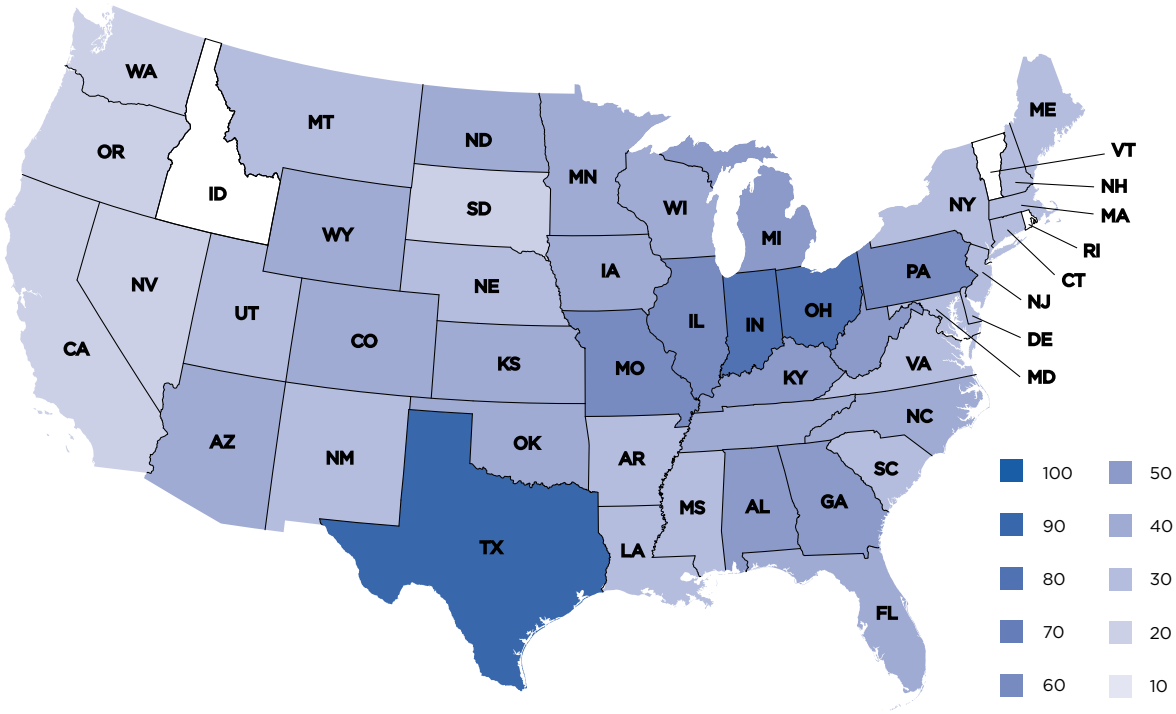
Figure 1.1: Sources of energy used for generation of electricity, 2006



Source: U.S. Energy Information Administration. Available from http://www.eia.doe.gov.

Figure 1.2: Coal consumption by U.S. utilities, 2006 (millions of tons)

By-state coal consumption by coal fired power plants. Texas led the nation, with states in the Ohio Valley that are close to coal fields and water transportation following closely behind.



Source: U.S. Energy Information Administration. Available from: http://www.eia.doe.gov/cneaf/coal/page/acr/table26.html.

fidence limits associated with these data, it is clear that burning coal has major adverse health effects.

In seeking to describe relationships between health and any single pollutant or any single source of the pollutant, notably burning coal, difficulties arise due to multiple sources of the pollutant in question and multiple health impacts. This is a particular issue with regard to SO_x, NO_x, and particulates, as there are many important sources of these pollutants in addition to burning coal. This is less of a problem in regard to mercury, where coal is the acknowledged largest single source of emissions. Thus, in this report we draw on literature that goes beyond that in which authors limit themselves to coal as the sole source of the pollutant in question.

In describing the health effects of coal combustion, this report utilizes an organ-system approach rather than a pollutant-based review. By considering coal's impact on the respiratory system, the cardiovascular system, and the central nervous system, we replace a piecemeal approach with a fuller and more integrated assessment of coal's overall effect on human health. To the best of our knowledge, this approach has not been taken in previous reviews of coal's health implications. To minimize bias, whenever possible we cite contemporary peer-reviewed medical literature and reports published by governmental agencies such as the U.S. Environmental Protection Agency and the Department of Energy. We hope that this report will provide physicians, other healthcare providers,

policy-makers, and concerned citizens with the information they need to make informed choices that affect the future of burning coal to produce electrical energy.

NOTES

1 Goodell J. Big coal: the dirty secret behind America's energy future. Boston: Houghton Mifflin; 2006.

2 Simkhovich BZ, Kleinman MT, Kloner RA. Air pollution and cardiovascular injury epidemiology, toxicology, and mechanisms. J Am Coll Cardiol 2008; 52(9):719–726.

3 Clancy L, Goodman P, Sinclair H, Dockery DW. Effect of air-pollution control on death rates in Dublin, Ireland: an intervention study. Lancet 2002; 360(9341):1210–1214.

4 EPA. Study of Hazardous Air Pollutant Emissions from Electric Utility Steam Generating Units - Final Report to Congress. 1998: EPA-453/R-98-004a.

5 Markandaya A, Wilkinson P. Energy and Health 2: Electricity Generation. Lancet 2007; 370:979–990.

6 Energy Information Administration. Electric power industry 2007: year in review. Available from: http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html.