science for a changing world

Emissions from Coal Fires and Their Impact on the Environment

Introduction—Coal Fires, Emissions, and Resource Implications

Self-ignited, naturally occurring coal fires and fires resulting from human activities persist for decades in underground coal mines, coal waste piles, and unmined coal beds. These uncontrolled coal fires occur in all coal-bearing parts of the world (Stracher, 2007) and pose multiple threats to the global environment because they emit greenhouse gases—carbon dioxide (CO_2), and methane (CH_4)—as well as mercury (Hg), carbon monoxide (CO), and other toxic substances (fig. 1). The contribution of coal fires to the global pool of atmospheric CO_2 is little known but potentially significant. For China, the world's largest coal producer, it is estimated that anywhere between 10 million and 200 million metric tons (Mt) of coal reserves (about 0.5 to 10 percent of production) is consumed annually by coal fires or made inaccessible owing to fires that hinder mining operations (Rosema and others, 1999; Voigt and others, 2004). At this proportion of production, coal amounts lost to coal fires worldwide would be two to three times that for China. Assuming this coal has mercury concentrations similar to those in U.S. coals, a preliminary estimate of annual Hg emissions from coal fires worldwide is comparable in magnitude to the 48 tons of annual Hg emissions from all U.S. coal-fired power-generating stations combined (U.S. Environmental Protection Agency, 2002).

In the United States, the combined cost of coal-fire remediation projects, completed, budgeted, or projected by the U.S. Department of the Interior's Office of Surface Mining Reclamation and Enforcement (OSM), exceeds $1 billion, with about 90% of that in two States—Pennsylvania and West Virginia (Office of Surface Mining Enforcement and Reclamation, 2008; fig. 2). Altogether, 15 States have combined cumulative OSM coal-fire project costs exceeding $1 million, with the greatest overall expense occurring in States where underground coal fires are predominant over surface fires, reflecting the greater cost of extinguishing underground fires (fig. 2) (see "Controlling Coal Fires").

In this fact sheet we review how coal fires occur, how they can be detected by airborne and remote surveys, and, most importantly, the impact coal-fire emissions may have on the environment and human health. In addition, we describe recent efforts by the U.S. Geological Survey (USGS) and collaborators to measure emissions of CO_2, CO, CH_4, and Hg, using ground-based portable detectors, and combining these approaches with airborne thermal imaging and CO_2 measurements. The goal of this research is to develop approaches that can be extrapolated to large fires and to extrapolate results for individual fires in order to estimate the contribution of coal fires as a category of global emissions.

Figure 1. Emissions from the Centralia, Penn., underground coal fire; subsidence resulting from burning and subsequent collapse of coal pillars used as roof supports for mining tunnels under the town is also evident. Centralia, the largest and best known U.S. coal fire, has been burning since 1962 and has resulted in relocation of nearly all of the town's residents. Photograph by Janet Stracher.

Self-Heating Processes Leading to Spontaneous Combustion

Exposure of underground coal and (or) coal waste piles to atmospheric oxygen promotes spontaneous heat-generating reactions, primarily oxidation of the coal itself, and the oxidation of pyrite present in coal. In this process, carbon, the largest constituent of coal, combines with available oxygen to produce CO_2 and heat. Similarly, the sulfur present in pyrite combines with oxygen to produce sulfate, releasing heat, and, in the presence of water, forming sulfuric acid that can result in acidic drainage. Adsorption of water vapor onto coal surfaces and interaction of bacteria with coal are other heat-producing processes (Kim, 2007). Where oxygen is present and because of the decrease in the minimum required temperatures for coal combustion at depth and the insulating capacity of coal overburden, these heat-producing reactions can result in spontaneous combustion or extend the life of coal fires started by inadvertent combustion in mines. Where exposed at the surface, as in the Powder River Basin of Wyoming and Montana, coal beds can be ignited by wildfires, lightning, and human activities, as well as by spontaneous combustion (Heffern and Coates, 2004).

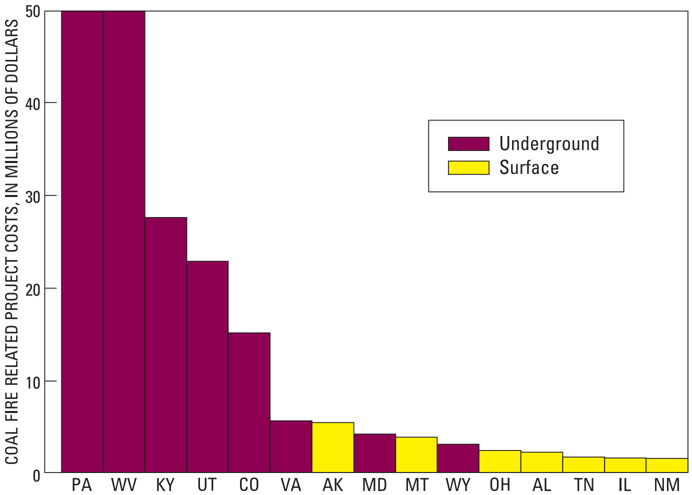

Figure 2. Histogram showing Office of Surface Mining Reclamation and Enforcement coal-fire-related project costs by State. Costs shown are for completed and future projects combined for 15 States where this amount exceeds $1 million. This figure shows that total costs are greatest in States where underground fires are predominant compared with States where costs for surface fires exceed those for underground fires. The bars for Pennsylvania and West Virginia are not shown to full extent in order to show more detailed perspective for other States; costs in Pennsylvania and West Virginia totaled $736 million and $238 million, respectively. Source: Office of Surface Mining Reclamation and Enforcement (2008).

Impact of Emissions

Direct hazards to humans and the environment posed by coal fires include emission of pollutants, such as CO, CO_2, nitrogen oxides, particulate matter, sulfur dioxide, toxic organic compounds, and potentially toxic trace elements, such as arsenic, Hg, and selenium (Finkelman, 2004). Mineral condensates formed from gaseous emissions around vents pose a potential indirect hazard by leaching metals from mineral-encrusted surfaces into nearby water bodies. Despite this combination of potential health hazards, few studies have concentrated on the immediate health impacts of coal fires (Finkelman, 2004). Some gaseous components from coal fires, such as Hg and CO_2, pose a global-scale threat. In the case of Hg, its addition to the atmosphere is thought to eventually contribute to high levels of the methyl form of Hg in some fish species, consumption of which is the primary human exposure pathway for Hg. In the case of CO_2 and other greenhouse gases, emissions contribute to climate change, but data on these emissions are not sufficient for uncontrolled coal fires to be taken into account as a source category in current climate model projections.

USGS Coal Fire Investigations

In cooperation with non-USGS collaborators, USGS scientists have recently developed a ground-based approach for determining CO_2 emissions from a coal fire. In this approach, measurements of CO_2 emitted through vents that exhaust hot gasses from the fire (vent emissions) are combined with measurements of CO_2 gradually diffused from an underground fire through the soil over the area of an underground coal fire (diffuse emissions). When combined, the vent and diffuse emissions give an estimate of the daily amount of CO_2 released by the coal fire. Vent emissions are also measured for gaseous CO, CH_4, hydrogen sulfide, and Hg.

The ground-based approach was initially applied in a study of a burning coal waste pile near the town of Mulga, outside of Birmingham in northern Alabama. The Mulga fire was selected because it provided a simple case study to test procedures for sampling diffuse CO_2 fluxes (the amount of CO_2 emitted per area per day), along four transects of the fire area (fig. 3). Temperature measurements show localized hot spots in the Mulga coal fire, some of which exceed 300°C (572°F) (fig. 3). Results for the four transects indicate that diffuse CO_2 flux varies by as much as three orders of magnitude (fig. 4). Comparison of diffuse CO_2 flux and surface soil temperature for the four transects shows some correlation between these parameters when all the results are combined. If such a relationship were found to be consistent, then it could be used to estimate diffuse CO_2 emissions based only on temperature for portions of the fire lacking diffuse CO_2 flux measurements. Using the same rationale, comparison of emissions from coal fires with similar attributes (for example, coal rank and type, caloric content, composition, size, and intensity) and weighting them according to the size and intensity of the fire may allow us to estimate areas or volumes of burning coal in order to calculate emissions on larger scales.

In May 2009, coal fires in the Powder River Basin of Wyoming and Montana were studied. The Powder River Basin was selected for study because of ongoing coal-fire activity and because ground-based and airborne sampling methods could be applied at the same time. The ground-based effort consisted of measuring diffuse CO_2 fluxes at 116 points and emissions of multiple gases from 29 vents in three fires along the Tongue River near Sheridan, Wyo. At the same time, the airborne crew analyzed for tropospheric CO_2 concentrations and collected airborne surface-temperature imaging throughout the northern half of the basin (fig. 5). The airborne results are currently being processed, and the airborne and ground datasets are being compared so that airborne and ground-based measurements of

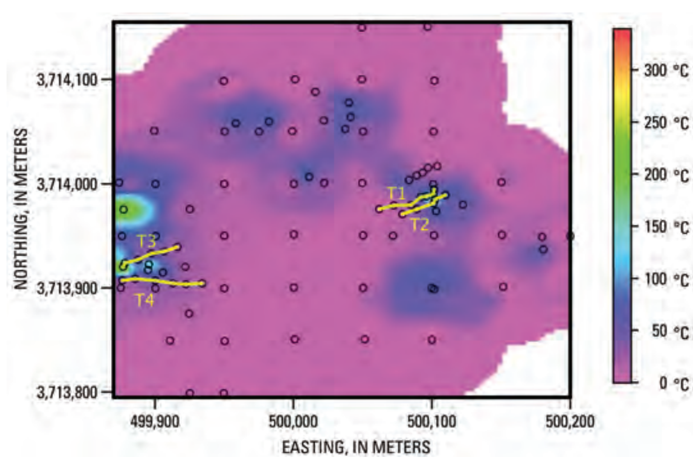

Figure 3. Map showing the distribution of surface temperature (at 10 centimeters depth), measured in degrees Celsius, in the Mulga, Ala., coal pile in December 2008 over the extent of the coal fire, an area of about 9.1 hectares (22.6 acres). Results are extrapolated from measurement points shown. Locations of transects 1 to 4 (T1, T2, T3, and T4) are also shown.

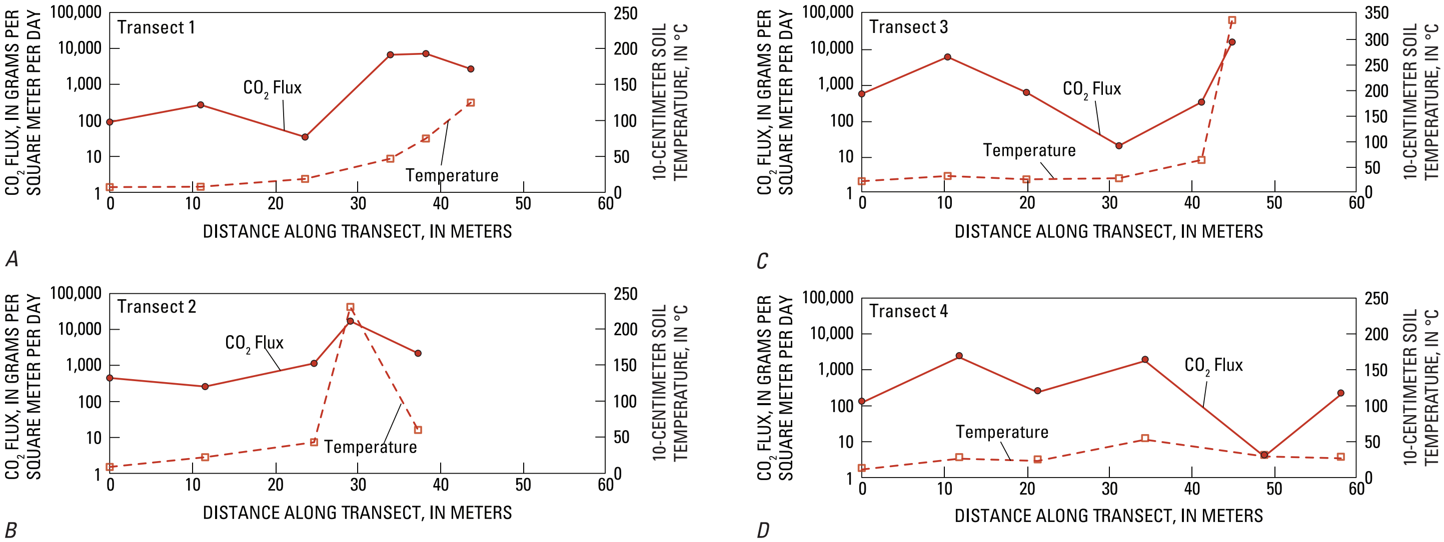

Figure 4. Plot of diffuse carbon dioxide (CO_2) flux against measured temperature determined for the Mulga, Ala., coal fire for (*A*) transect 1, (*B*) transect 2, (*C*) transect 3, and (*D*) transect 4.

coal fires can be integrated into a combined sampling approach in future studies.

Airborne and Satellite Remote Sensing Techniques

Early detection and routine monitoring of coal fires are two critical components in strategizing fire fighting efforts and controlling these fires. Hot spots (local areas of elevated temperatures) are a precursor to impending coal mine fires (Prakash and others, 1997). Temperature profiles across developing hot spots, when used as input in numerical models, help to estimate depth of underground fires (Prakash and Berthelote, 2007). Airborne thermal infrared (TIR) sensors, such as those operating in the broad 8- to 14-micrometer wavelength, are very effective in identifying subtle hot spots and in quantifying the temperature distribution of active coal fires (fig. 5).

Satellite remote sensing in the TIR wavelength offers a simple, cost-effective tool for detecting, mapping, monitoring, and characterizing coal fire areas. Currently available technology with spatial resolution ranging from 60 to 120 meters (m) can detect hot spots associated with individual large coal fires. With advancements in sensor technology, future satellite missions will likely have TIR sensors with higher spatial resolution, on the order of 10 to 20 m, and a shorter revisit cycle of about 4 to 5 days. Such a configuration will be better suited for early detection and monitoring of coal fires.

Controlling Coal Fires

While remote sensing techniques are helpful in pinpointing the locations of existing and potential underground coal fires, extinguishing burning coal beds can be difficult and costly. As a result, in many parts of the world, coal-bed or underground mine fires have burned uncontrollably for decades. There is no one best method to control coal fires, but several approaches have been tried. For near-surface fires, combustion may be contained by excavating the fire, but this can be expensive and disruptive to the environment, especially in the case of large fires. Another approach is to inject a flowable mixture of materials underground to help extinguish the fire (Colaizzi, 2004).

Products engineered to control underground coal fires generally consist of a solid noncombustible material, such as mud, fly ash, or cement, combined with an inert gaseous component, such as nitrogen or CO_2, and, in some cases, water as a third component. Some combination of these materials is applied or injected to contain the fire and cut off the supply of oxygen. The approach used and the sequence of steps needed to extinguish coal fires depend very much on the geometry, depth, and geologic setting of the fire.

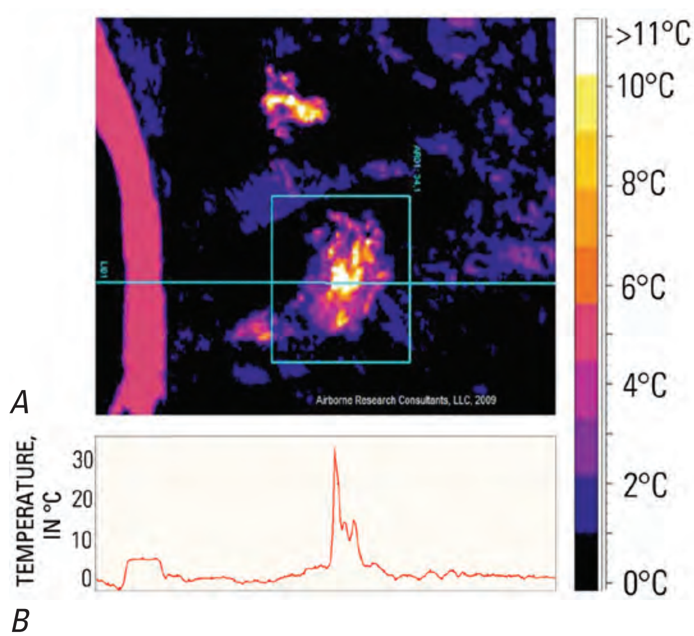

Figure 5. *A,* Predawn quantitative airborne thermal infrared image (from May 2009) of the Welch Ranch coal fire, along the Tongue River (at left margin of image), near Sheridan, Wyo., measuring surface temperature, in degrees Celsius. Blue-green-border box indicates main active fire area. *B,* Plot of temperature distribution (in degrees Celsius) along an analysis line through the fire (shown in fig. 5*A* as a blue-green line). Image is courtesy of Airborne Research Consultants, LLC. Image orientation is not at N–S.

Summary and Conclusions

Uncontrolled coal fires occur in the United States and virtually all coal-bearing parts of the world. One of the deleterious effects of these fires is the emission of greenhouse gases and potentially toxic substances harmful to humans and the environment on global to local scales. Additionally, these fires limit access to coal resources and inadvertently consume a portion of these resources that may have otherwise been available for use. Initial work by USGS researchers and non-USGS collaborators has concentrated on quantifying emissions for fires in the United States selected to develop ground-based and combined ground-based/airborne measurement approaches. The goal of this research is to develop approaches that can be extended to larger fires and, ultimately, to begin to quantify the impact of coal fires on global emissions of substances such as Hg and CO_2. The magnitude of this impact is little known. The nature and extent of coal-fire emissions must be quantified so that they can be taken into account in global atmospheric models and so their potential impact on people residing in proximity to fires and on the environment can be better assessed.

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For more information, contact

Allan Kolker	Mark Engle
U.S. Geological Survey	U.S. Geological Survey
12201 Sunrise Valley Drive	12201 Sunrise Valley Drive
Mail Stop 956	Mail Stop 956
Reston, VA 20192	Reston, VA 20192
Telephone: (703) 648–6418	Telephone: (703) 648–6454
E-mail: *akolker@usgs.gov*	E-mail: *engle@usgs.gov*

By Allan Kolker,[1] Mark Engle,[1] Glenn Stracher,[2] James Hower,[3] Anupma Prakash,[4] Lawrence Radke,[5] Arnout ter Schure,[6] and Ed Heffern[7]

[1]U.S. Geological Survey Eastern Energy Resources Science Center, Reston, VA.
[2]East Georgia College, Swainsboro, GA.
[3]University of Kentucky, Center for Applied Energy Research, Lexington, KY.
[4]Geophysical Institute, University of Alaska-Fairbanks, Fairbanks, AK.
[5]Airborne Research Consultants LLC, Saunderstown, RI.
[6]Electric Power Research Institute, Palo Alto, CA.
[7]U.S. Bureau of Land Management, Branch of Solid Minerals, Cheyenne, WY.