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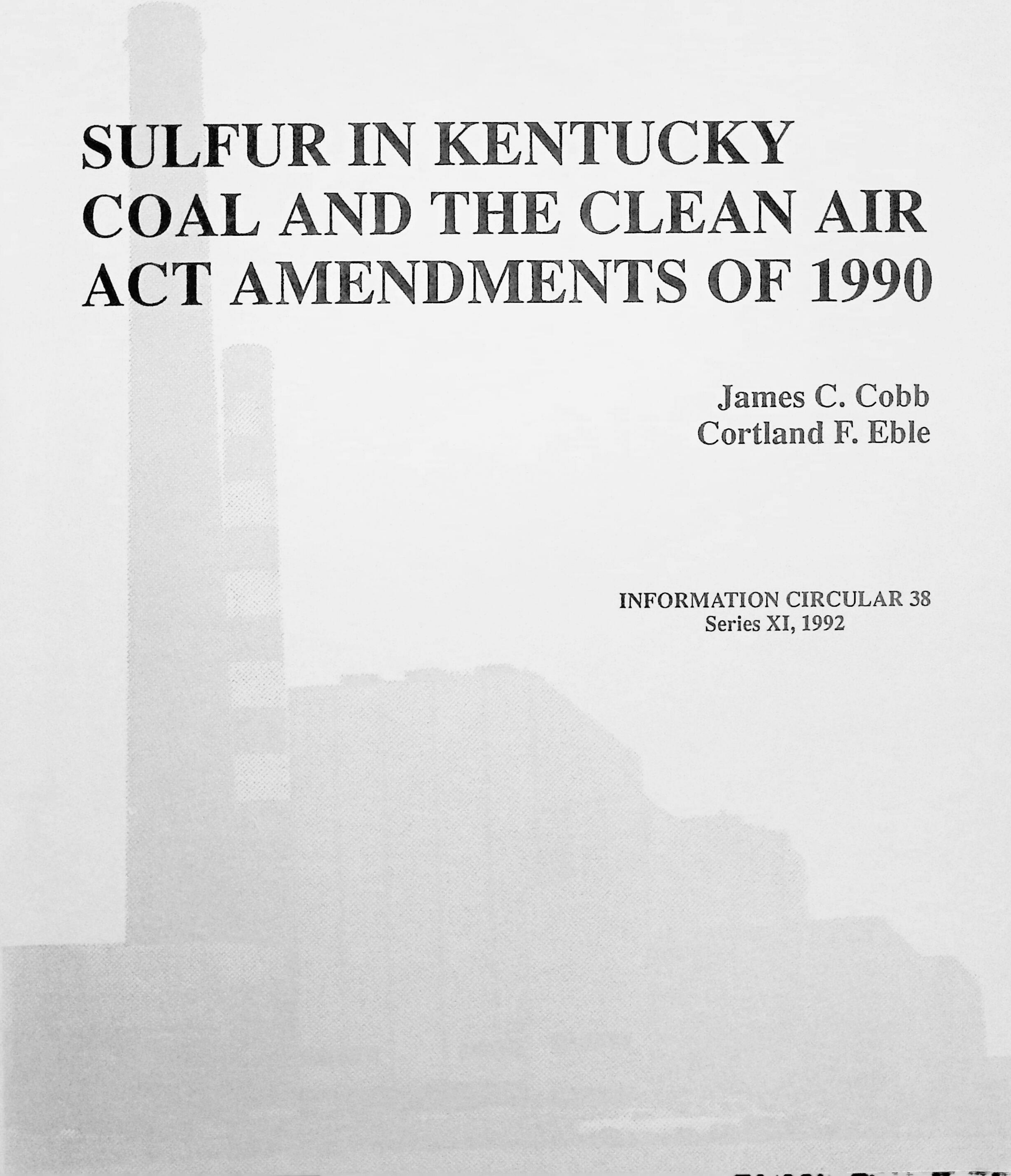
UNIVERSITY OF KENTUCKY, LEXINGTON
Donald C. Haney, State Geologist and Director

SULFUR IN KENTUCKY COAL AND THE CLEAN AIR ACT AMENDMENTS OF 1990



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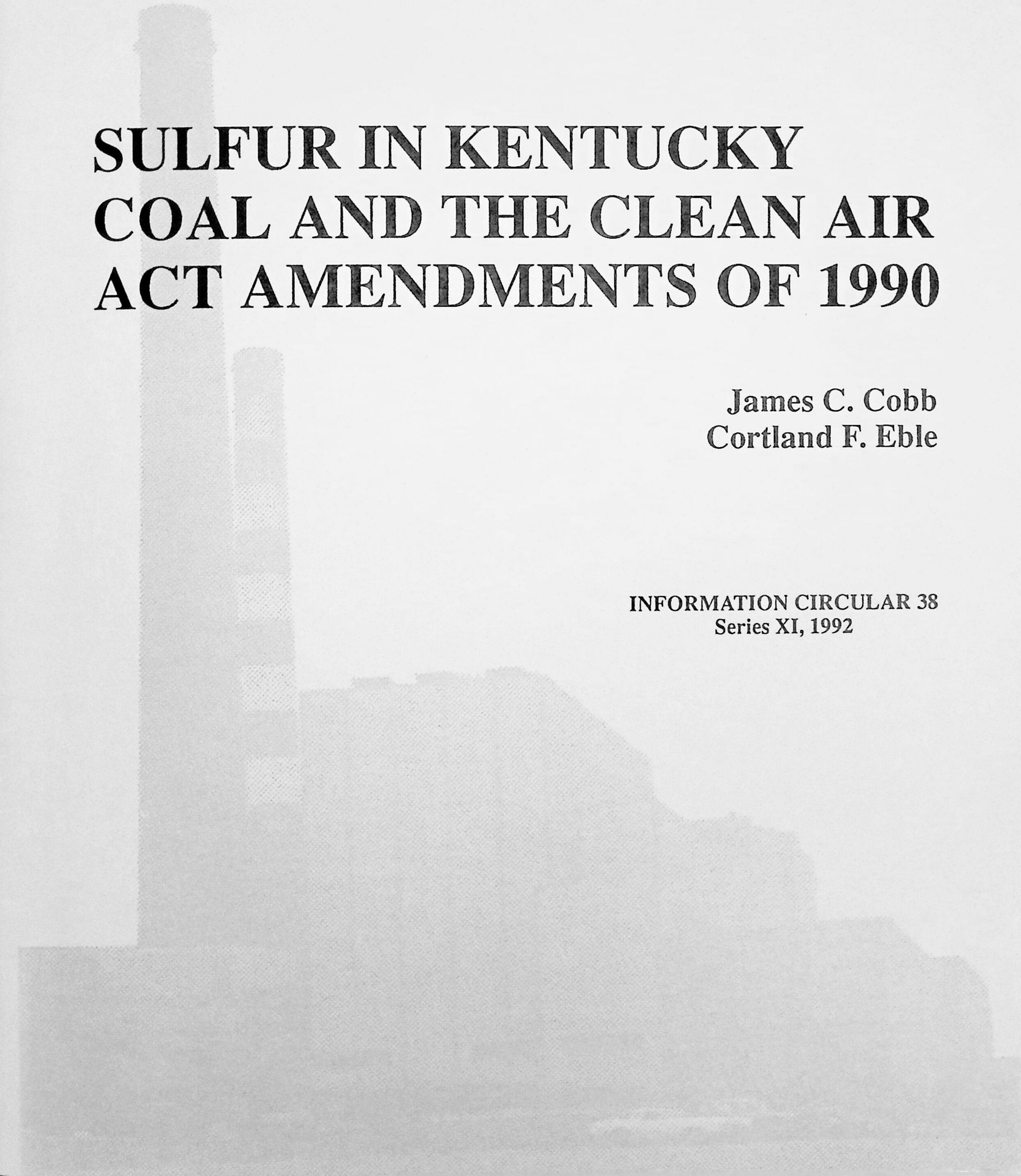

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CONTENTS

	Page
Introduction	1
The Acid Rain Bill	1
Coal Resources in Kentucky	2
The Problem of Sulfur in Coal	3
The Forms of Sulfur in Coal	4
The Origin of Sulfur in Coal	4
Methods of Sulfur Removal	5
Compliance Coal	6
The Future of Coal in Kentucky	10
References Cited	11
Further Information	12

ILLUSTRATIONS

Figure **Page**

1. Generalized geologic map of Kentucky showing the Eastern and Western Kentucky Coal Fields 2
2. Original coal resources of the Eastern and Western Kentucky Coal Fields greater than 14 inches in thickness without regard to mineability or recoverability and their estimated compliance 3
3. Total production of Kentucky coal from the Eastern and Western Kentucky Coal Fields 3
4. Total sulfur content in channel samples of the Springfield (Western Kentucky No. 9) coal bed of the Western Kentucky Coal Field 4
5. Total sulfur content in channel samples of the Herrin (Western Kentucky No. 11) coal bed of the Western Kentucky Coal Field 5
6. Total sulfur content in channel samples of the Lower Elkhorn–Pond Creek coal bed of the Eastern Kentucky Coal Field 6
7. Total sulfur content in channel samples of the Upper Elkhorn No. 3 coal bed of the Eastern Kentucky Coal Field 6
8. Total sulfur content in channel samples of the Fire Clay coal bed of the Eastern Kentucky Coal Field 7
9. Pyrite filling cell lumens 7
10. Pyrite framboids 7
11. Isolated pyrite euhedra 7
12. Schematic diagram of (a) coal cleaning/preparation, (b) flue–gas desulfurization, and (c) fluidized bed combustion 8
13. Coal–burning power plants in Kentucky equipped with scrubbers and fluidized–bed combustion furnaces 9
14. Limestone and dolomite resources in Kentucky available for sulfur–removal technology 10
15. Method to determine potential SO_2 emissions from sulfur content and Btu value 10
16. Cumulative distribution of potential SO_2 emissions for western Kentucky coal resources 11
17. Cumulative function of potential SO_2 emissions for eastern Kentucky coal resources 11

SULFUR IN KENTUCKY COAL AND THE CLEAN AIR ACT AMENDMENTS OF 1990

James C. Cobb and Cortland F. Eble

INTRODUCTION

Passage of Title IV of the Clean Air Act Amendments of 1990 (Public Law 101–549), also known as the Acid Rain Bill, has produced many questions about Kentucky's coal resources. The purpose of this report is to present an overview about sulfur in Kentucky coal with respect to the Acid Rain Bill. This bill is highly complex; for those who require specific information contained in this bill, please refer to Public Law 101–549.

The Eastern and Western Kentucky Coal Fields are both major producers of coal, but they differ greatly in the amount of sulfur their coals contain. The Eastern Kentucky Coal Field has medium– to low–sulfur coal and the Western Kentucky Coal Field has predominantly high–sulfur coal. The 1990 amendments to the Clean Air Act require coal–burning power plants to reduce sulfur dioxide (SO_2) emissions by approximately 20 percent by 1995, and by approximately 50 percent by the year 2000. Since the principal markets for Kentucky coal are coal–burning power plants, disruptions in the coal industry in Kentucky are expected as the power plants take steps to reduce the amount of sulfur dioxide they emit.

Many questions concerning Kentucky's coal resources arise because of the importance of the coal industry in Kentucky. With the recent focus on acid rain and sulfur in coal, questions concerning these issues have become more frequent. To understand these issues and how complex they are, one needs some basic understanding about the scientific aspects of sulfur in coal.

Coal is the most abundant fossil fuel in the United States. It generates 95 percent of Kentucky's electrical power and 57 percent of the electrical power used in the United States. It is also a vital fuel and raw material for industry and manufacturing. Kentucky produces coal for electrical power and industrial uses such as coke plants, chemical users, domestic users, and export. Kentucky coal was sold to 149 power plants in 26 states in 1990 (Governor's Office for Coal and Energy Policy–Kentucky Coal Association, 1991). Kentucky coal mines have produced nearly 7 billion tons of coal in the 200 years that coal has been mined in this State. Approximately 1,800 mines are in operation in Kentucky, directly employing 30,498 miners, and indirectly providing another 85,000 coal–related jobs (Governor's Office for Coal and Energy Policy–Kentucky Coal Association, 1991). In recent years Kentucky has produced more than 170 million tons of coal annually (Kentucky Department of Mines and Minerals Annual Report, 1990). In 1990, coal mining in Kentucky generated approximately $570 million in revenues to the State's general fund, or about 13 percent of the State's economy (Kentucky Department of Mines and Minerals Annual Report, 1990).

A continuing mission of the Kentucky Geological Survey is to investigate the geology and coal resources of Kentucky. The Kentucky Coal Resources Information System (KCRIS) constitutes one of the largest coal data bases in the United States. Through KCRIS, the Survey maintains descriptions of coal beds, coal thickness measurements, coal–quality analyses, bed maps, and geophysical logs. Much of these data are available in electronic form for computer applications. Publications and public data bases about the coal resources of Kentucky are listed at the end of this report.

THE ACID RAIN BILL

When the original Clean Air Act was passed by Congress in 1970 and later amended in 1977, no specific consideration was given to the phenomenon known as acid rain. Since 1977, evidence has been collected that links emissions of sulfur dioxide and nitrogen oxides to ecological damage to lakes and forests. To combat this damage, many coal–fired power plants in the United States have installed pollution–control devices to limit sulfur dioxide emissions. In fact, United States sulfur dioxide emissions have decreased by 28 percent since 1977, even though power plants increased their coal consumption by 60 percent (Kentucky Department of Mines and Minerals Annual Report, 1990). Nonetheless, coal–burning power plants are still responsible for approximately 67 percent of the sulfur dioxide emitted into the atmosphere. After a long debate over the still–controversial question of acid rain, an amendment to the Clean Air Act was passed by Congress to reduce the emissions related to acid rain. This amendment established a strategy for controlling acid rain by limiting the amount of sulfur dioxide that power plants can legally emit. The National target for sulfur dioxide emissions reduction is 10 million tons annually. The primary target of this legislation is coal-burning power plants. This SO_2 reduction strategy is to take effect in two phases—phase I beginning in 1995 and phase II beginning in the year 2000.

In phase I, targeted power plants will be required to reduce their SO_2 emissions by the year 1995 to a level equal to the emissions that would be produced by meeting an emissions rate of 2.5 pounds of SO_2 per million Btu while burning the average amount of fuel consumed in that plant during the years 1985, 1986, and 1987. Collectively, these 3 years are referred to as *baseline years.* This phase will result in a reduction of approximately 3.5 million tons of SO_2 emissions (Governor's Office for Coal and Energy Policy–Kentucky Coal Association, 1991). In phase II, nearly all power plants must reduce their emissions to a level of either 1.2 pounds of SO_2 per million Btu, their actual rate during the baseline years, or their allowable rate in those years, whichever is the lesser value. It should be emphasized that the emissions ceilings of 2.5 and 1.2 are relative and site–specific; they depend heavily on a particular utility's potential for increased coal consumption. The more coal a utility burns over and above that consumed during the baseline years, the stricter the emission limit is for that utility.

A major provision of the acid rain bill is the creation of a system of "emissions allowances" that will allow power plants to buy or sell emissions credits, depending on their particular situations. Power plants can choose to burn compliance coal, use scrubbers or other sulfur–reduction devices to reduce sulfur emissions, or buy emissions allowances from other companies who have exceeded their reduction requirements.

COAL RESOURCES IN KENTUCKY

In Kentucky, coal is mined in two geographically separate coal fields (Fig. 1). The Eastern Kentucky Coal Field is part of the Central Appalachian Basin, and the Western Kentucky Coal Field is part of the Eastern Interior Basin (Illinois Basin). As summarized in Cobb

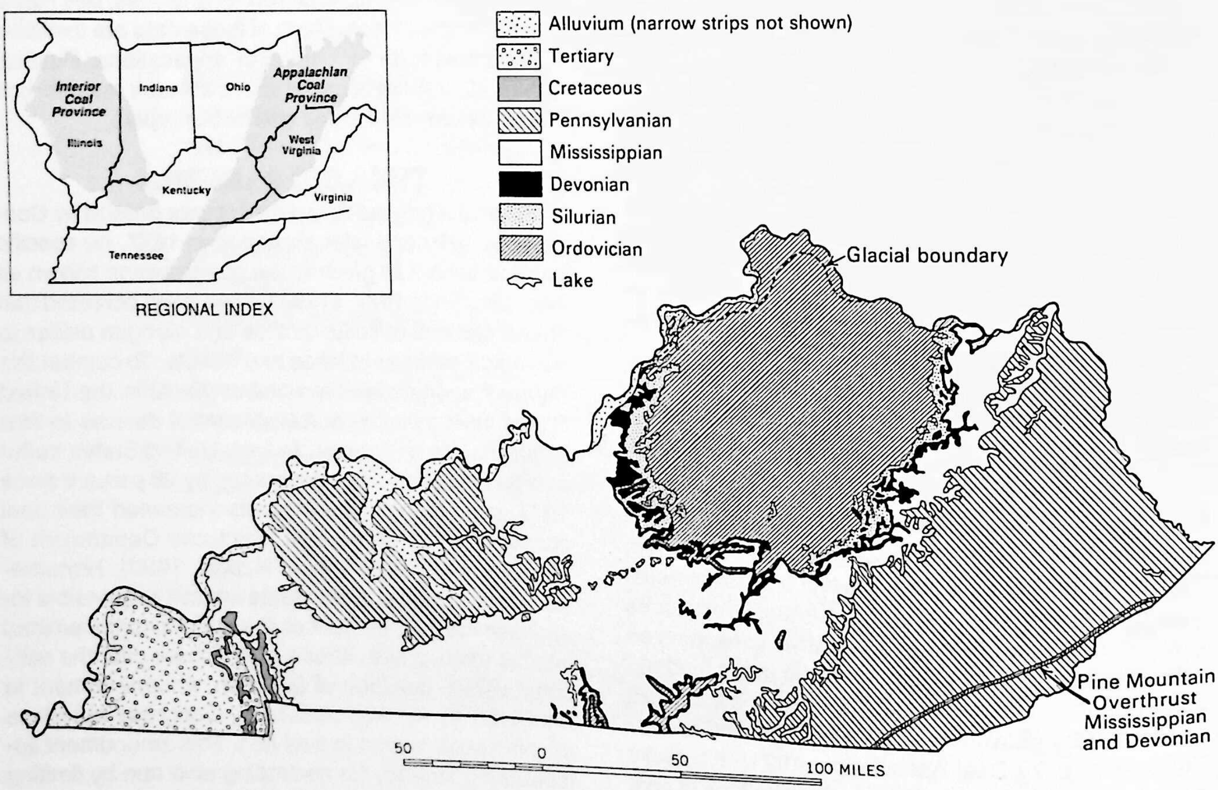


Figure 1. Generalized geologic map of Kentucky showing the Eastern and Western Kentucky Coal Fields.

(1991), the Eastern Kentucky Coal Field contained an estimated 63 billion tons of coal greater than 14 inches in thickness before mining began in the late 1700's. Similarly, the Western Kentucky Coal Field contained an estimated 42 billion tons of coal greater than 14 inches in thickness prior to mining (Fig. 2). Kentucky has produced nearly 7 billion tons of coal since mining began, 4.5 billion tons from eastern Kentucky and 2.2 billion tons from western Kentucky (*see* Fig. 3). In 1990, the eastern coal field produced 131 million tons, or 73 percent of the total State production, and the western field produced 48 million tons or 27 percent.

Coal in the Western Kentucky Coal Field is generally higher in sulfur than coal in the Eastern Kentucky Coal Field. The sulfur content of the major coal seams in western Kentucky ranges from 2.5 to 9 percent. Some of this sulfur is removable by routine coal–cleaning methods currently in use. The Springfield (Western Kentucky No. 9) coal, which is the leading producing bed in the Western Kentucky Coal Field, varies in sulfur content from 2.8 to 5.8 percent and averages about 4.0 percent (Fig. 4). The Springfield coal produces more than 30 million tons of coal per year and is Kentucky's biggest producer. The Herrin coal bed (Western Kentucky No. 11) ranks second in production. It varies in sulfur content from 2.8 to 5.2 percent (Fig. 5). Virtually all of the coal in the western field is above the limit for burning without the use of scrubbers or other sulfur–reducing technologies.

In contrast, coals in the Eastern Kentucky Coal Field are generally lower in sulfur than those in the Western Kentucky Coal Field. Eastern Kentucky's largest producer, the Lower Elkhorn–Pond Creek coal bed, with an annual production of 20 million tons, ranges in total sulfur content from 0.4 to 3.8 percent (Fig. 6). Two other major eastern Kentucky producers, the Upper Elkhorn No. 3 and the Fire Clay, range in sulfur from about 0.5 to about 4.5 percent (Figs. 7–8).

Not all eastern Kentucky coals are considered to be compliance coals, however. Some coals in eastern Kentucky have sulfur contents as high as those in western Kentucky. In addition, the sulfur content of a coal bed can vary a great deal across its area of occurrence. Commonly, the sulfur content of a coal bed also varies from the bottom to the top of the bed. In some cases the top and bottom several inches of coal are much higher in sulfur than the remainder of the bed. When the sulfur content of the final product is a key issue, these sulfur–rich layers can frequently be isolated and excluded during the mining process, a technique referred to as *high–grading*. However, while this process

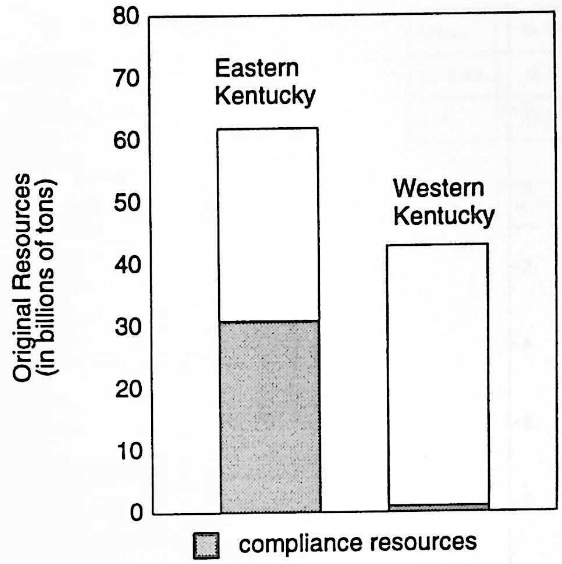


Figure 2. Original coal resources of the Eastern and Western Kentucky Coal Fields greater than 14 inches in thickness without regard to mineability or recoverability and their estimated compliance.

is an effective sulfur–reduction method, valuable coal is lost in the process of high–grading.

THE PROBLEM OF SULFUR IN COAL

When coal is burned, sulfur in the coal is released and combines with oxygen to form sulfur dioxide, which is released as a gas into the air. The SO_2 gas reacts in

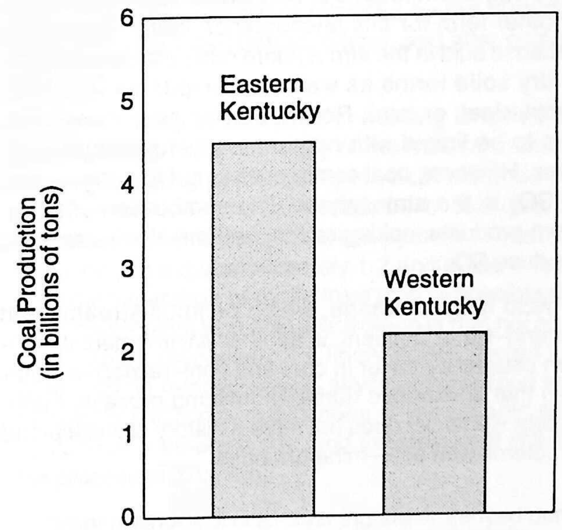


Figure 3. Total production of Kentucky coal from the Eastern and Western Kentucky Coal Fields.

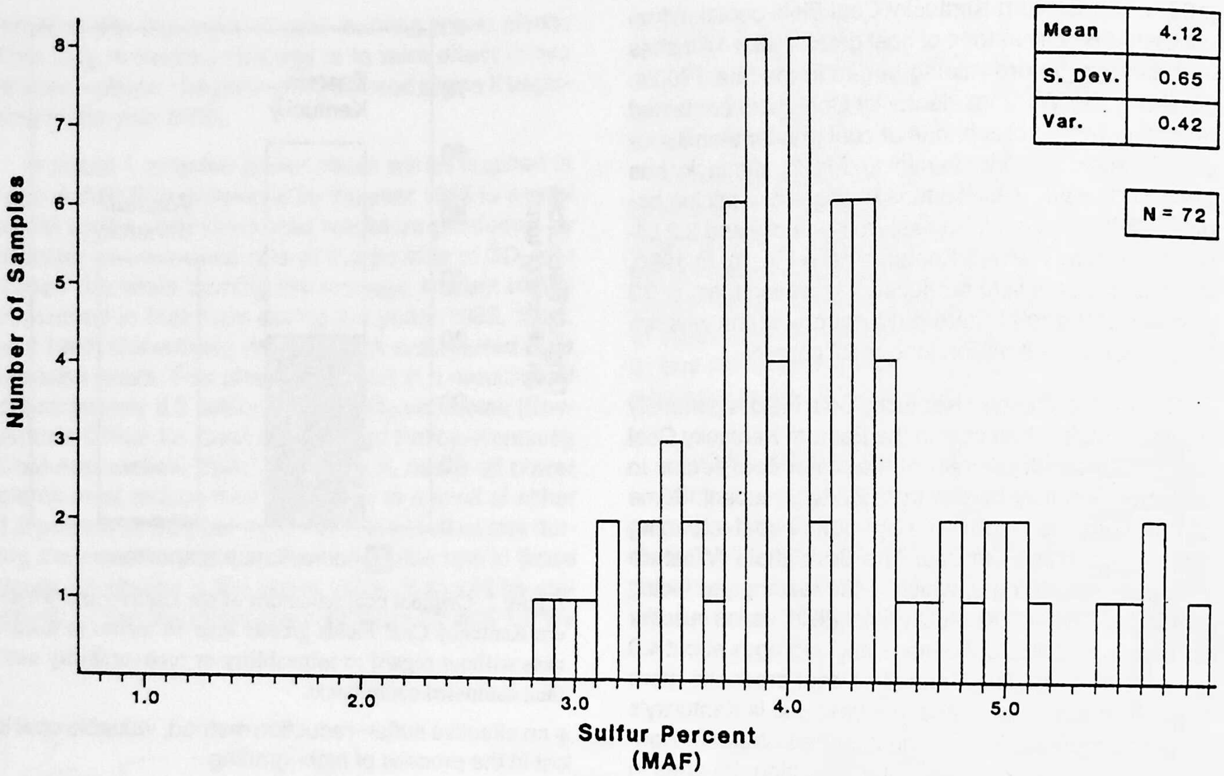


Figure 4. Total sulfur content in channel samples of the Springfield (Western Kentucky No. 9) coal bed of the Western Kentucky Coal Field. From Cobb and others (1982).

the atmosphere with water to form sulfuric acid (H_2SO_4), which returns to earth in the form of acid rain. Another term for this phenomenon is *acid deposition* because acid in the atmosphere can be carried to earth in dry solid forms as well as precipitation (such as snow, sleet, or rain). Recent studies have shown acid rain to be linked with numerous environmental problems. However, coal combustion is not the only source of SO_2 in the atmosphere. The combustion of petroleum products, coking ovens, and metal smelters also produce SO_2.

Acid mine drainage, which pollutes streams and ground–water aquifers, is another environmental problem caused by sulfur in coal and coal–related overburden that is exposed during the mining process. Fortunately, Kentucky does not have a history of widespread problems with acid–mine drainage.

THE FORMS OF SULFUR IN COAL

Sulfur in coal can occur in organic and inorganic forms. In the organic form, sulfur is chemically bound to various organic compounds that make up the coal. In the inorganic form, it occurs predominantly as the mineral pyrite, FeS_2. Several types of pyrite occur in coal seams. Some pyrite is easily seen with the unaided eye, but other types require microscopic examination. Fresh pyrite has a metallic golden appearance, which is the reason for its informal name, *fools gold.* Pyrite concretions are large spheres of pyrite in coal and associated strata. Pyrite also occurs in veins in coal beds and in coal cleats. Microscopic forms of pyrite include pore fillings (Fig. 9), framboids (Fig. 10), and crystals (Fig. 11).

Organic sulfur cannot be seen because it is chemically bound to organic molecules. It typically ranges from 0.4 to 0.8 percent, while pyritic sulfur content ranges from 0.3 to 9.0 percent.

THE ORIGIN OF SULFUR IN COAL

Although the origin of sulfur in coal is highly complex, both chemically and geologically, it can be summarized into rather simple terms. Sulfur is a fundamental chemical element found in all living matter, both plant and animal. Plants living today contain from 0.1 to 3.0 percent sulfur. Because coal is formed from partial-

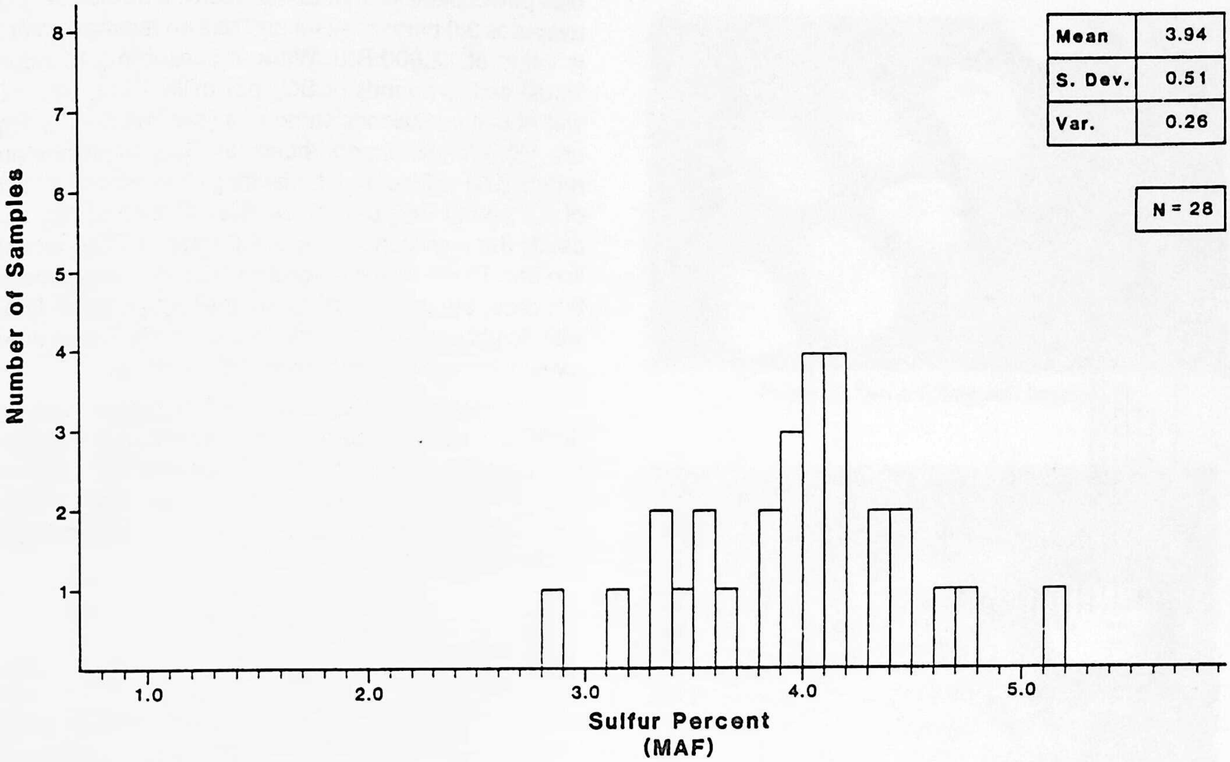


Figure 5. Total sulfur content in channel samples of the Herrin (Western Kentucky No. 11) coal bed of the Western Kentucky Coal Field. From Cobb and others (1982).

ly decomposed plant material called peat, it contains naturally occurring sulfur from plants.

Sulfur can also be introduced into coal during the conversion from peat to coal. In this process the peat is buried beneath sediments, some of which were deposited with ocean water. Since ocean water contains dissolved sulfur, more sulfur can be carried into the coal–forming peat and become chemically bound to it.

Pyrite, the dominant form of sulfur in coal, can form during both early and late stages of the coal–forming process. Framboidal pyrite (shown in Figure 10) is a type of early–forming pyrite. In contrast, vein– and cleat–filling pyrite are formed in the late stages of the coal–forming process. These types of pyrite are referred to as late because the peat had become brittle enough to crack and allow sulfur–bearing fluids to permeate and deposit minerals in the fractures.

METHODS OF SULFUR REMOVAL

The Federal government and private industry are currently investing billions of dollars in research on clean coal technologies aimed at reducing sulfur dioxide and other gaseous emissions from coal combustion. The amount of sulfur released by the burning of coal can be reduced before, during, and after combustion.

The cleaning of coal prior to burning is called coal preparation. It removes many of the mineral impurities in coal, including pyrite, using physical methods (Fig. 12). This method is the most common for coal cleaning. The difference in density between pyrite and coal is so large, coal being approximately 1.2 and pyrite 5.0, that physical separation of pyrite from coal is possible (Fig. 12). The problem with coal preparation is that not all the pyritic sulfur (especially the finely disseminated varieties) can be removed using physical separation techniques. In addition, virtually none of the organic sulfur can be removed physically, and valuable coal is lost in the process of cleaning.

Other methods of coal cleaning are employed during and after the combustion process and include fluidized–bed combustion (FBC) and flue–gas desulfurization (FGD; also referred to as "scrubbing") (Fig. 12). Fluidized–bed combustion involves burning coal in a

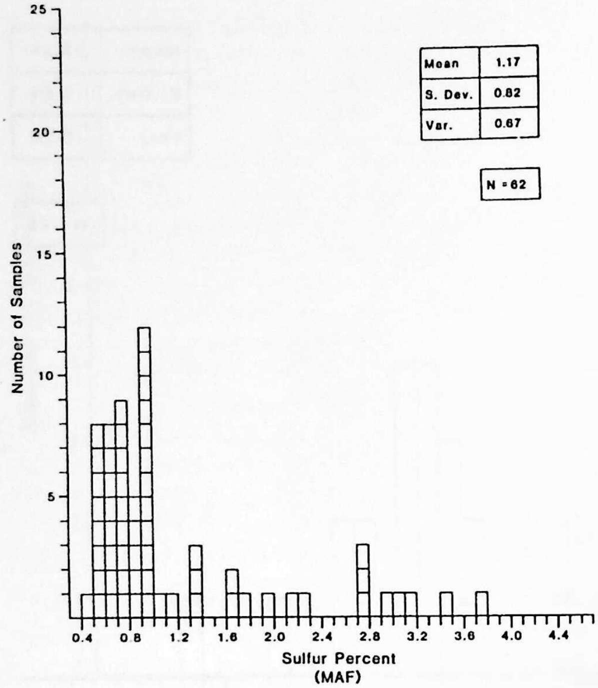


Figure 6. Total sulfur content in channel samples of the Lower Elkhorn–Pond Creek coal bed of the Eastern Kentucky Coal Field. From Cobb and others (1982).

bed of crushed limestone, into which compressed air is injected. As the coal burns, sulfur is released and reacts with limestone, calcium carbonate ($CaCO_3$), to form calcium sulfate ($CaSO_4$), an inert solid. This process prevents sulfur from entering the atmosphere. In Kentucky three commercial plants have installed fluidized–bed combustion units in steam–generating systems, including a 160–megawatt utility-scale demonstration plant, the Shawnee Plant, operated by the Tennessee Valley Authority, near Paducah, Kentucky (Fig. 13). Fluidized–bed combustion units in the State have used both limestone and dolomite as sulfur sorbents.

Flue–gas desulfurization units are large devices attached to new or existing coal–burning plants that remove sulfur from gaseous emissions. They work by spraying a mixture of water and calcite or lime into the escaping flue gas (Fig. 12), which, like the fluidized–bed combustion process, reacts with the gaseous sulfur to form calcium sulfate. The calcium sulfate byproduct of both processes is then disposed of, usually by burial. Wet–scrubbing systems for flue–gas desulfurization have been installed at 10 coal–fired power plants in Kentucky (Fig. 13). Limestone is the scrubbing reagent at four plants and lime is used in six plants.

An example of SO_2 reduction using flue–gas scrubbers is the Tennessee Valley Authority's (TVA) Paradise power plant in western Kentucky. It burns coal that averages 3.0 percent sulfur and has an average calorific value of 12,000 Btu. Without scrubbing, this coal would emit 5 pounds of SO_2 per million Btu, which is well above compliance standards (*see* line B–B' in Figure 13). With scrubbers, however, SO_2 emissions are reduced 88 to 90 percent, resulting in an emission level of 0.6 pound SO_2 per million Btu. This reduction exceeds the emission ceiling of 1.2 pounds SO_2 per million Btu. The resulting earned emissions allowances, in this case, are used to offset an operating unit not fitted with scrubbers that is producing more SO_2 than is allowed (Jim Brewer, TVA, personal commun.).

Limestones from Kentucky of Mississippian and Ordovician age have performed successfully as sulfur sorbents. Pilot–plant tests indicate that a variety of Kentucky dolomites and limestones would work effectively in both fluidized–bed combustion and flue–gas desulfurization systems (Fig. 14).

COMPLIANCE COAL

So–called compliance coal can be burned without scrubbing or other emission–reduction devices. An emissions level of 1.2 pounds SO_2 per million Btu is often cited as the compliance coal standard because a large number of power plants are required to meet this

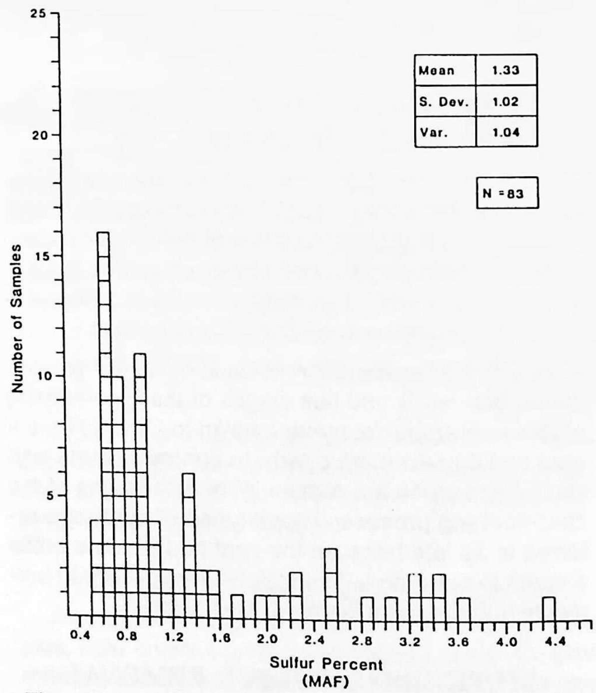


Figure 7. Total sulfur content in channel samples of the Upper Elkhorn No. 3 coal bed of the Eastern Kentucky Coal Field. From Cobb and others (1982).

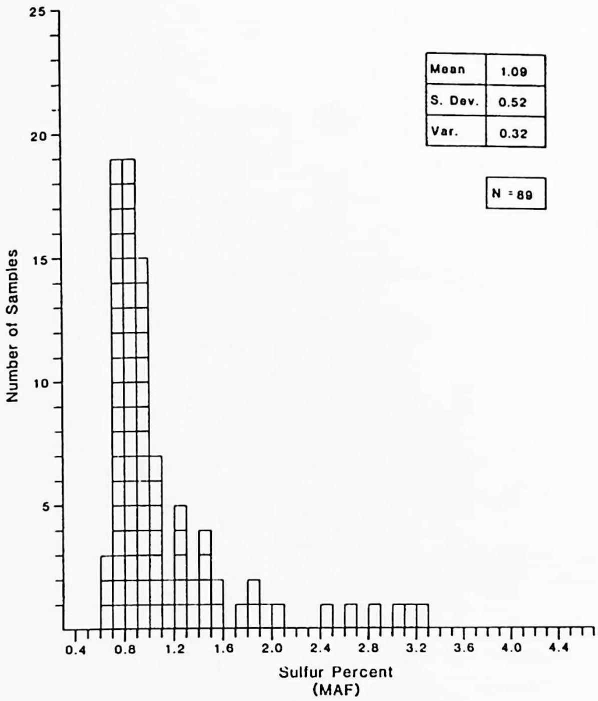


Figure 8. Total sulfur content in channel samples of the Fire Clay coal bed of the Eastern Kentucky Coal Field. From Cobb and others (1982).

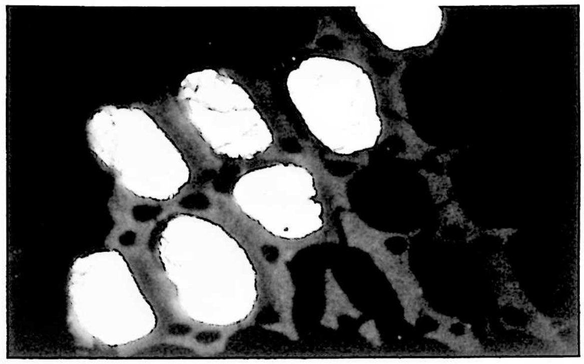


Figure 9. Pyrite filling cell lumens.

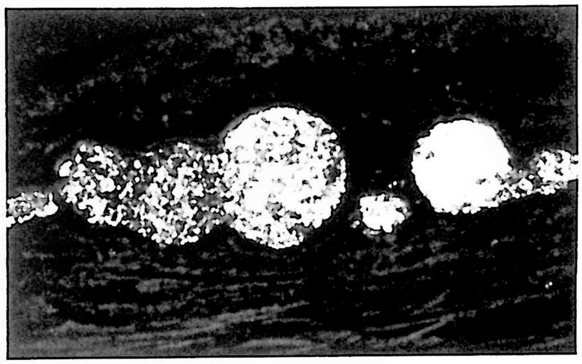


Figure 10. Pyrite framboids. Each framboid is composed of many individual pyrite crystals.

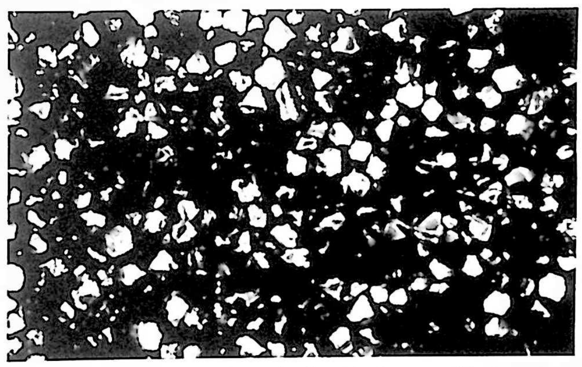


Figure 11. Isolated pyrite euhedra. Each crystal is less than 15 microns in diameter.

limit. However, a number of provisions and limitations inherent to the Acid Rain Bill, many of which are site–specific, will force some power plants to meet even lower SO_2 emissions levels. The compliance status of a coal is determined by its total sulfur content and its calorific value, which is usually expressed in Btu per pound. For example, a coal containing 0.8 percent sulfur and 13,100 Btu per pound meets an SO_2 emissions standard of 1.2 pounds of SO_2 per million Btu. The formula, *pounds of SO_2 emissions per million Btu = 20,000 times percent sulfur divided by the calorific value in Btu per pound,* can be used to calculate the SO_2 emissions that will result when a coal is burned. This formula can also be shown in a graph (Fig. 15). It should be noted that the calculation factor of 19,500 can also be used instead of the calculation factor of 20,000. The sulfur and Btu values used in this formula must be on the same basis (as determined, moisture free, or moisture and ash free).

Cobb and others (1982, 1989) characterized the coal resources of Kentucky in terms of their potential sulfur dioxide emissions. Figure 16 shows the potential sulfur emissions for eastern Kentucky coal resources. Approximately 51 percent of eastern Kentucky resources comply at 1.2 pounds of SO_2 per million Btu (Cobb and others, 1989). Gibian (1991) has determined that only about 20 percent of the coal shipped to power plants from eastern Kentucky meets a 1.2 pounds of SO_2 per million Btu compliance standard.

Figure 17 shows the resources of western Kentucky broken down by potential SO_2 emissions. Virtually none of these resources are within a 1.2 pounds of SO_2 per million Btu compliance standard (Cobb and others, 1989).

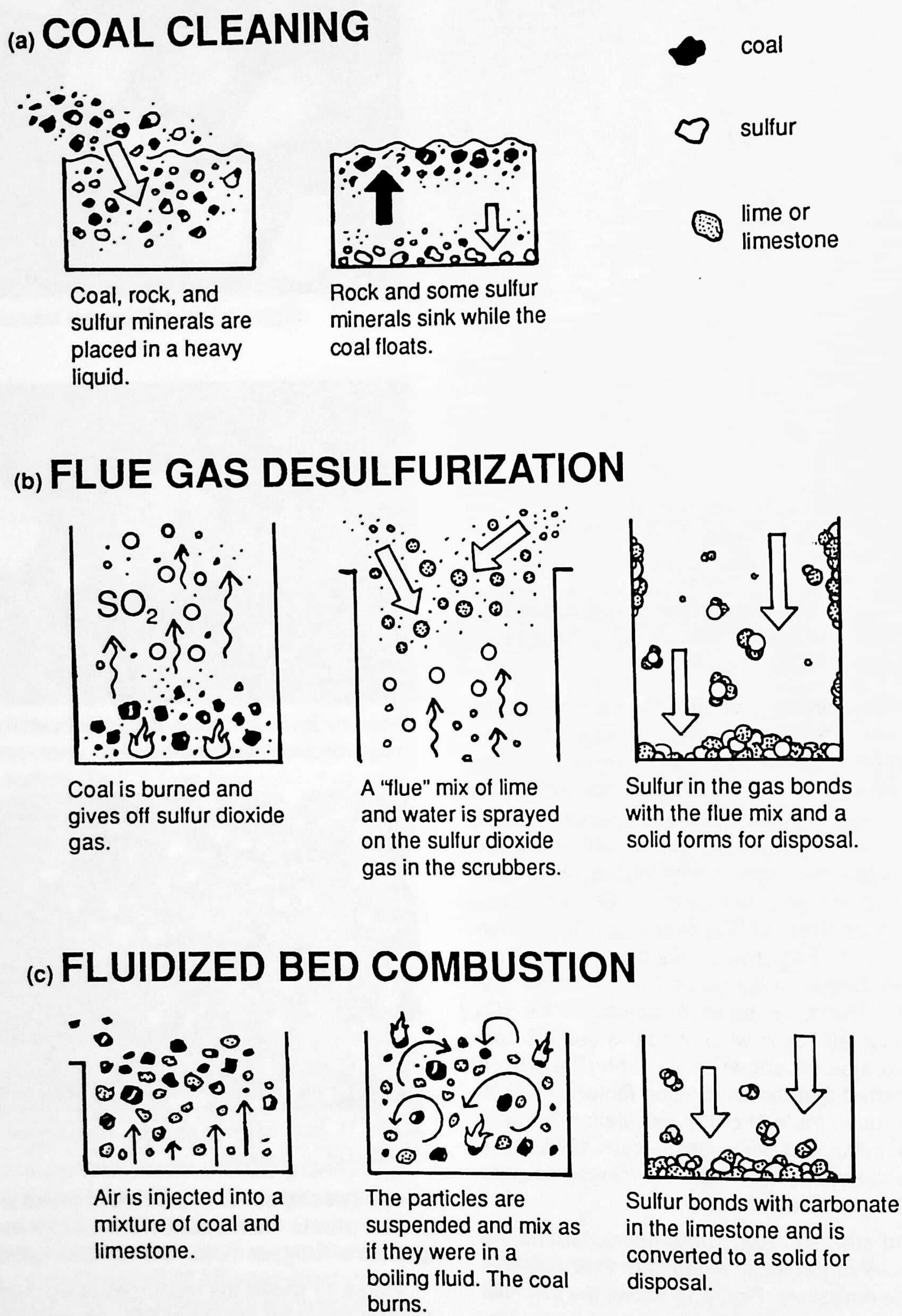
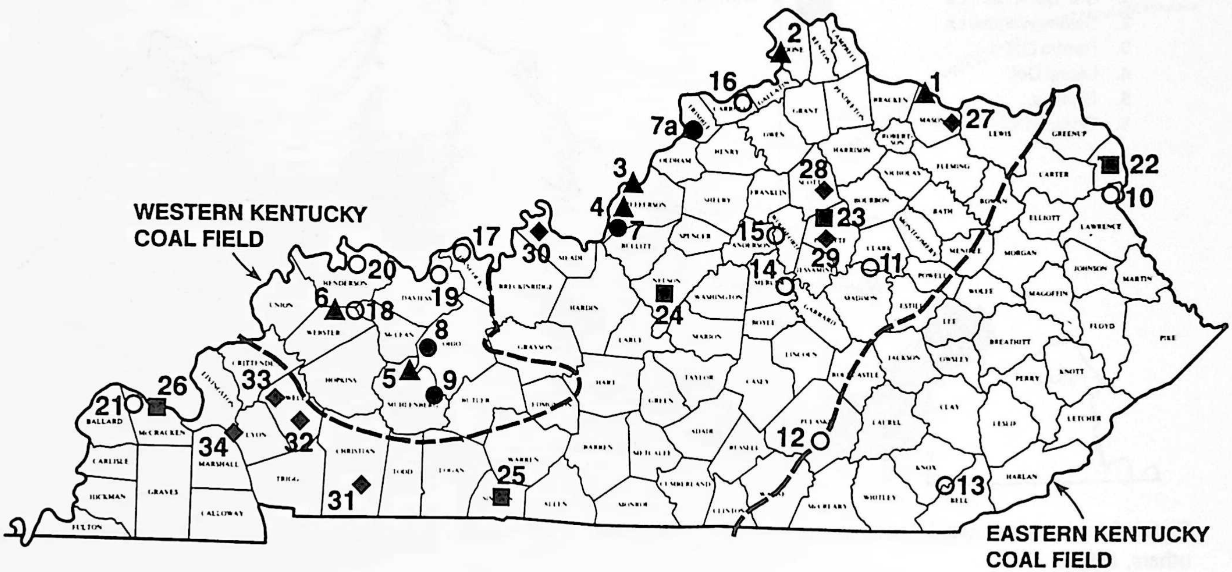


Figure 12. Schematic diagram of (a) coal cleaning/preparation, (b) flue–gas desulfurization, and (c) fluidized bed combustion.



Explanation

COAL–FIRED ELECTRIC–UTILITY PLANTS

▲ FGD—Lime

1. East Kentucky Power Spurlock—*inactive*
2. Cincinnati Gas & Electric East Bend—*active*
3. Louisville Gas & Electric Paddys Run—*inactive*
4. Louisville Gas & Electric Cane Run—*active*
5. Kentucky Utilities Green River—*active*
6. Big Rivers Electric Green—*active*

● FGD—Limestone

7. Louisville Gas & Electric Mill Creek—*active*

7a. Louisville Gas & Electric Trimble—*active*

8. Big Rivers Wilson—*active*
9. Tennessee Valley Authority Paradise—*active*

○ Low– and Medium–Sulfur Coal

10. Kentucky Power Big Sandy—*active*
11. East Kentucky Power Dale—*active*
12. East Kentucky Power Cooper—*active*
13. Kentucky Utilities Pineville—*active*
14. Kentucky Utilities Brown—*active*
15. Kentucky Utilities Tyrone—*active*
16. Kentucky Utilities Ghent—*active (FGD limestone being installed; target date, 1995)*
17. Big Rivers Coleman—*active*
18. Big Rivers Reid—*active*
19. Owensboro Municipal—*active (FGD limestone being installed; target date, 1995)*
20. Henderson Municipal—*active*
21. Tennessee Valley Authority Shawnee—*active*

■ FBC Plants

22. Ashland Petroleum Co.—*active*
23. University of Kentucky—*research/demonstration*
24. Bardstown Fuel Alcohol Co.—*inactive*
25. Kentucky Agricultural Energy Corp.—*inactive*
26. Tennessee Valley Authority Shawnee—*active*

◆ Quarry/Mine

27. Dravo Lime Co. mine
28. Nally & Gibson Georgetown Inc. quarry
29. Vulcan Materials Co. mine
30. Kosmos Cement Co. quarry
31. Hopkinsville Stone Co. quarry
32. Kentucky Stone Co. quarry
33. Fredonia Valley Quarries quarry
34. Reed Crushed Stone Co. quarry

Figure 13. Coal–burning power plants in Kentucky equipped with scrubbers and fluidized–bed combustion furnaces (modified from Enoch, 1983).

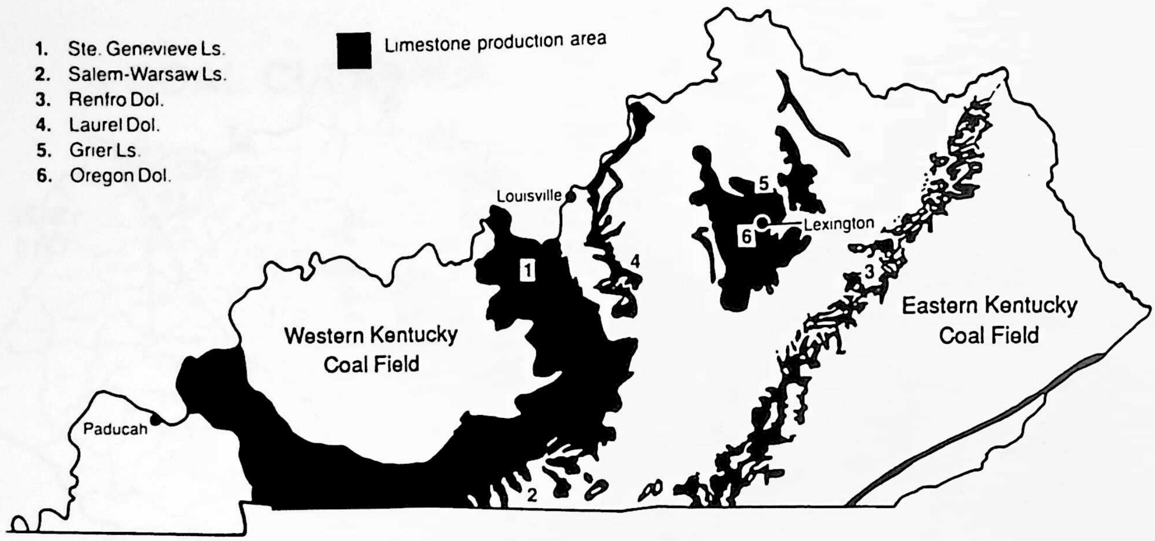


Figure 14. Limestone and dolomite resources in Kentucky available for sulfur–removal technology. Modified from Barron and others, 1991).

When phase II of the Clean Air Act Amendments takes effect in the year 2000, and many power plants cannot emit more SO_2 than would have been emitted by burning a coal with 1.2 pounds of SO_2 per million Btu for the average amount of Btu burned in the base-line years of 1985, 1986, and 1987, some plants are expected to adopt sulfur–reduction technology to comply with this regulation, while others will burn compliance coal. Some utilities may opt to "overcomply" (produce less SO_2 than is required) with one unit by using emissions control devices, and apply the gained allowance credits to another unit that is "undercomplying" (producing more SO_2 than is allowed). This practice would allow the utility to run both units and remain within compliance standards.

THE FUTURE OF COAL IN KENTUCKY

Coal in Kentucky will continue to be both a major energy resource for the Nation and a valuable asset for the Commonwealth. Substantial reserves of mineable coal within sulfur compliance standards still exist in Kentucky. These reserves will be of great importance in the years to come. However, it is not yet possible to remove enough sulfur to meet emission standards prior to combustion for a large portion of Kentucky's coal reserves. Fortunately, it is possible to remove much of the sulfur from these coals during and after the burning process using scrubbing and fluidized bed combustion technologies.

In the future, coal–burning utilities will be faced with several options in order to reduce SO_2 emissions. These options include: (1) burn low–sulfur compliance

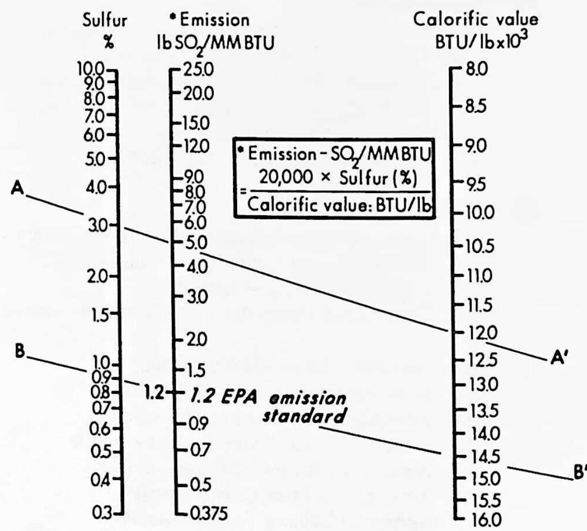


Figure 15. Method to determine potential SO_2 emissions from sulfur content and Btu value. Line A–A' represents a typical non–compliance western Kentucky coal with 3.0 percent sulfur and a calorific value of 12,000 Btu/lb. Note the emission rate of 5 lb. SO_2/mmBtu. Line B–B' represents a typical compliance eastern Kentucky coal with 0.9 percent sulfur and a calorific value of 14,500 Btu/lb. In this case, the emission rate is 1.2 lb. SO_2/mmBtu, within EPA compliance standards. Modified from Cavallaro and others (1976).

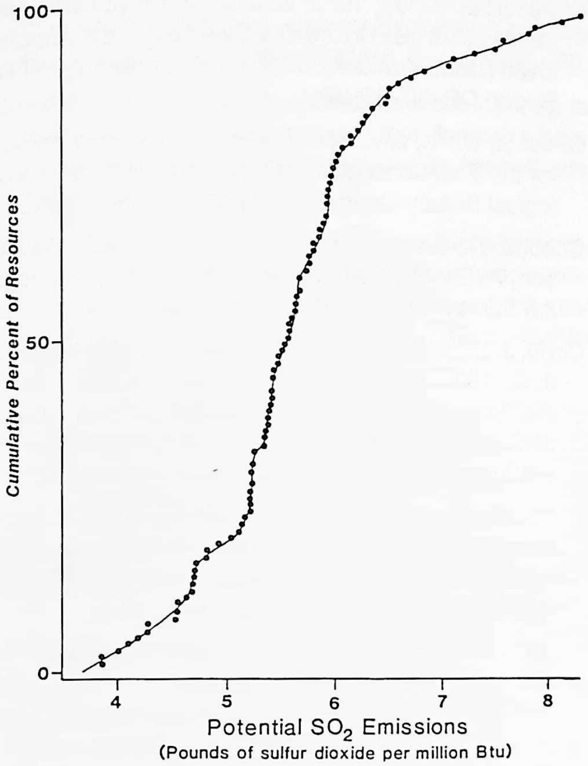


Figure 16. Cumulative distribution of potential SO_2 emissions for western Kentucky coal resources.

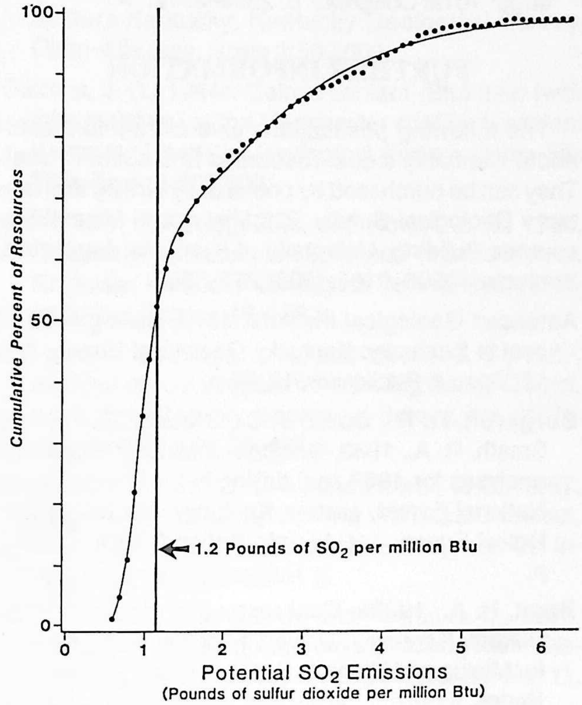


Figure 17. Cumulative function of potential SO_2 emissions for eastern Kentucky coal resources.

coal in conventional furnaces, (2) burn high–sulfur coal in furnaces equipped with sulfur–reducing devices, (3) burn less high–sulfur coal, (4) "overcomply" at one facility and transfer earned emissions allowances to units that "undercomply," or (5) purchase the necessary emissions allowances from other utilities.

Coal is Kentucky's most important mineral resource and is responsible for generating nearly all of the electricity used in the State. Because coal plays such an important role in the Commonwealth's economy and the energy needs of this State, it is an important issue to every citizen of Kentucky. It is hoped that this brief overview will help answer some questions about sulfur in Kentucky coal and how Kentucky will be affected by the Acid Rain Bill.

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FURTHER INFORMATION

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