Chapter H

Production and Depletion of Appalachian and Illinois Basin Coal Resources

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Edited by Brenda S. Pierce and Kristin O. Dennen

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Production and Depletion of Appalachian and Illinois Basin Coal Resources

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Abstract

Most of the coal consumed in the United States since the beginning of the 19th century has been produced from the Pennsylvanian strata of the Appalachian and Illinois Basins. Until 1970, these two basins, combined, produced 85 to 95 percent of the Nation's coal annually. During the last 25 years, however, the proportion of the Nation's annual coal production from these basins has declined markedly and today (2005 data) is only about 43 percent of the U.S. total, even though the two basins combined produce about 490 million tons annually. Tons, as used in this report, refers to short tons (2,000 lb) unless otherwise specified.

To meet the demands of the electrical-power-generating industry, the amount of coal produced annually in the Appalachian Basin has been rising slowly over the last several decades, from about 308 million tons in 1961 to 397 million tons in 2005. Historically, during the past two centuries, a large proportion of Appalachian production has come from a relatively few counties in southwestern Pennsylvania, northern and southern West Virginia, eastern Kentucky, and Virginia. Many of these counties are decades past their years of peak production, and several are almost depleted of economic deposits of coal. Because the major consumer of Appalachian and Illinois Basin coal is the electrical-power industry, coal quality, especially sulfur content, is an important consideration for its marketability.

In the Appalachian Basin, high-sulfur coal deposits in western Pennsylvania and Ohio are in low demand when compared with the low-sulfur coals of Virginia, southern West Virginia, and eastern Kentucky. At present, only 10 counties in the basin with a cumulative production of 500 million tons or more are producing coal at relatively high levels and are increasing in production. Of these, nine are in the central part of the basin, in West Virginia, Kentucky, and Virginia, and only one, Greene County, Pennsylvania, is in the northern part of the basin. The coal-production models presented herein, which are based either on annual production-decline rates or on the projected rate of depletion of estimated economically producible resources, or "potential reserves," indicate that annual coal production from the Appalachian Basin will enter into a period of irreversible decline during the next several decades as these several counties are depleted. Coal production may be 200 million tons or less by the middle of this century unless large blocks of coal are discovered and developed in the deep, unmined part of the basin, or unless the large amounts of remaining medium- and high-sulfur coal resources are utilized by industry.

Coal production from the Illinois Basin began in the early 1800s. Since then, production trends have followed the same economically driven cycles as Appalachian Basin production, with major peaks coincident with World War I, World War II, and a third cycle driven by increasing demand for coal-fired electrical-power generation that began in the early 1960s. Since the 1960s, however, annual production of coal from the Appalachian Basin has not reached the levels attained during World Wars I and II. Unlike the Appalachian Basin, coal production from the Illinois Basin exceeded the annual production levels it attained during the two World Wars several times in the 1970s and twice since then, in 1984 and in 1990. Since 1990, however, with the implementation of the Clean Air Act, production of the relatively high sulfur coal resources of the Illinois Basin has declined sharply, from 144 million tons in 1984 to 93 million tons in 2005. Only two counties in the Illinois Basin, Saline County in Illinois, and Webster County in Kentucky, have produced 10 million tons or more annually at least once during the 1990s. At current decline rates, Illinois Basin coal production could be as little as 70 million tons annually by 2010. Instead, because of the large coal resources remaining in the Illinois Basin and the increasing demand for coal to produce petroleum liquids and electricity in response to declining petroleum reserves, it is likely that Illinois Basin coal production will increase during the next several decades.

Introduction

Although small quantities of coal were first produced from the Appalachian Basin (fig. 1) in the early 1700s, the first production statistics of significance were gathered during the census of 1830 (Eavenson, 1942). Since then, about 35 billion tons of bituminous coal has been produced from the

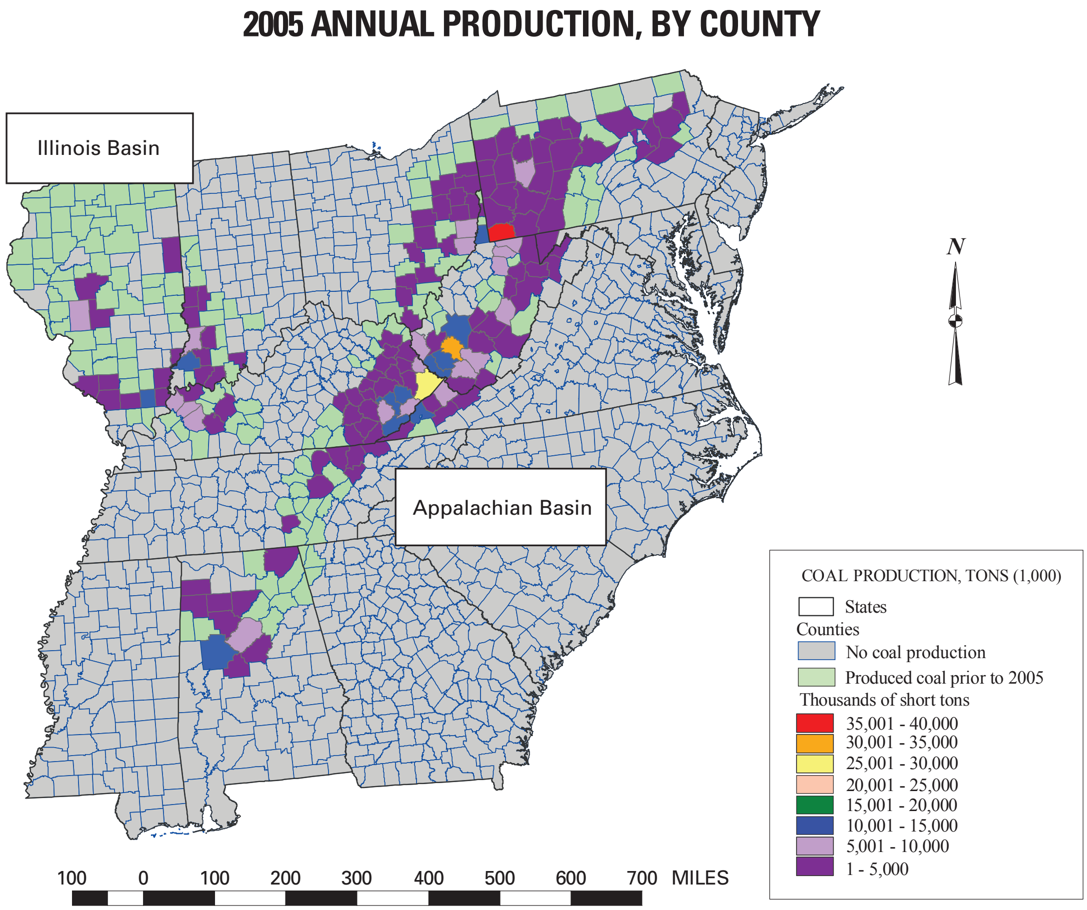


Figure 1. Location and extent of Appalachian and Illinois Basins, showing 2005 coal production, by county, and the extent of previous coal production (data from Energy Information Administration, 2000a).

Appalachian Basin from an original potential coal reserve ($PCR_{(0)}$) estimated herein to range from about 60 to 90 billion tons. The term "reserve" refers to economically producible coal, and a "potential coal reserve" ($PCR_{(N)}$) is a general estimate of the amount of coal that may be economically recoverable in a region (State, coal field) over a defined time period (N = 20, 30, and so forth, years) and under a range of economic, societal, and technological conditions. Thus, cumulative production plus $PCR_{(N)}$ equals estimated cumulative production ($ECP_{(N)}$) in (N) years. The term "resources" refers to the amount of coal in the ground, both economic and noneconomic. With time, increased demand for energy in competitive markets, together with improvements in technology and the development of new uses for coal of certain characteristics, commonly increases the amount of coal that may be extracted economically, so that $PCR_{(N)}$ "grows."

The purpose of this paper is to present and analyze the historical production data and trends for the Appalachian Basin, with an emphasis on the central and northern parts of the Appalachian Basin, and for the Illinois Basin, by State, by coal-producing region, and by county. The northern Appalachian bituminous coal fields consist of deposits of Pennsylvanian age in Pennsylvania, Ohio, and northwestern West Virginia. The central Appalachian coal fields encompass eastern Kentucky, southern West Virginia, and southwestern Virginia. The southern Appalachian coal fields include the Pennsylvanian deposits of Tennessee, Georgia, and Alabama. In the Illinois Basin, Pennsylvanian-age coal underlies a large part of Illinois, west-central Indiana, and western Kentucky. The historical production data, coupled with coal-quality information, are used herein to estimate future coal-production trends in both the Appalachian and Illinois Basins.

This paper is based primarily on a digital, historical, coal-production database by county, by region, and by State for the Appalachian and Illinois Basins. Sources of the original data include several State geological surveys (Carroll, 1994; Crowell, 1995; Currens and Smith, 1977; Hibbard 1990), the U.S. Geological Survey (USGS) (U.S. Geological Survey, 1907–1926), the former U.S. Bureau of Mines (USBM) (U.S. Bureau of Mines, 1927–1933, 1933–1976), and the U.S. Department of Energy, Energy Information Administration (EIA) (Energy Information Administration, 1979–1993, 1979, 1994–2006). Some of these data are available digitally on the Internet (Milici, 1997b). This report, and others like it (Milici, 1996a, 1996b, 1997a, 1998, 2000; Milici and Campbell, 1996, 1997), are products of the U.S. Geological Survey's National Coal Resource Assessment Project.

Major Production Cycles

Until the latter part of the 20th century, the Appalachian Basin consistently led all other regions of the country in coal production, and until 1970 the basin produced 70 percent or more of the coal produced annually in the Nation (fig. 2). Since 1970, however, production from coal fields in the Western United States has increased significantly, and the relative amount of coal coming from the Appalachian Basin has declined from about 70 percent to about 35 percent in 2005.

The Illinois Basin supplied from about 15 to 24 percent of the Nation's coal needs during the middle of the 20th century. More recently, production from the basin has continued to decline in spite of the increased demand for coal, and the Illinois Basin prodduced about 8 percent of the coal in the United States in 2005 (fig. 2). The percentage of the Nation's coal produced collectively from the Appalachian and Illinois Basins had declined from more than 90 percent of the coal produced in the United States during much of the 20th century to a little less than half of the Nation's coal production by the end of the 20th century.

Historically, coal production from the Appalachian and Illinois Basins may be divided into three economically driven cycles (fig. 3). The peak rates of coal production during two of these cycles are the result of the increased industrial demands that occurred during World Wars I and II, and the third cycle is based upon a more recent decision of the electrical-power industry to use coal as its primary fuel for power generation, rather than nuclear power. These cycles occurred (1) from the days of early mining in the mid-to late 1800s through World War I (1914) to the Depression (1921), (2) from the Depression through World War II (1944) to a post-War economic adjustment, and (3) from this adjustment (1970) through the current period of ever-increasing demand for coal by the electrical-power industry. Overall, annual coal production from the Appalachian Basin has declined only a little since 1990 during this third production cycle, in spite of Clean Air Act restrictions and rigorous competition from other coal-producing areas of the country. Appalachian Basin coal is very much in demand and, even though 35 billion tons has been mined since 1830, the resource has not yet been economically depleted. In contrast, production of high-sulfur coal from the Illinois Basin declined markedly in the 1990s in spite of a very large remaining resource, chiefly as a result of Clean Air

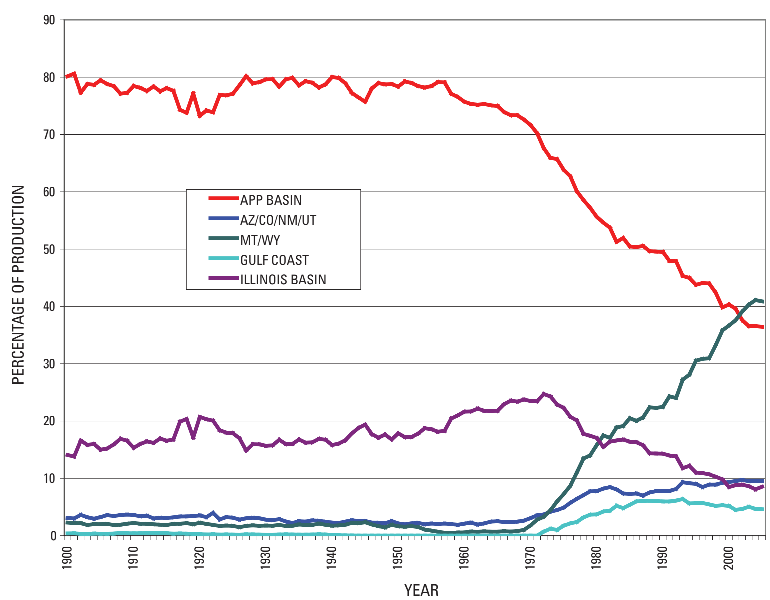
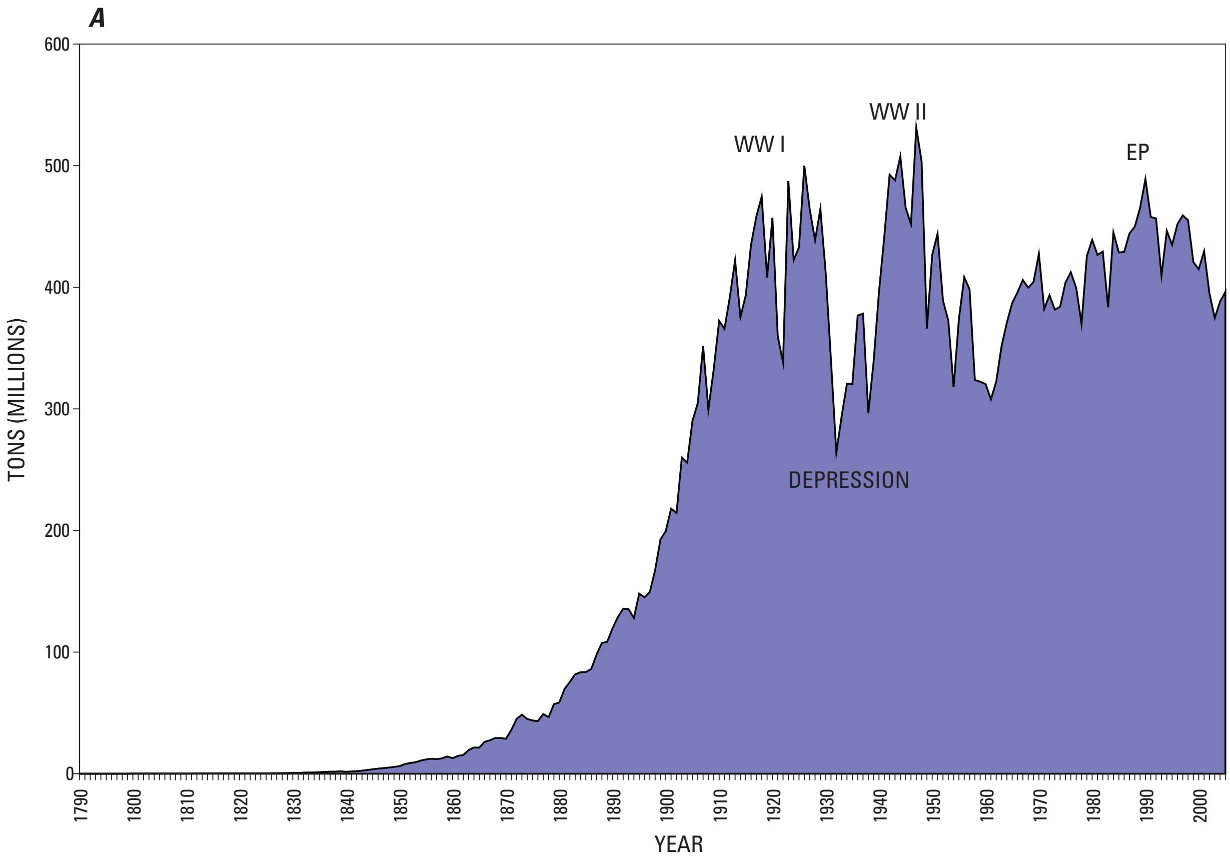


Figure 2. Percentage of national coal production from the major coal-producing regions of the United States. APP BASIN, Appalachian Basin; AZ, Arizona; CO, Colorado; NM, New Mexico; UT, Utah; MT, Montana; WY, Wyoming. See "Introduction" for sources of data.


A
TONS (MILLIONS)
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500
400
300
200
100
0
WW I
WW II
EP
DEPRESSION
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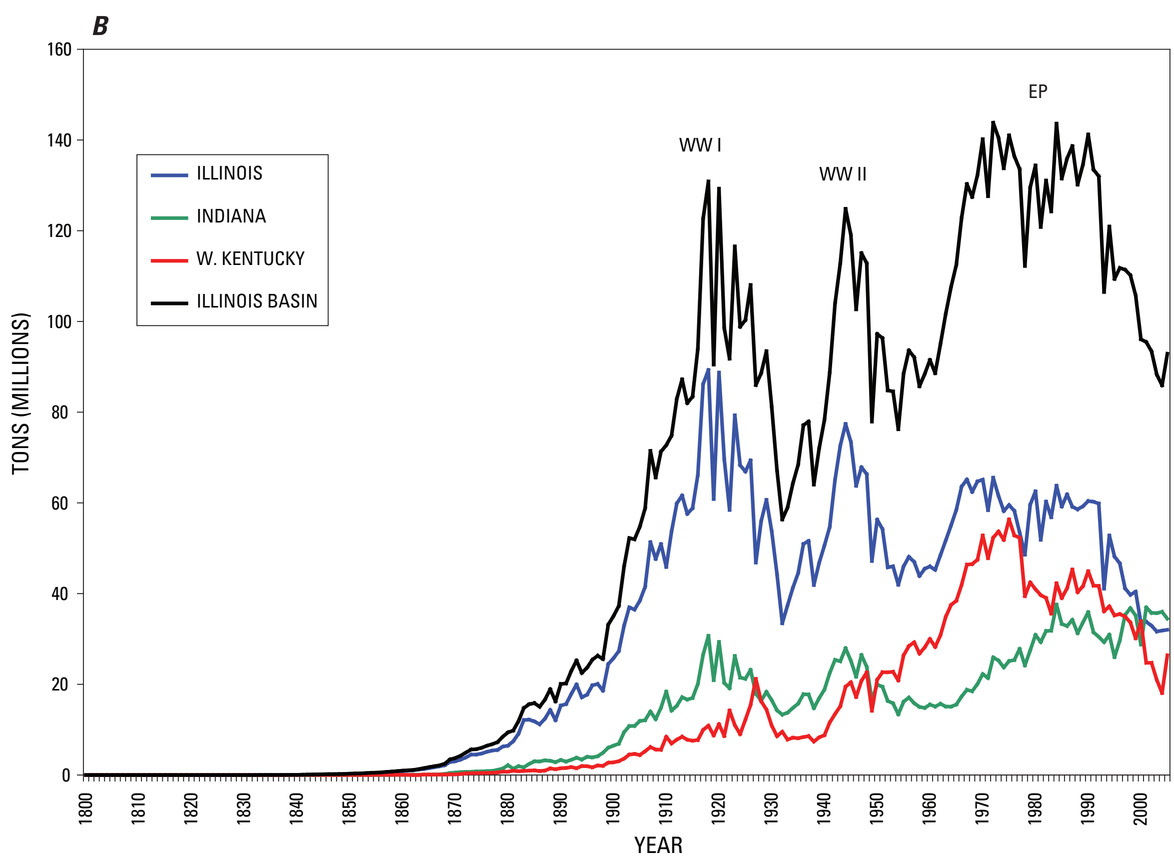
B
TONS (MILLIONS)
160
140
120
100
80
60
40
20
0
ILLINOIS
INDIANA
W. KENTUCKY
ILLINOIS BASIN
WW I
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EP
1800
1810
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1830
1840
1850
1860
1870
1880
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1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
YEAR

Act restrictions and competition from low-sulfur western coal fields for traditional Illinois Basin markets.

Regionally within the Appalachian Basin, production trends on a county-by-county basis exhibit a much different picture. Many counties that produced most of the coal from the Appalachian Basin during the early and middle parts of the 20th century have been significantly depleted so that their remaining economic resources are small and their current production is low and continuing to decline.

Similarly, the proportion of the Nation's coal produced from the Illinois Basin has declined from approximately 24 percent in 1976 to 8 percent in 2005. About 11 billion tons of coal has been produced from the Illinois Basin since the inception of mining in the mid-1800s. In contrast with the Appalachian Basin, the amount of coal produced from the Illinois Basin has declined sharply in recent years (fig. 3*B*). Production from the basin peaked in 1973, and again in 1985 at about 144 million tons, and since then has declined generally to about 93 million tons in 2005.

Effects of Clean Air Standards on Appalachian Coal Production

Although abundant amounts of coal exist in the Appalachian and Illinois Basins, there is a wide range in the quality of its resources. Because much of the coal produced in the Appalachian and Illinois Basins is, at present, used in electrical-power generation, coal quality, especially sulfur content, has a major function in determining the economic viability of these deposits. Based on the Federal Clean Air Act of 1970 and its amendments in 1990, the emission-control standard established by the U.S. Environmental Protection Agency (USEPA) is 1.2 pounds (lb) of sulfur dioxide (SO_2) (0.6 lb sulfur[S]) produced and emitted into the atmosphere for each million (MM) Btu's of specific energy (heat) produced. Title IV of the Clean Air Act Amendments of 1990 on electric utility emissions (Energy Information Agency, 1997) restricted SO_2 emissions in two phases. Phase-I restrictions, which were in effect from 1995 to 1999, allocated emission allowances to powerplants based on the basis of average annual Btu's that the plants burned from 1985 through 1987 multiplied by 2.5 lb SO_2 per million Btu's. In Phase II, which took effect on January 1, 2000, emission allowances are calculated by multiplying the average annual Btu's burned from a 1985 to 1987 baseline by 1.2 lb of SO_2. Although new powerplants may receive purchase allowances initially given to other units, they will not be allocated their own emission allowances. In addition to emission allowances, powerplants may comply with the standards of the Clean Air Act by switching to low-sulfur coal or by installing desulfurization units to remove SO_2 from waste flue gases.

In general, the use of lower sulfur coal was the compliance method of choice during Phase I and will most likely continue to be the choice during Phase II (Energy Information Agency, 1997), so long as there are sources of abundant, cheap, low-sulfur coal. The U.S. Energy Information Administration (EIA), however, predicted that, "While low-sulfur coal displaces high-sulfur coal throughout the forecast (to 2015), high-sulfur coal displaces more expensive medium-sulfur coal as compliance strategies shift from fuel switching to flue-gas desulfurization in Phase 2" (Energy Information Agency, 1996b, p. 71). Also Eastern U.S. coals, while higher in sulfur, are more suitable than lower rank Western U.S. coals for producing synthetic gas for new technologically advanced powerplants.

Sulfur Content of Appalachian and Illinois Basin Coals

In general, EIA classifies coal by sulfur content into three categories: low-sulfur coal, 0.6 lb or less (≤) S/MMBtu; medium-sulfur coal, 0.61–1.67 lb S/MMBtu; and high-sulfur coal, 1.68 lb S/MMBtu or more (≥). Low-sulfur coal, when burned, complies with the emission standard of 1.2 lb SO_2 per MM Btu's generated. Medium- and high-sulfur coals do not. EIA's (1998) estimate of recoverable reserves for the northern and central parts of the Appalachian Basin, by sulfur content, are shown in table 1. Although EIA does not separate its coal-quality data for West Virginia by coal field, most of the low-sulfur coal in West Virginia is in the central Appalachian fields, and most of the high-sulfur coal is in the northern Appalachian coal fields. The difference in sulfur content of coal from the northern Appalachian coal fields compared to the central Appalachian coal fields has had a profound effect on production from each of the regions.

Coal-quality data, for coal as-received at powerplants and reported as lb S/MMBtu of washed coal product (Attanasi and Milici, 1998), illustrate the distribution of sulfur in Appalachian coal beds by county. These maps demonstrate the occurrence of the relatively high sulfur coal in the northern part of the Appalachian Basin and relatively low sulfur coal in the central Appalachian Basin. Reserve estimates by sulfur content (Energy Information Agency, 1998, table 105) were used to illustrate the relative percentages of compliance and noncompliance coal by region (fig. 4).

Figure 3. (facing page) ***A***, Historical coal production from the Appalachian Basin, illustrating three major economic cycles, World War I (WWI), World War II (WWII), and growth in demand by the electrical-power industry (EP). ***B***, Historical coal production from the Illinois Basin illustrating three major economic cycles, World War I (WWI), World War II (WWII), and growth in demand by the electrical-power industry (EP).

Table 1. Estimated recoverable reserves (Energy Information Administration, 2000a) by sulfur content in northern and central Appalachian Basin and in the Illinois Basin (millions of tons).

Basin	Low sulfur	Medium sulfur	High sulfur	Total
APPALACHIAN				
Pennsylvania	280	5,747	5,609	11,635
Ohio	249	1,379	10,044	11,672
West Virginia	6,997	6,657	5,668	19,322
E. Kentucky	2,180	3,101	1,469	6,750
Virginia	782	508		1,290
Total	10,488	17,392	22,790	50,669
ILLINOIS				
Indiana	308	850	3,130	4,287
Illinois	234	1,947	36,025	38,206
W. Kentucky		155	9,072	9,227
Total	542	2,952	48,227	51,720

Figure 4*B* illustrates the almost complete absence of compliance coal (≤ 0.6 lb S/MM Btu) in the northern part of the Appalachian Basin. Almost all of the low-sulfur coal in the Appalachian Basin is in the central Appalachian coal fields, in eastern Kentucky, southern West Virginia, and Virginia.

In general, net production from the Appalachian Basin has increased in spite of the production decline in the northern part of the basin. Eastern Kentucky, where about 43 percent of the coal meets compliance requirements (Cobb and others, 1995), exhibits an almost continuous growth in coal production, from 35 million tons in 1961 to 128 million tons in 1990. Since 1990, eastern Kentucky production declined to about 95 million tons in 2005. Coal production in southern West Virginia, however, declined during much of the 1970s to a low of 48 million tons in 1978. Since 1978, southern West Virginia's coal production rose almost continuously, in response to the demand for low-sulfur coal, to a peak of 113 million tons in 1992. Virginia's coal production, much of it mined for metallurgical purposes, peaked at nearly 47 million tons in 1990 and declined to about 28 million tons annually (2005). This decline has resulted partly from a decrease in demand for U.S. metallurgical-grade coal because of foreign competition, especially from Australia (Energy Information Administration, 2001) and partly from economic depletion of the resource. In comparison, Ohio's coal production has declined from 56 million tons in 1970 to 25 million tons in 2005, and Pennsylvania's from 89 million tons in 1979 to 55 million tons in 1993 because of low demand for high-sulfur coal. More recently, Pennsylvania's bituminous coal production rebounded to nearly 66 million tons in 2005, apparently because of the relatively low cost of the coal produced from highly efficient longwall operations in the Pittsburgh coal bed in Greene County. Much of this coal is used in powerplants equipped with scrubbers, and the Energy Information Administration (2000b) forecasts that about thirty-seven 300-megawatt plants will be retrofitted with scrubbers by 2020. Annual production of medium- to high-sulfur coal in northern West Virginia has oscillated during the last several decades, from about 37 to 55 million tons, and has shown little or no general increase in response to the current demand for coal for electrical-power generation.

The relative tonnage and percentage of low-, medium-, and high-sulfur coal in the Illinois Basin are illustrated in table 1 and figure 5. Although the basin contains almost 52 billion tons of coal as a potential coal reserve (38.2 billion tons in Illinois) (Energy Information Administration, 2000a, table 105), only about 1 percent of the resource is classified as low-sulfur, 6 percent as medium-sulfur, and 93 percent as high-sulfur coal. Figure 6 (Energy Information Administration, 2000a) summarizes the relative sulfur content of coal resources remaining in the major producing regions of the United States. By far, the largest resource (Energy Information Administration, 2000a, classifies them as reserves) of low-sulfur coal in

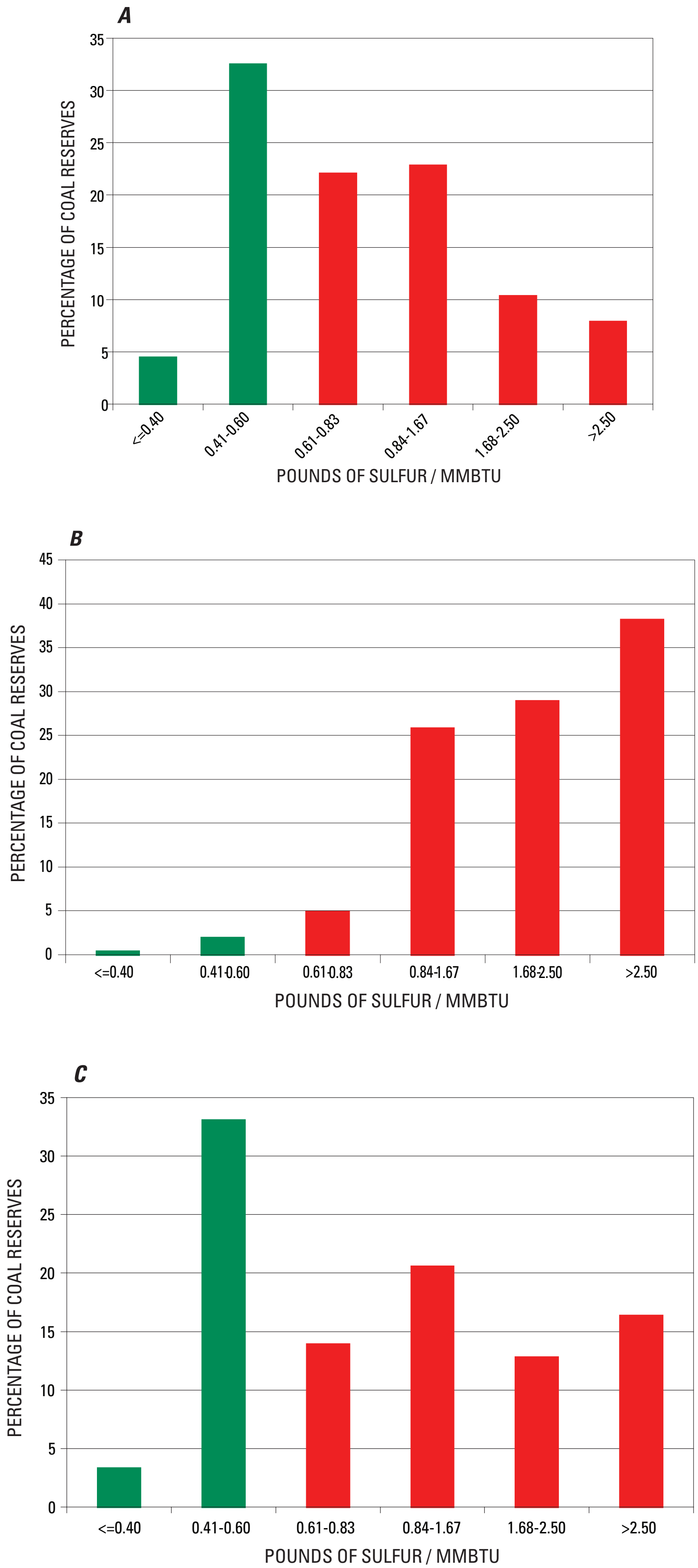

Figure 4. Relative sulfur content of Appalachian coal reserves (Energy Information Administration, 1998, table 105). Green bars indicate compliant coal; red bars indicate noncompliant coal. ***A***, Virginia and eastern Kentucky; ***B***, Pennsylvania and Ohio; ***C***, West Virginia. MMBtu, thousand thousand British thermal units.

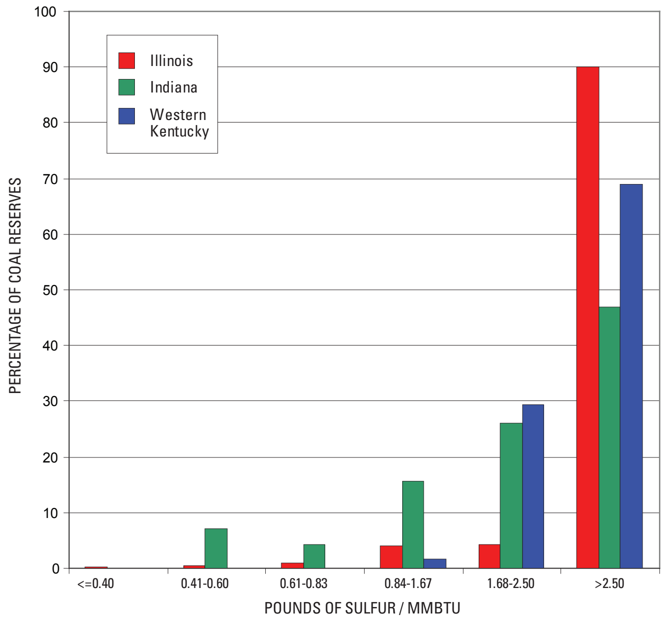

Figure 5. Sulfur content of Illinois Basin coal resources (Energy Information Administration,1998, table 105). Only Indiana has significant amounts of compliance coal.

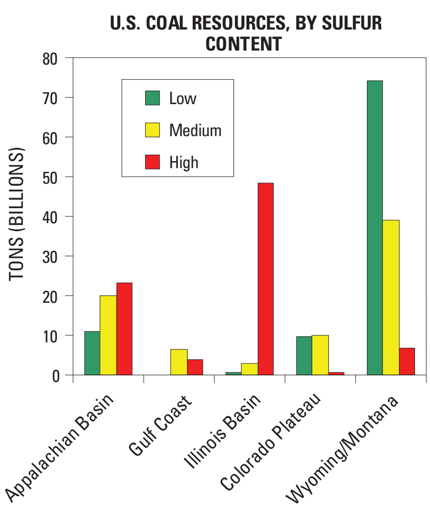

Figure 6. Relative amounts of low-, medium-, and high-sulfur coals in major producing basins of the United States. Appalachian Basin includes Black Warrior Basin.

the United States is in the Powder River Basin of Wyoming and Montana.

Effects of the Clean Air Act, Phase II, on Coal Production

Phase II of the Clean Air Act Amendments (CAAII), which went into effect at the beginning of the year 2000, restricted emissions of sulfur dioxide from coal-fired powerplants to 1.2 pounds per million Btu's (MMBtu). Compliance may be achieved by burning low-sulfur coal, by installing flue-gas desulfurization controls (scrubbers), or by the use of tradable emission allowances (one sulfur dioxide allowance permits 1 ton of sulfur dioxide emissions) (Energy Information Administration, 1997). As of 1997, for most of the operating units, the least expensive option for achieving compliance was to use or switch to burning low-sulfur coal (Attanasi, 1998).

Historical coal-production data from the central and northern parts of the Appalachian Basin are illustrated in figure 7. In the Eastern United States, almost all of the coal produced from the northern part of the Appalachian Basin and Illinois Basin is medium- to high-sulfur coal, and this has had a significant effect on production from these regions. Production data from the central and northern Appalachian coal fields (fig. 7*A*) show clearly the effects that the Clean Air Act had on coal production from each region in the years following 1970, when there was a sharp upturn in central Appalachian coal production concurrent with a sharp downturn in northern Appalachian production.

County-Level Coal-Production Data

For the Appalachian Basin, which has produced coal for more than two centuries, historical coal-production data, by county, may be used to define and describe the major coal deposits in the basin, the areas that have been largely depleted by long-term mining, and the areas of significant current production and potential. These county coal-production data include cumulative production, year of maximum production, amount of coal produced during the year of maximum production, and current year production (Milici, 1999). During the history of coal production from the Appalachian Basin, three general areas within the basin have supplied almost all of the coal from the region: a 13-county area in western Pennsylvania and adjacent Ohio and West Virginia, 13 counties in southern West Virginia and adjacent Kentucky, and 1 county in Alabama. Each of these counties has produced 500 million tons or more, and several have produced more than 1 billion tons of coal. Although many of these 27 counties were depleted of most of their coal reserves many years ago, several continue to produce large amounts of coal.

Production data from 10 counties with stable or increasing production that are currently yielding almost half of the coal from the Appalachian Basin are shown in figure 7*B*.

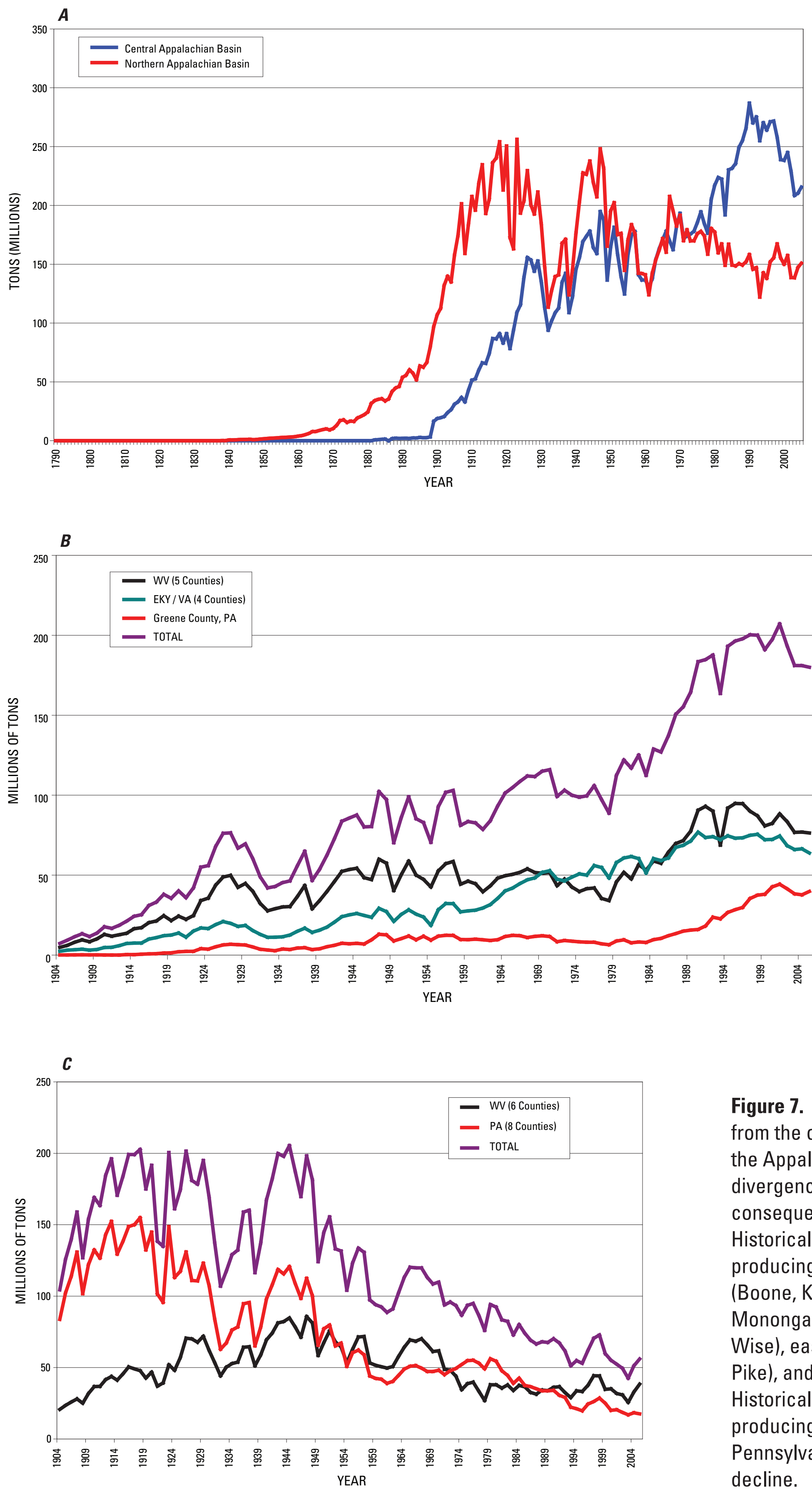

Figure 7. ***A***, Historical coal production from the central and northern parts of the Appalachian Basin. Note abrupt divergence of production in 1970, a consequence of the Clean Air Act. ***B***, Historical coal production from 10 major producing counties in West Virginia (Boone, Kanawha, Logan, Mingo, Monongalia), Virginia (Buchanan, Wise), eastern Kentucky (Perry, Pike), and Pennsylvania (Greene). ***C***, Historical coal production from 14 major producing counties in West Virginia and Pennsylvania that are in irreversible decline.

These counties are Buchanan and Wise in Virginia; Perry and Pike in Kentucky; Greene in Pennsylvania; and Boone, Kanawha, Logan, Mingo, and Monongalia in West Virginia.

The production from 14 counties in the northern Appalachian coal fields that have collectively produced as much as 200 million tons of coal annually during the first half of the 20th century is shown in figure 7*C*. During the last half of the last century, all of these counties exhibited steep declines in production primarily because of depletion of their coal reserves. These counties include Fayette, Harrison, Marion, McDowell, Raleigh, and Wyoming Counties in West Virginia, and Allegheny, Cambria, Clearfield, Fayette, Indiana, Somerset, Washington, and Westmoreland Counties in Pennsylvania. It appears that when the four counties in the Appalachian Basin (Greene County in Pennsylvania, Pike County in Kentucky, and Boone and Mingo Counties in West Virginia) that collectively produced about 113 million tons in 2005 are depleted within the next few decades, the Appalachian Basin, in its entirety, will enter into a period of steep decline unless large blocks of economically recoverable coal remain in the deep, unmined part of the basin.

In 2005, 110 counties in the entire Appalachian Basin produced coal (tables 2 and 3). Of this total only 3 counties produced 20 million tons or more each, 9 produced from 10 to 20 million tons, 41 produced from 1 million to 10 million tons, and 67 produced a million tons or less. Clearly, a few counties in the Appalachian Basin produce most of the coal mined in the Appalachian region, and when their production declines, the production of the basin, in general, will decline.

Illinois coal production began a decline in coal production in 1992, from about 35 million tons each year to about 32 million tons in 2005 (fig. 3*B*); western Kentucky production declined from about 56 million tons in 1975 to 26 million tons in 2005. Of the three States in the Illinois Basin, only Indiana did not experience a significant decline in coal production during the 1990s, probably because of its greater percentage of low- and medium-sulfur coal when compared with Illinois and western Kentucky. In 2000, the Illinois Basin produced less than 100 million tons of coal for the first time since 1992 (fig. 3*B*, fig. 8).

In 1998, there were 36 counties producing coal in the Illinois Basin of the 98 counties that produced coal sometime in the past. In general, the historical production from this selected group of 36 counties had increased steadily during most of the last century until 1990, when they collectively produced 120 million tons of coal out of the 141 million tons for the entire basin. Production from these counties declined to about 110 million tons in 1998. Illinois Basin production has remained fairly steady since then with production of 93 million tons in 2005.

Estimated Potential Coal Reserves in the Appalachian Basin

The Energy Information Agency (1998) has estimated that there are about 53 billion tons of coal as the reserve for the Appalachian Basin (table 4). This reserve estimate, plus 2005 cumulative production (37.5 billion tons, table 4), equals about 90 billion tons as a potential for the maximum cumulative production of coal from this basin. This estimate is supported by the trend of the cumulative production curve for the Appalachian Basin (fig. 9), which currently appears to be flattening to somewhere between 70 and 90 billion tons of coal. Sometime during the latter part of the 21st century this curve is projected to reach the potential maximum.

Of the estimated coal reserves (Energy Information Agency, 2000a) for the Appalachian Basin, approximately 40 percent is classified as high-sulfur coal. Although much of the high-sulfur coal may be technically recoverable, under current economic and environmental conditions it is not generally economic. The potential reserve of low- and medium-sulfur coal in the Appalachian Basin is about 31 billion tons (BT) (table 4). Accordingly, the amount of low- and medium-sulfur coal reserves (31 BT) plus the cumulative production (37.5 BT) yields an estimate of about 67 billion tons for the amount of coal that may be preferentially produced from the basin under current economic conditions, technology, and environmental restrictions. Although this figure is regarded as a low estimate of the potential original coal resource for the Appalachian Basin, because high-sulfur coal is currently being burned by the electrical-power industry, it provides a reasonable estimate of the minimum amount of coal that may be produced from the Appalachian Basin. Most likely, widespread use of flue-gas scrubbers and alternative uses of high-sulfur coal, such as feedstock for synfuel plants, may eventually increase the amount of coal that will ultimately be produced from the basin, perhaps close to the 90-million-ton estimate (table 4).

The large remaining resources of high-sulfur coal in Ohio and Pennsylvania (table 4), which are currently uneconomic or have limited markets, will be the coal reserves of the future when competitively priced low-sulfur coal reserves in the central Appalachian Basin are exhausted and as the technology for mining, reclamation, and combustion improves. Indeed, these high-sulfur coals may eventually be used as the preferred feedstock for coal-to-methane synthetic fuel plants as prices for natural gas and oil increase.

Estimated Potential Coal Reserves in the Illinois Basin

The Illinois Basin has produced a little more than 10 billion tons out of a potential reserve of about 52 billion tons of coal (Energy Information Agency, 1998). The recoverable reserve estimates made by the Energy Information

Table 2. Appalachian coal production by State in thousands of short tons.

[N = number of counties in logarithmic size class (Energy Information Administration, 2005]

	Size class and number (N) in class						
State	1–1,000	N	1,001–10,000	N	10,001–40,000	N	State total
Pennsylvania	5,583	19	22,076	6	39,834	1	67,493
Ohio	5,277	12	19,443	5			24,720
Maryland	1,311	1	3,872	1			5,183
Subtotal	12,171	32	45,391	12	39,834	1	97,396
West Virginia	2,657	8	66,049	14	84,945	5	153,651
Virginia	1,581	2	11,561	3	14,601	1	27,743
E. Kentucky	2,212	12	29,880	9	62,514	4	94,606
Subtotal	6,450	22	107,490	26	162,060	10	276,000
Tennessee	896	6	2,320	1			3,216
Alabama	1,580	7	9,177	2	10,581	1	21,338
Subtotal	2,476	13	11,497	3	10,581	1	24,554
Total	21,097	67	164,378	41	212,475	12	397,950

Table 3. Counties in Appalachian Basin producing 10 million tons or more of coal in 2005.

[From Energy Information Administration, 2006]

State	County	2005 coal production (thousands of tons)
Pennsylvania	Greene	39,834
West Virginia	Boone	30,893
E. Kentucky	Pike	28,374
Virginia	Wise	14,601
West Virginia	Mingo	14,542
West Virginia	Marshall	13,925
West Virginia	Kanawha	13,528
E. Kentucky	Perry	13,091
West Virginia	Logan	12,057
E. Kentucky	Harlan	10,701
Alabama	Tuscaloosa	10,581
E. Kentucky	Knott	10,348
Total		201,984

Table 4. Coal reserve estimates for northern, central, and southern Appalachian Basin.

[Original reserves from Energy Information Administration, 2000a. Reserve estimates in billions of tons]

Appalachian Basin State	Original reserves	Recoverable reserves	Cumulative production (2005)	Total low- and medium-sulfur coal
Dominantly low- and medium-sulfur coal				
West Virginia	30.6	18.2	12.4	13.6
E. Kentucky	11.7	5.8	5.9	5.3
Alabama	4.6	2.8	1.8	2.8
Virginia	3.4	1.1	2.3	1.3
Subtotal	50.3	27.9	22.4	23.0
Dominantly medium- and high-sulfur coal				
Pennsylvania	22.6	12.0	10.6	6.0
Ohio	15.2	11.8	3.4	1.7
Subtotal	37.8	23.8	14.0	7.7
Low-producing States				
Maryland	0.76	0.5	0.27	0.2
Georgia	0.2	0	0.2	0
Tennessee	1.14	0.5	0.63	0.4
Subtotal	2.1	1.0	1.1	0.6
Grand total	90.2	52.7	37.5	31.3

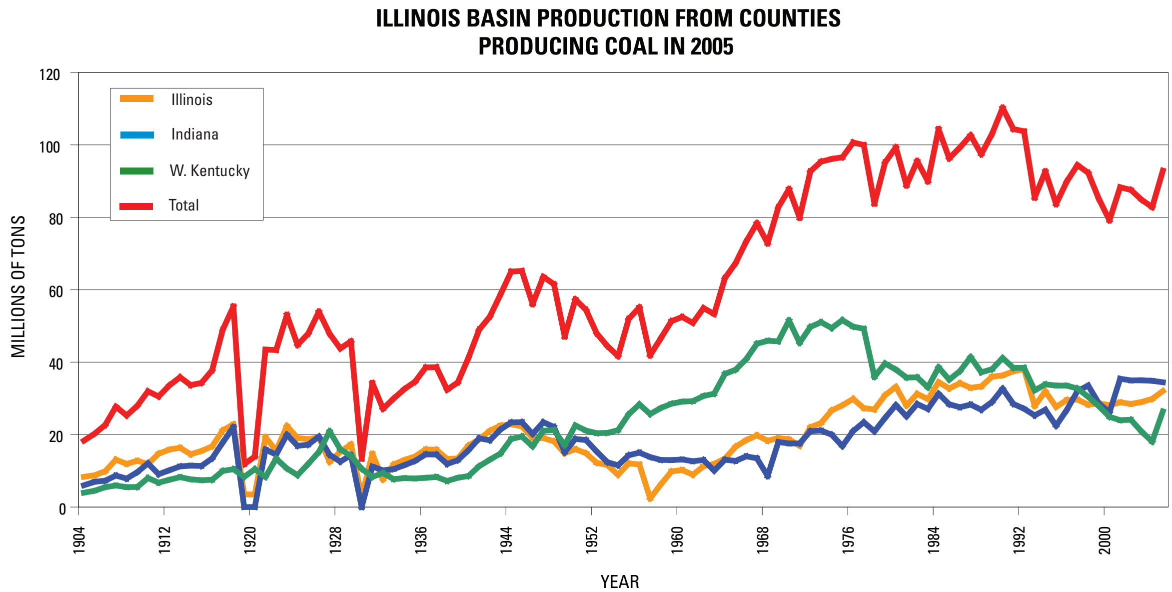

Figure 8. Historical coal production from the 36 counties in the Illinois Basin that remained in production during 2005. Coal is no longer being produced from the 62 other counties that once produced coal in the basin.

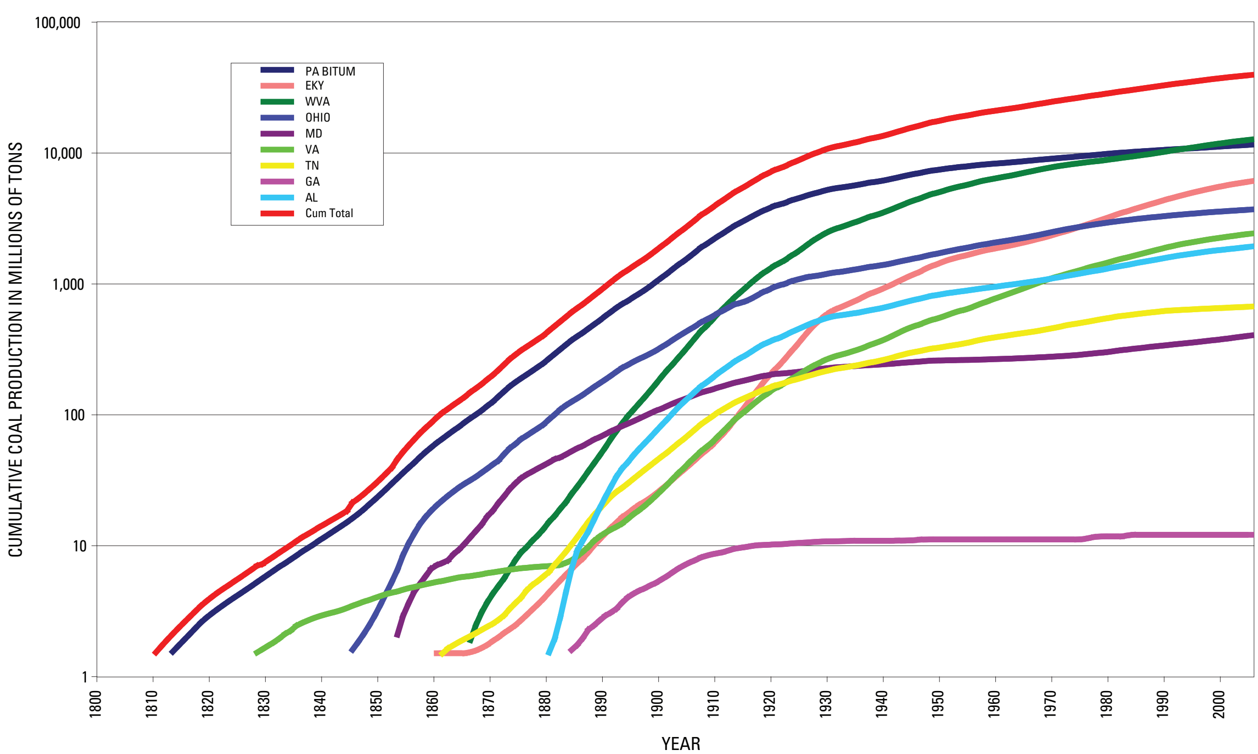

Figure 9. Appalachian Basin cumulative coal production, by State. Curves on a logarithmic scale trend toward horizontal during periods of declining production and indicate depletion.

Administration for the Illinois Basin are listed in table 5. Much of this coal is technically recoverable but has been uneconomical to mine since the Clean Air Act Amendments in 1990 because of its high sulfur content. However the potential for production of this large amount of high-sulfur coal has been greatly enhanced by advances in coal gasification technology and other advances that allow the coal to be used without significant emissions of sulfur dioxide to the atmosphere.

At present, coal production in the Illinois Basin is clearly in decline (fig. 3*B*). In Illinois, only seven counties (Jackson, Macoupin, Perry, Randolph, Saline, Sangamon, and Vermilion) with a cumulative coal production of 100 million tons, or more, produced significant amounts of coal in 2005. Collectively, they accounted for about 25 million tons of Illinois' 32 million tons of coal production for that year. Seven more counties in Illinois (Christian, Fulton, Franklin, Madison, Montgomery, St. Clair, and Williamson), also with more than 100 million tons of cumulative production each, no longer produce coal.

Coal production in Indiana and western Kentucky, however, has not been as seriously affected by the Clean Air Act as Illinois. In Indiana, seven of eight counties that have produced 100 million tons or more are still producing coal, and in western Kentucky five of the six counties that each have a cumulative production greater than 100 million tons are still in production. Coal production in several counties in western Kentucky (Hopkins, Muhlenberg, and Ohio), however, has declined significantly during the past few decades. Log plots for coal production from the Illinois Basin are approaching horizontality (fig. 10), and cumulative production from the basin is projected to be no more than 12 billion tons by 2025.

Production Projections

Coal reserve estimates, coupled with current production data, may be used to calculate reserve-decline rates and to extrapolate coal-production rates into the future. Reserve-decline-rate projections are useful for areas that contain relatively small reserves that are in high demand, such as the low-sulfur coal deposits in southwestern Virginia.

Table 5. Coal reserve estimates for the Illinois Basin.

[Original reserves from Energy Information Administration, 1998. Reserve estimates in billions of tons]

State	Original reserves	Re-coverable reserves	Cumulative production (2005)	Total low- and medium-sulfur coal
Illinois	44.0	38.3	5.7	2.2
Indiana	6.5	4.1	2.4	1.2
W. Kentucky	11.7	9.1	2.6	0.1
Total	62.1	51.5	10.7	3.5

Reserve-decline-rate projections are much less reliable where the coal reserve is very large but in low demand, because of its high sulfur content, as it is in the northern Appalachian coal fields and in the Illinois Basin. Reserve-decline-rate estimates are made by adding an estimated amount of reserves to current cumulative production and then by declining the estimated remaining reserves by an average (geometric mean) of the previous 10 years of production.

In addition, short-term production forecasts may be made by extrapolating the decline rates of current production data into the future. Decline-rate projections are made by reducing current annual production by the average decline rate (geometric mean) of the previous 10 years. Both of these methods apply a calculated decline rate, either to estimated reserves or to current production, in order to estimate future annual production. In regions with an abundance of high-sulfur coal, declining production trends may provide a fair short-term estimate of the amount of economically producible coal in the current production cycle. Long-term decline projections, such as the one in figure 11, which is based on a reserve estimate of about 30 billion tons for the Appalachian Basin (31.3 billion tons of low- and medium-sulfur coal, table 4), are useful only in that they illustrate the influence of resource limitations on coal-production scenarios. For example, the projection illustrated in figure 11 indicates that annual production from the Appalachian Basin will fall below 200 million tons sometime between the middle and end of the 21st century. If 11 billion tons—EIA's 2000a estimate for the remaining amount of low-sulfur coal in the basin—is used instead of 30 billion tons to calculate the projection, the decline is steeper and annual coal production from the Appalachian Basin falls below 100 million tons prior to the middle of the 21st century (fig. 12). In contrast with these artificial decline-rate projections, historical production data fluctuate constantly in response to economic, technological, environmental, and societal changes and needs during the lifetime of a resource and eventually diminish as the resource is depleted.

The Illinois Basin contains large amounts of coal that could be economically produced if there were additional markets (such as for synfuel feedstock) or utilization of improvements in technology that would allow burning of this high-sulfur coal. As a result it is difficult to predict future production rates from estimated reserves with any certainty, especially for more than a few years. Accordingly, the decline-rate diagram (fig. 13) utilizes current production-decline rates and extrapolates them for about 25 years. If coal production from the Illinois Basin continues at present decline rates, Illinois Basin production would decrease to about 75 million tons annually by 2025. With the depletion of world petroleum reserves, however, it is likely that production of coal from the Illinois Basin will increase during the next several decades in order to meet

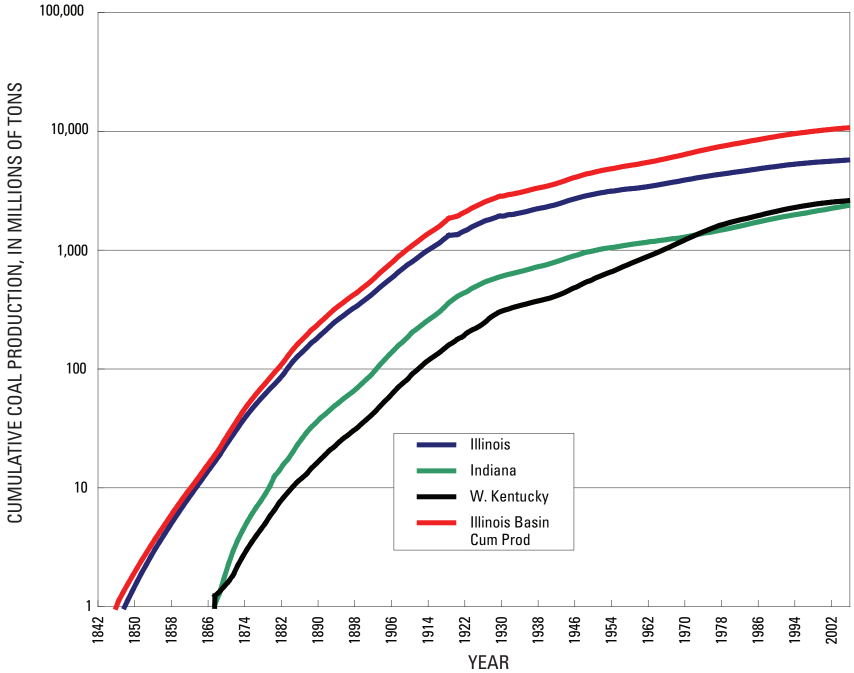

Figure 10. Illinois Basin cumulative coal production, by State. Curves on a logarithmic scale trend horizontal during periods of declining production and indicate economic depletion.

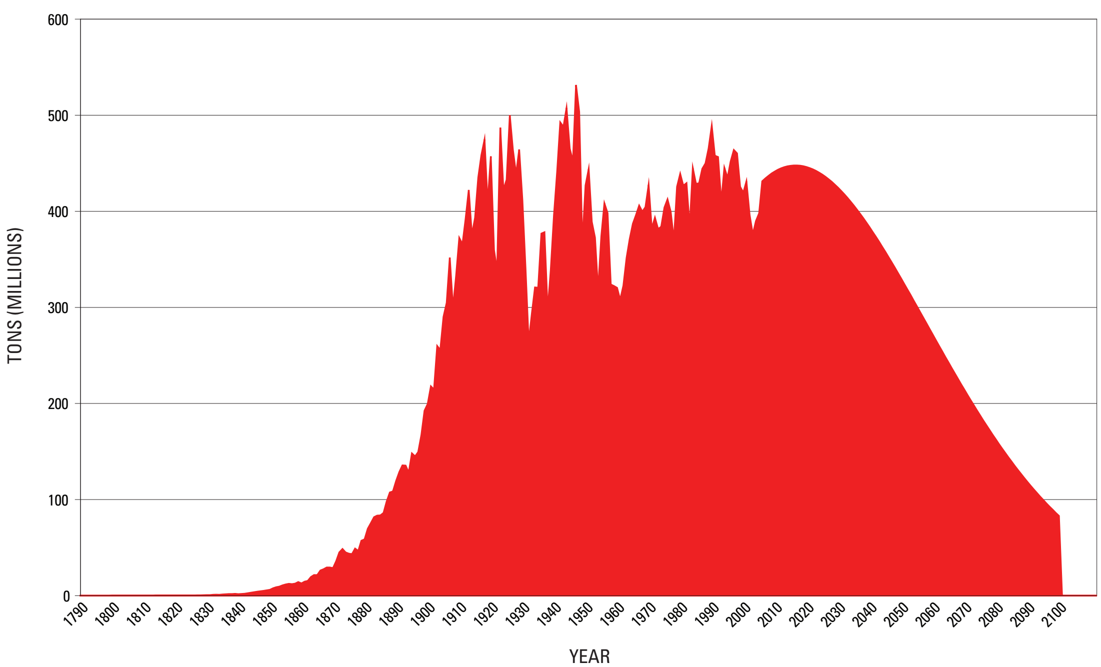

Figure 11. Decline curve for the Appalachian Basin, based on 30 billion tons of potentially economically producible coal and depletion of reserves at current rates. Addition of hypothetical 30 billion tons of reserves to data causes apparent short-term increase in production before ultimate decline. The projection does not illustrate potential changes in environmental regulation, technology, and economics that might make more or less of the coal profitable to mine.

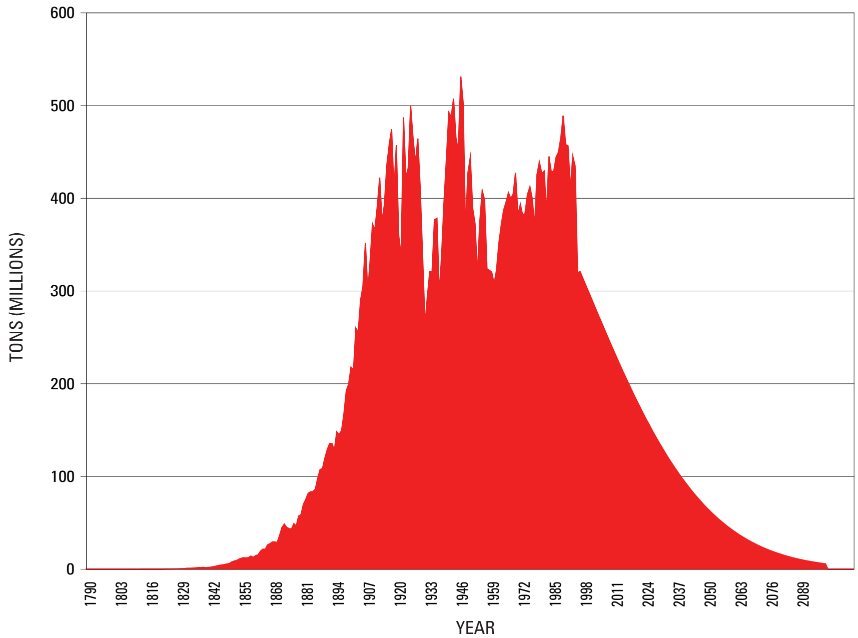

Figure 12. Decline of Appalachian coal production, based on potential reserves of 11.3 billion tons of low-sulfur coal ≤ 0.6 lb sulfur/MMBtu) (Energy Information Agency, 1996, table B2).

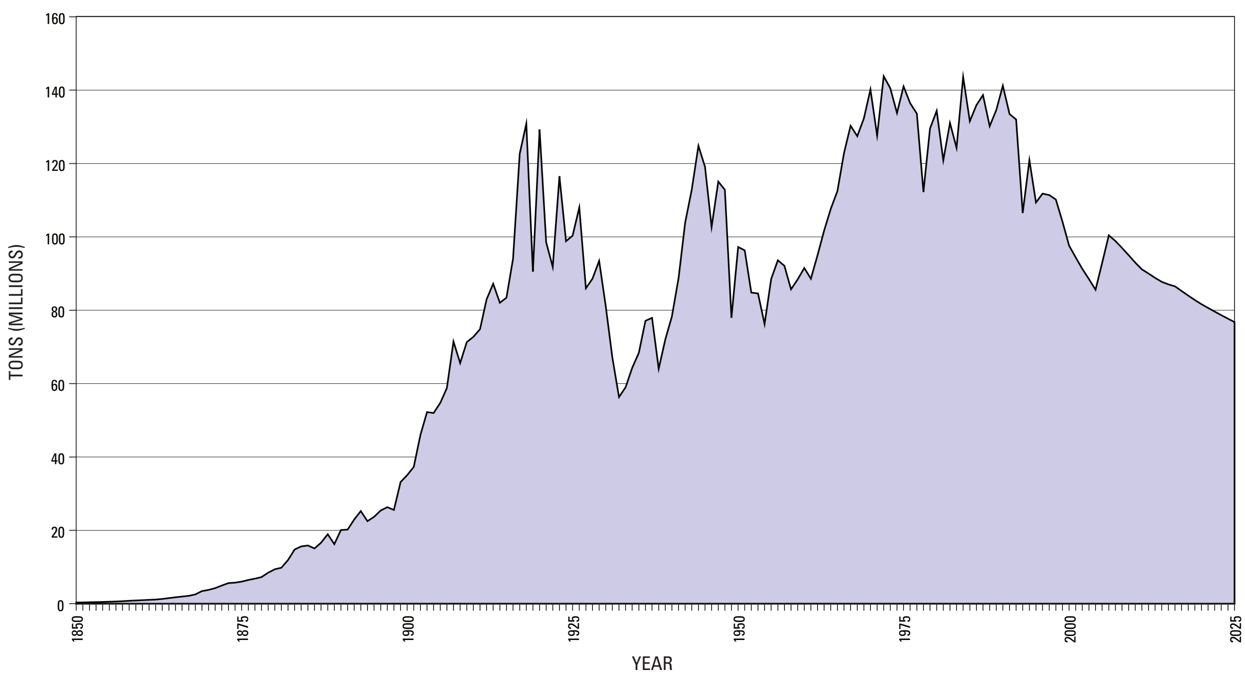

Figure 13. Decline of Illinois Basin coal production based on extrapolation of current production-decline rates. At current rates of decline, the Illinois Basin could be producing as little as 75 million tons by 2025. Because of the depletion of the world's petroleum resources, however, the decline of Illinois Basin coal production may reverse significantly during the next several decades.

the demands for increased electrical-power generation and coal-derived petroleum liquids.

More conventional coal-resource estimates, such as those undertaken by the U.S. Geological Survey in cooperation with the States (see Ruppert and others, 1996), require detailed geologic and coal-quality information that may serve as a basis for economic analysis (Attanasi, 1998). The mapped and measured coal-resource and coal-quality data are the basis for calculating economic recoverability (Rohrbacher and others, 1993a, 1993b, 1994a, 1994b; Staff, Intermountain Field Operations, 1995; Scott, 1995; D.C. Scott, U.S. Geological Survey, unpublished report, 1997; D.D. Teeters, U.S. Geological Survey, unpublished report, 1997). In general, coal recoverability studies thus far indicate that in the areas studied in the Appalachian Basin, only about 10 percent of the original coal resources are economically recoverable. Sufficient regional coal resource work needed to make an economically based reserve estimate for the entire basin has not been completed at this time.

Conclusions

In 2005, the Appalachian Basin produced about 398 million tons of coal annually (table 2), 301 million tons from the central and southern Appalachian coal fields, and 97 million tons from the northern Appalachian coal fields. Of that amount, some 360 million tons were consumed by electrical powerplants in the Eastern United States. Powerplants east of the Mississippi River that are equipped with scrubbers, exclusive of those in Illinois, Indiana, western Kentucky, and southern Alabama, are burning about 100 million tons of coal annually, a little less than one-quarter of the central and northern Appalachian Basin production combined. About 260 million tons are burned unscrubbed. With increasing demand for coal for electrical-power generation and higher prices after the year 2000, the Appalachian Basin may be able to produce 80 to 90 million tons of compliance coal per year (0.6 lb S/MMBtu)—well short of the potential demand for low-sulfur coal under Phase-II guidelines. Attanasi (1998) calculated that 125 million tons of coal was sent to plants without scrubbers from the northern Appalachian Basin and the Illinois Basin, areas that "have virtually no coal that meets the Clean Air Act Phase-II requirements." Without retrofitting plants with scrubbers, about 216 million tons of eastern coal could be burned with emission allowances annually, or they could be replaced by 280 million tons of lower Btu Powder River Basin coal, or by other low-sulfur western coals (Attanasi, 1998).

The predicted shortfall of as much as 200 million tons of low-sulfur coal from the Appalachian region for use in electrical-power generation may be replaced in several ways: by increased shipments of low-sulfur coal from Western States, by use of emission credits, by installation of scrubbers on existing powerplants that will allow use of higher sulfur coal, and by utilization of alternate fuels, such as natural gas. At 13,500 Btu/lb, an estimate for the average calorific value for Appalachian Basin coal, the amount of energy that will have to be replaced annually in eastern powerplants is about 5.4 quadrillion Btu. Industry response to the shortfall is likely to encompass several strategies. If, however, industry's fuel of choice is natural gas, the amount of gas required to replace the loss of high-sulfur coal for electrical-power generation could be as much as 5.4 trillion cubic feet annually (1,000 Btu/ft^3).

The future of coal production in the Illinois Basin and northern part of the Appalachian Basin depends, to a large degree, on installation of flue-gas scrubbers in existing and new powerplants and in other improvements in technology that would allow the medium- to high-sulfur coal deposits produced from these coal fields to be burned in a less polluting manner. In addition, these medium- to high-sulfur coal deposits may prove useful as a feedstock for synfuel production, especially petroleum liquids and methane, where pollutants (sulfur, carbon dioxide) could be controlled in the manufacturing process.

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