Coal Assessments and Coal Research in the Appalachian Basin

By Susan J. Tewalt and Leslie F. Ruppert

Chapter D.4 of

Coal and Petroleum Resources in the Appalachian Basin: Distribution, Geologic Framework, and Geochemical Character

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Conversion Factors

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 pound avoirdipois)	0.9072	metric ton (megagram=1,000 kilograms)
	Gas-in-place content of coal bed	
cubic foot per short ton (CF/ton)	0.03122	cubic meter per metric ton (m^3/metric ton)
	Calorific value	
British thermal unit (Btu)	1,055.056	joule (J)

Letter Symbols for Units of Measure

BCF billion cubic feet (ft^3 x 10^9)

CF/ton cubic feet per short ton

TCF trillion cubic feet (ft^3 x 10^{12})

Coal Assessments and Coal Research in the Appalachian Basin

By Susan J. Tewalt[1] and Leslie F. Ruppert[1]

Abstract

Coal is one of our most important domestic energy resources, producing 37 percent of the Nation's electricity in 2012. Coal mining within the Appalachian basin has been ongoing for three centuries and, cumulatively, the basin is the most productive coal region in the United States. In 2012, only the Powder River basin produced more coal than the Appalachian basin. Coal is the most important mined product within the basin, and research on the quality and quantity of the coal is one of the primary functions of the U.S. Geological Survey (USGS) and the State geological surveys of Alabama, Kentucky, Maryland, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia. The USGS and the State geological surveys historically have worked together on coal research and assessment projects to achieve mutually beneficial science goals.

The 2000 USGS coal resource assessment of the Appalachian basin (Northern and Central Appalachian Basin Coal Regions Assessment Team, 2001, USGS Professional Paper 1625–C) was done in close collaboration with scientists of the State geological surveys of Kentucky, Maryland, Ohio, Pennsylvania, Virginia, and West Virginia. Five of the top-producing coal beds and coal zones within the basin were quantitatively assessed, and results show that ample coal resources remain. Coal quality, not coal quantity, is the principal driver for coal production and use within the basin and will be for the foreseeable future.

Cumulative coalbed-methane (CBM) production within the Appalachian basin has been about 2.3 trillion cubic feet (TCF), and most of the production has come from Alabama and Virginia (Milici and Polyak, this volume, chap. G.2). Significant CBM resources occur throughout the coal-producing States in the Appalachian basin, and commercial production is possible in all.

State geological surveys are concentrating on mapping and correlating coal beds and coal zones and studying CBM potential and production. Both State surveys and the USGS are researching the potential for carbon dioxide sequestration in unmined coal beds and other geologic reservoirs. In addition, the State geological surveys continue their long-term collaboration with the USGS and provide coal stratigraphic data to the National Coal Resources Data System (NCRDS).

Introduction

Coal is one of our most important domestic energy resources, producing 37 percent of the Nation's electricity in 2012 (Energy Information Administration, 2013b). The Appalachian basin is one of the most significant coal-producing regions in the Nation and the world, having produced bituminous coal throughout the last three centuries. Historically, the Appalachian basin coal-bearing strata have been divided into three coal regions on the basis of regional geologic structure and stratigraphy (fig. 1). The three regions are informally called the northern, central, and southern Appalachian basin coal regions. Recent and historic production records (Milici and Polyak, this volume, chap. D.3) reveal that about 34.5 billion short tons of coal have been produced in the three regions and that 95 percent originated from the northern and central coal regions. According to the Energy Information Administration's (2013b) data for U.S. coal production, the total Appalachian basin production in 2012 was 291.929 million short tons and was second only to production in the Powder River basin (401.442 million short tons).

Currently, Appalachian basin coal is used primarily within the Eastern United States for electrical power generation, but some of it is suitable for metallurgical uses. Appalachian basin coal will be used for the foreseeable future; therefore, coal researchers investigate a wide variety of topics: remaining and recoverable coal resources, coal quality, previously mined areas, coalbed-methane (CBM) potential, and possible use of deep coal for carbon dioxide (CO_2) sequestration. This chapter summarizes recent and current Appalachian basin coal research by the U.S. Geological Survey (USGS) and the State geological surveys of Alabama, Kentucky, Maryland, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia. The USGS and the State geological surveys historically have worked together on coal research and assessment projects to achieve mutually beneficial science goals.

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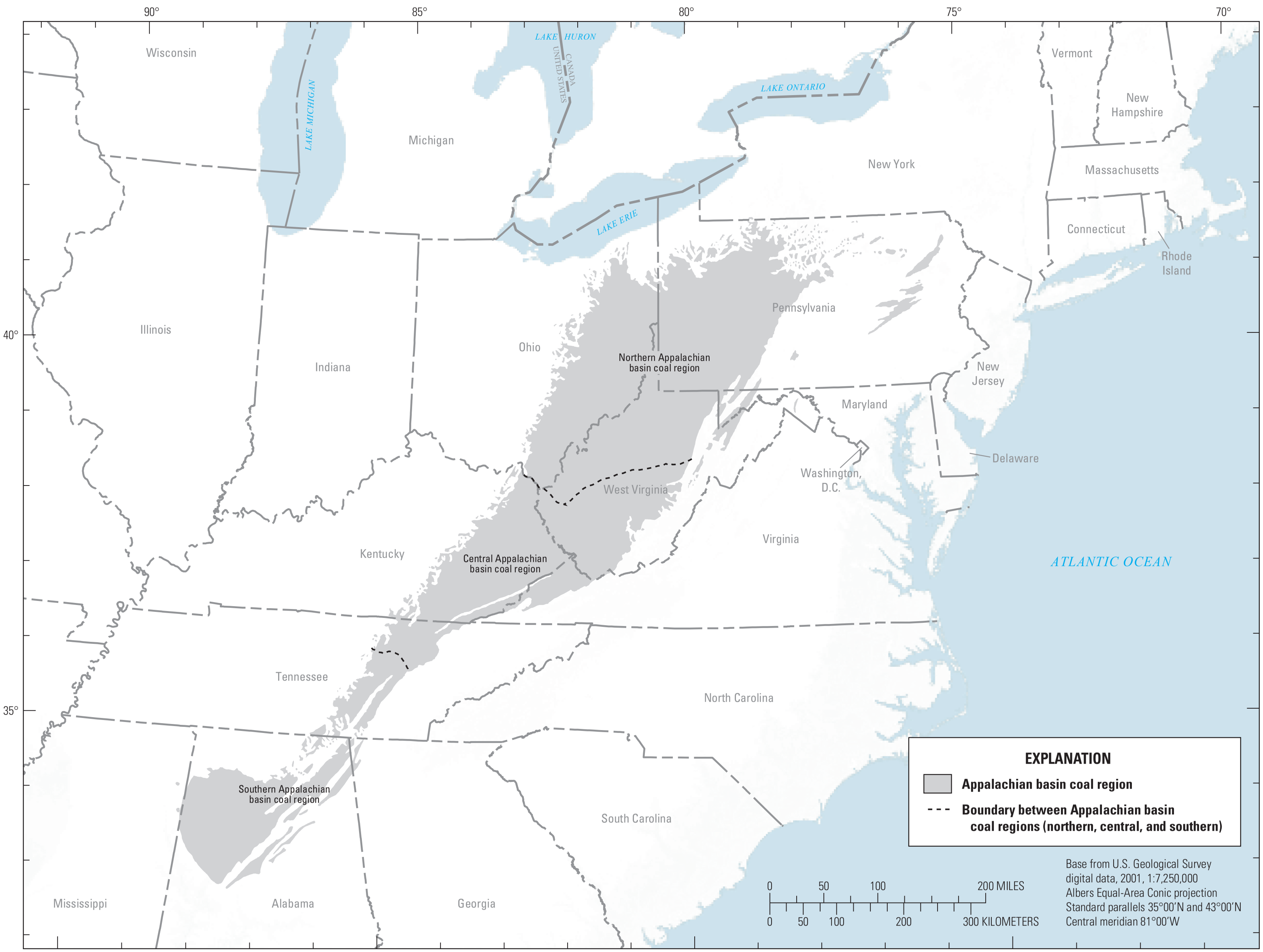

Figure 1. Map showing locations of the informally defined northern Appalachian basin coal region, central Appalachian basin coal region, and southern Appalachian basin coal region. The boundary between the northern and central regions was adapted from the hinge line of Arkle (1974) and separates Lower to lower Middle Pennsylvanian relatively low sulfur and low ash coals of southern West Virginia, western Virginia, and eastern Kentucky from upper Middle to Upper Pennsylvanian higher sulfur and higher ash coals of northern West Virginia, eastern Ohio, western Maryland, and Pennsylvania. The boundary between the central and southern coal regions is placed at the southern boundary of the Wartburg basin, Tennessee, on the basis of structural and sedimentological features (Ruppert and others, this volume, chap. B.1).

USGS Coal Resource Assessment of 2000

Methodology

Between 1995 and 2000, the USGS conducted a digital resource assessment of selected coal beds and zones in the northern and central Appalachian basin coal regions by using geographic information system (GIS) software (Northern and Central Appalachian Basin Coal Regions Assessment Team, 2001). Past coal production was the primary criterion for determining which coal beds and coal zones were assessed; secondary criteria included the availability of geologic maps and coal stratigraphic data for the correlation of coal beds within and between States.

Figure 2 shows the stratigraphic occurrence of the coal beds and coal zones that were digitally assessed. A simplified stratigraphic naming convention was used to speed correlations in the database manager used in the assessment. The complex formal stratigraphic names of Pennsylvanian strata within the Appalachian basin (Ruppert and others, this volume, chap. D.2) were simplified to the Pottsville, Allegheny, Conemaugh, and Monongahela Groups in the 2000 assessment.

The digital coal resource assessments were conducted in cooperation with State geological surveys. In the northern Appalachian basin coal region, the West Virginia Geological and Economic Survey (WVGES), the Pennsylvania Bureau of Topographic and Geologic Survey (PAGS), the Ohio Division of Geological Survey (OGS), and the Maryland Geological Survey (MGS) cooperated with the USGS in assessments of the Pittsburgh, Upper Freeport, and Lower Kittanning coal beds. In the central Appalachian basin coal region, the Pond Creek and Fire Clay coal-zone assessments were conducted in partnership with the Kentucky Geological Survey (KGS), the Virginia Division of Mineral Resources (VDMR), and the WVGES. Also in the central region, the VDMR and the WVGES worked with the USGS to assess the Pocahontas No. 3 coal bed. Figures 3 and 4 show the spatial distribution of the assessed beds and zones.

Other top-producing coal zones of the central Appalachian basin coal region were not modeled in the 2000 USGS assessment because detailed coal-bed maps and verified, correlated coal-thickness data were not available. The coal zones not assessed include, from youngest to oldest, the No. 5 Block coal zone of the Allegheny Group and the following zones of the Pottsville Group: the Stockton and Coalburg coal zone, the Winifrede (Hazard) coal zone, the Williamson (Amburgy) coal zone, the Campbell Creek (Upper Elkhorn No. 3) coal zone, and the Upper Elkhorn Nos. 1 and 2 (Powellton) coal zone (fig. 5). However, stratigraphic correlations, production history, resources, and chemistry for each coal zone were discussed in detail by Neuzil (2001).

System	Series	Group	Assessed coal bed or zone
Pennsylvanian	Upper	Monongahela Group	Pittsburgh coal bed
		Conemaugh Group	
	Middle	Allegheny Group	Upper Freeport coal bed
			Lower Kittanning coal bed
		Pottsville Group	Fire Clay coal zone
			Pond Creek coal zone
	Lower		Pocahontas No. 3 coal bed

Figure 2. Generalized stratigraphic column showing the six Appalachian basin coal beds and coal zones assessed by the USGS (Northern and Central Appalachian Basin Coal Regions Assessment Team, 2001); from Ruppert (2001, fig. 4). Major stratigraphic subdivisions for rocks in southwestern Pennsylvania (Pottsville, Allegheny, Conemaugh, and Monongahela Groups) were extended throughout the basin to create a simplified nomenclature to improve data management by software used in the assessment; thus, it does not conform to Pennsylvanian stratigraphic nomenclature used by Rice and others (1994) and used elsewhere in this report (Ruppert, Trippi, and Slucher, this volume, chap. D.2).

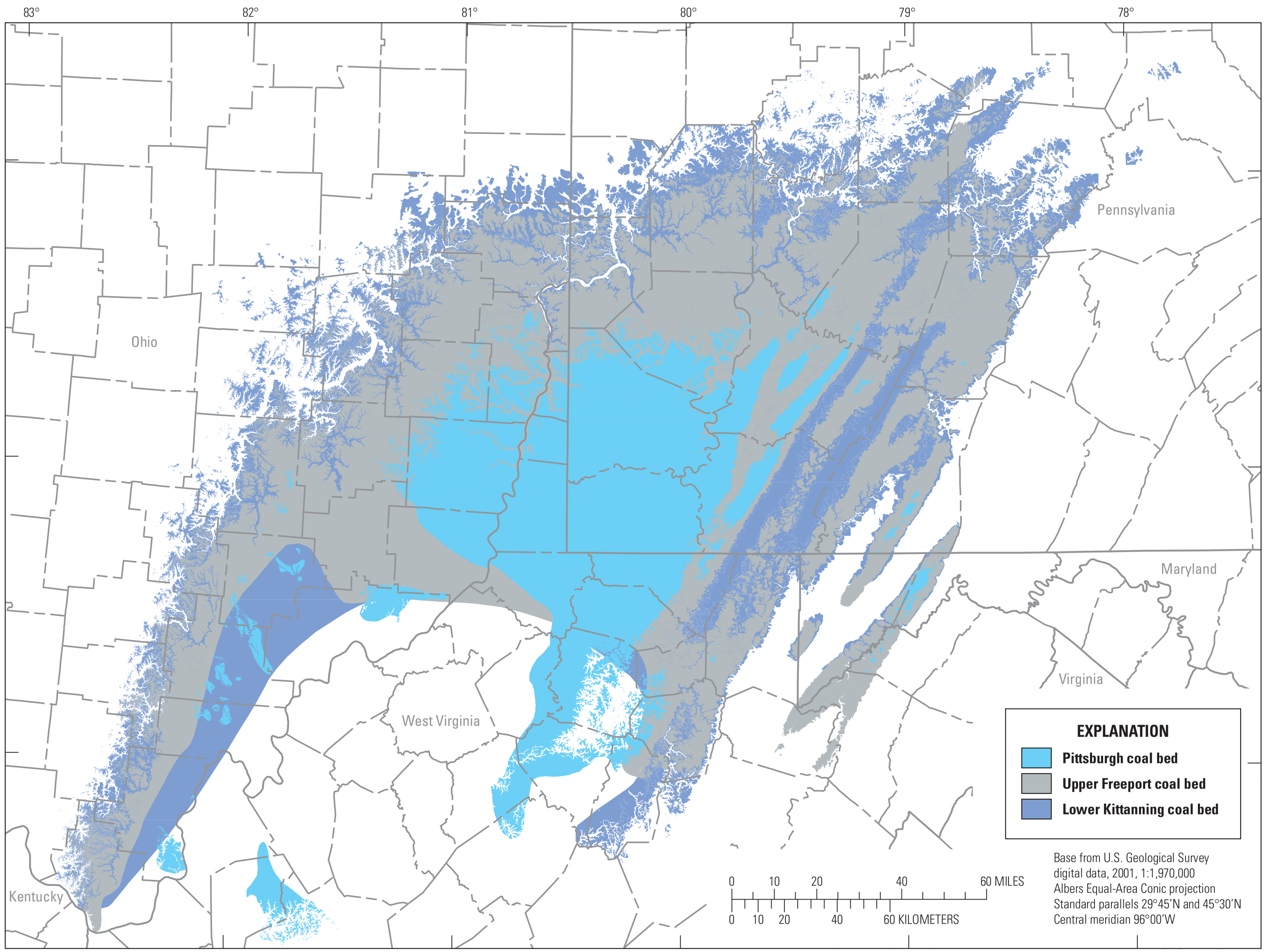

Figure 3. Map showing the three coal beds in the northern Appalachian basin coal region assessed by the USGS (Northern and Central Appalachian Basin Coal Regions Assessment Team, 2001); modified from Ruppert (2001, fig. 5). The three coal beds, in descending stratigraphic order, are the Pittsburgh, Upper Freeport, and Lower Kittanning. The three beds underlie parts of Ohio, West Virginia, Pennsylvania, and Maryland.

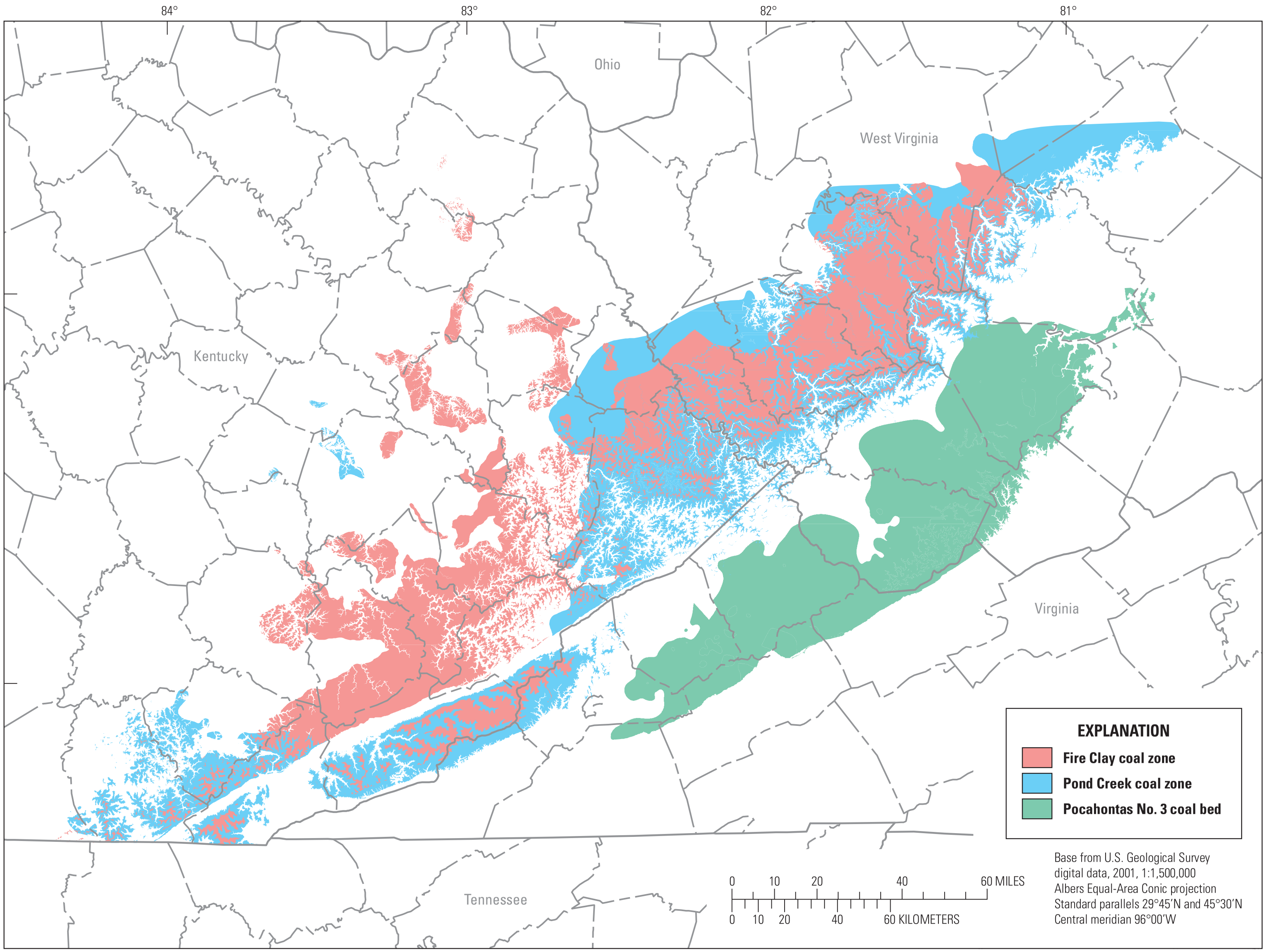

Figure 4. Map showing the two coal zones and one coal bed in the central Appalachian basin coal region assessed by the USGS (Northern and Central Appalachian Basin Coal Regions Assessment Team, 2001); modified from Ruppert (2001, fig. 6). The stratigraphically younger Fire Clay coal zone overlies the Pond Creek coal zone in eastern Kentucky, southwestern Virginia, and southern West Virginia. The older Pocahontas No. 3 coal bed extends through southwestern Virginia and southern West Virginia.

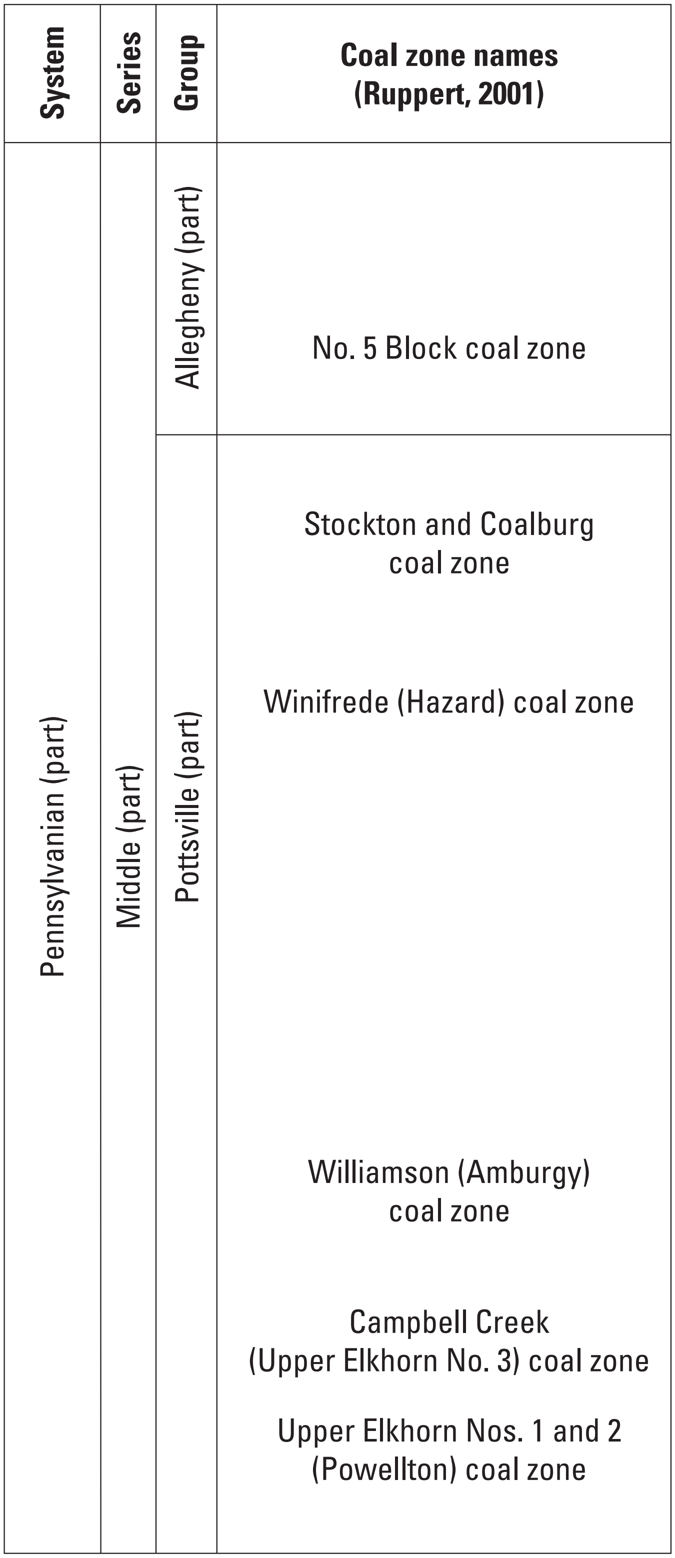

Figure 5. Generalized stratigraphic column showing the Middle Pennsylvanian Allegheny Group and Pottsville Group coal zones that were not assessed by the USGS (Northern and Central Appalachian Basin Coal Regions Assessment Team, 2001) because detailed coal-bed maps and verified coal thickness data were not available. These coal zones are important coal producers within the central Appalachian basin coal region. Figure from Ruppert (2001, fig. 7).

More than 1,000 published and unpublished maps were digitized and combined in a GIS to create a database that describes the areal extent and mined areas for each of the assessed coal beds and zones. Bed-specific stratigraphic databases, geochemical maps, and GIS coverages of coal-bed thickness, elevation, and overburden thickness were created for five of the six assessed coal zones and coal beds. The data were used to calculate original and remaining resources by the methodology of Wood and others (1983). The Lower Kittanning coal bed was assessed in a similar fashion except that original and remaining resources could not be calculated because areal extent and complete mined-area maps were not available for use in the GIS.

USGS Assessment Results

Table 1 lists the resources estimated for the digitally assessed coal beds. Although the number of coal mines operating in the northern and central Appalachian basin coal regions is decreasing, the remaining mines are increasingly productive. Remaining mines include large longwall underground mines in the Pittsburgh and Pocahontas No. 3 coal beds, as well as mountain-top-removal surface mines in the Coalburg, Stockton, and No. 5 and No. 6 Block coal zones. Sufficient high-quality, thick, bituminous resources remain in these coal beds and coal zones to last for several decades at current production rates. After these beds are mined, given current economic and environmental restrictions, Appalachian basin coal production is expected to decline. The Upper Freeport and Lower Kittanning coal beds and the Fire Clay and Pond Creek coal zones, which are the other top-producing coal units, already have peaked in production. The remaining coal in these units is deeper (>1,000 feet (ft)), is thinner (<3.5 ft), or has environmentally less desirable medium to high ash yields and sulfur contents than the previously mined coal.

Assessment results have been used by the USGS to determine the total amount of coal from the Pittsburgh coal bed that is available for mining (Watson and others, 2001) and recoverable from mining operations under different cost scenarios

Table 1. Original and remaining resources by State for the Pittsburgh, Upper Freeport, Fire Clay, Pond Creek, and Pocahontas No. 3 coal beds or coal zones.

[Coal resources were rounded to millions of short tons and two significant figures. Resources were not calculated for the Lower Kittanning coal bed because data were not available. Data are from Ruppert (2001, table 1)]

Coal bed or zone	State	Original resource	Remaining resource
Pittsburgh	Pennsylvania	15,000	5,000
	West Virginia	13,000	7,800
	Ohio	5,900	3,200
	Maryland	260	0
	Total	34,000	16,000
Upper Freeport	Pennsylvania	16,000	14,000
	West Virginia	5,000	4,500
	Ohio	12,000	12,000
	Maryland	910	<810
	Total	34,000	<31,000
Fire Clay	Kentucky	4,200	3,200
	Virginia	55	49
	West Virginia	2,100	1,800
	Total	6,300	5,100
Pond Creek	Kentucky	4,600	3,300
	Virginia	570	370
	West Virginia	5,600	5,000
	Total	11,000	8,700
Pocahontas No. 3	Virginia	2,900	2,500
	West Virginia	4,300	2,600
	Total	7,200	5,100
Total		93,000	66,000

(James Luppens, USGS, oral commun., 2006). In these coal-availability and coal-recoverability studies, restrictions on mining (land use, environmental, societal, technological, and geologic) are identified and applied as overlays to maps of coal-bed thickness, depth, and mined and lost-in-mining areas (Carter and others, 2001). Tonnages of original, mined and lost-in-mining, remaining, restricted, and available coal resources are calculated and used to estimate future mining and washing losses and to determine the amount of economically recoverable coal.

Coal-availability and coal-recoverability studies have been conducted at scales ranging from 1:24,000 to 1:250,000. The USGS and State geological surveys of Kentucky, Ohio, Pennsylvania, Virginia, and West Virginia have completed 32 coal-availability studies at 1:24,000 scale and 25 coal-recoverability studies; they concluded that only a fraction of the original coal resource can be extracted and marketed economically under current societal and technological restrictions (Carter and others, 2001, and references therein). Estimates of the resources of the five assessed beds occurring under Federal lands were generated by using available GIS coverages and totaled 4 billion short tons (Tewalt, 2001). However, the restrictions on the minability of these resources may be significant because the resources are geographically scattered; mineral rights ownership is complex and uncertain; and legal, surface, and technological restrictions are unknown (Tewalt, 2001).

With the rising availability of natural gas and decreased demand for electricity, coal production continues to decrease in the Appalachian basin, and much of the remaining production comes from the central Appalachian basin coal region. The central Appalachian basin coal region (fig. 4) produces coal that is more marketable than coals from the northern Appalachian basin coal region (fig. 3), where the thickest and highest quality coals have already been mined. Much of the coal from the central region meets emissions requirements mandated by Phase II of the Clean Air Act Amendments of 1990 (CAAA90, Public Law 101–549, available at http://www.epa.gov/oar/caa/), which took effect in 2000, but much of the remaining coal from the northern Appalachian basin coal region does not. Phase II of the CAAA90 limits sulfur dioxide emissions from coal-fired powerplants to a maximum of 1.2 pounds of sulfur dioxide per million British thermal units (Btu) or 0.6 pound of sulfur per million Btu. Powerplants using high-sulfur coals can remove sulfur-bearing minerals or install flue-gas-desulfurization units, commonly called scrubbers, to meet emission limits. If emission limits are exceeded, powerplants can use sulfur dioxide credits to compensate for the increases. The credits were established by the U.S. Congress when it passed the CAAA90 as a market trading system for sulfur dioxide. Powerplants that voluntarily reduce emissions by installing pollution-control devices or switching to low-sulfur coal earn credits that can be sold to other powerplants that exceed emission limits.

Credits increased in value after the U.S. Environmental Protection Agency (2007a) issued the Clean Air Interstate Rule (CAIR) on March 10, 2005. CAIR required 28 eastern States and the District of Columbia to reduce sulfur dioxide emissions by 70 percent and nitrogen oxide emissions by 60 percent by 2015. Coal-fired powerplants began installing scrubbers to meet emission requirements, which were expected to result in an increased demand for coal from the northern Appalachian basin coal region. On July 11, 2008, the District of Columbia Court of Appeals vacated CAIR and the associated Federal Implementation Plan and directed the U.S. Environmental Protection Agency to promulgate a new rule (*State of North Carolina* v. *Environmental Protection Agency*, decision available at http://www.epa.gov/cair/pdfs/05-1244-1127017.pdf. Accessed December 5, 2014.)

Another significant driver for Appalachian basin coal production was the Clean Air Mercury Rule (CAMR) issued by the U.S. Environmental Protection Agency (2007b) on March 15, 2005. The rule was designed to permanently cap and reduce mercury emissions from coal-fired powerplants by using a variety of control technologies, including scrubbers and selective catalytic reduction (SCR). In general, mercury contents tend to be higher in coal in the northern Appalachian region than in coal in the central Appalachian region (Ruppert, 2001), but powerplants that use scrubbers and SCR technologies may choose to use either northern or central Appalachian region coals. On February 8, 2008, the District of Columbia Court of Appeals vacated CAMR (*State of New Jersey et al.* v. *Environmental Protection Agency*, decision available at http://www.ecolex.org/ecolex/ledge/view/RecordDetails;DIDPFDSIjsessionid=13328FC35A8DB8A2B32DF065C84A6A4B. Accessed June 18, 2014.)

USGS Studies of Coalbed-Methane Resources

Coal-bed gas, which consists mostly of methane, makes up almost 8 percent of the total U.S. natural gas production. Coalbed methane (CBM) is both a significant resource within the Appalachian basin and a potential mining hazard, as it is combustible at concentrations as low as 5 percent in air. Coal beds act as a source and a reservoir for methane, which is contained within pore spaces and fractures of the coal. Methane in coal has three possible sources: thermogenic, biogenic, or mixed thermogenic and biogenic. Most of the CBM within the Appalachian basin is thermogenic (Ruppert and others, this volume, chap. F.2). Gas of microbial origin may be present in the less thermally mature coals east of the 0.8-percent vitrinite-reflectance isograd shown by Ruppert and others (this volume, chap. F.2), but there are no commercially producing CBM wells east of this line.

Commercial production of CBM began in the Black Warrior basin, Alabama, in 1980 and the Pocahontas basin, Virginia, in 1988, after degasification in advance of underground coal mining produced significant amounts of methane (Milici and Hatch, 2004). In 2005–2007, annual CBM production in the Appalachian basin was about 216 billion cubic feet (BCF) from about 8,500 wells (R.C. Milici, USGS, oral commun., 2008). Cumulative CBM production within the Appalachian basin has been about 2.3 TCF, and most of the production has come from Alabama and Virginia (Milici and Polyak, this volume, chap. G.2).

Appalachian basin coals have great potential for CBM production into the next few decades. The USGS recently published a new assessment of undiscovered Upper Mississippian and Pennsylvanian CBM resources of the Appalachian basin (Milici and Hatch, 2004; Milici, this volume, chap. G.1); the assessment team used a total petroleum system approach. Three assessment units (AUs) were quantitatively assessed—the Pocahontas Basin, East Dunkard (Folded), and Black Warrior AUs—and were estimated to contain a mean CBM resource of 15,455.98 BCF (Milici and Hatch, 2004).

Four other AUs have the potential for commercial production but were not quantitiatively assessed because production was either absent or limited (Milici and Hatch, 2004); these units are the West Dunkard (Unfolded), Central Appalachian Shelf, Appalachian Anthracite and Semi-Anthracite, and Cahaba Basin AUs.

USGS Current Research

National Coal Resources Data System

The USGS has maintained a cooperative effort with one or more State agencies in the Appalachian basin since 1975. Stratigraphic information submitted by USGS scientists and cooperating States is housed in a centralized database (USTRAT), which is the major component of the National Coal Resources Data System (NCRDS). The database contains values for multiple parameters for each coal bed or coal zone, including rank, thickness, and elevation. The stratigraphic data in the NCRDS are used by government and industry personnel to conduct assessments and to guide exploration.

The NCRDS database for the United States contains an ever-increasing number of public coal stratigraphic records, which total about 200,000 in 2008. Public coal stratigraphic records can be searched and downloaded at http://ncrdspublic.er.usgs.gov/ncrds_data/ (accessed December 10, 2014). The approximate number of records on coal for each State in the Appalachian region are as follows in 2008: about 10,300 records for Alabama, 7,100 for Kentucky, 730 for Maryland, about 25,500 for Ohio, 2,617 for Pennsylvania, 2,500 for Tennessee, 240 for Virginia, and about 55,000 for West Virginia. In addition, 581 records are in the NCRDS database for coal in Georgia, which has minimal coal resources and no coal production.

Coal-Quality Research

One of the highest priorities for the Nation is to minimize the environmental impacts of utilizing fossil fuels. Of the fuels that we currently use to generate electricity, coal has the greatest potential for environmental degradation and adverse effects on human health; the effects may result from both coal mining and coal use. Understanding the occurrence of elements in coal, particularly potentially hazardous elements, and documenting how the elements partition during beneficiation, combustion, and the formation of coal combustion products (CCPs) are critical to developing preventive or remediation measures for coal usage. USGS researchers are collaborating with workers at powerplants in the Appalachian basin and other coal-producing regions of the United States to collect and analyze (1) as-received and feed coal, (2) minerals and carbonaceous materials that are removed, or cleaned, from the coal before it is fed to the boilers, (3) economizer, fly, and bottom ash, (4) scrubber wastes, and (5) other available samples to determine what happens to elemental constituents during coal combustion. Researchers focus on elements, such as mercury and arsenic, that are known to affect human health.

USGS research also focuses on geology and human health. Researchers are conducting laboratory and field experiments to determine aqueous leachability and toxicological properties of constituents in coal that have potential for environmental or human health risks, especially those that can be mobilized during mining, combustion, and storage of combustion byproducts. Work in the Appalachian basin includes examining impacts of coal-mining activities on water quality and freshwater mussel decline.

COALQUAL is the largest public database containing coal-quality information. The USGS released the first version of COALQUAL in 1994 and the second in 1998 (Finkelman and others, 1994; Bragg and others, 1998). Approximately 12,000 additional coal samples have been analyzed from the 1990s to the present, and the USGS is in the process of verifying the data for eventual release.

Carbon Dioxide Sequestration Research

Carbon dioxide (CO_2) storage in coal beds is one option for mitigating anthropogenic releases of carbon dioxide to the atmosphere. Estimates of global storage capacity indicate that coal beds may be able to accommodate up to several hundred gigatons of carbon dioxide (Dooley and Friedman, 2005). Storage in unmined coal beds is receiving consideration because of the potential for concomitant recovery of methane—known as enhanced coalbed methane (ECBM) recovery—during carbon dioxide injection. To better characterize these interactions, the USGS has studied coal samples collected from the Appalachian basin and other locations to determine their capacity to store methane and carbon dioxide gas; the USGS also has conducted preliminary investigations of the environmental ramifications associated with carbon dioxide storage in deep (about 1 kilometer below land surface) coal beds (Kolak and Burruss, 2005, 2006).

Coalbed-Methane Research

USGS coalbed-methane research in the Appalachian basin has been focused in the State of West Virginia. The USGS has worked in cooperation with the West Virginia Geological and Economic Survey and the U.S. Department of Energy, National Energy Technology Laboratory to examine the potential for CBM production at two sites in West Virginia: Mylan Park, Monongalia County, and Meadowfill Landfill, Harrison County. Results of these studies are reported by Ruppert and others (this volume, chaps. G.3 and G.4). The USGS research effort has included assessment of CBM in the Appalachian basin (Milici and Hatch, 2004) and compilation of recent CBM production statistics in collaboration with the State geological surveys (Milici and Polyak, this volume, chap. G.2).

Current State Research

State geological surveys in the Appalachian basin continuously conduct coal research and resource assessments and disseminate that information to the public. A brief summary of State-level major coal projects follows.

Alabama

Alabama produced 19.321 million short tons of coal in 2012 from 8 underground and 38 surface mines (Energy Information Administration, 2013a). The Geological Survey of Alabama (GSA) mapped the resources of the Cahaba coal field (Pashin and others, 1995) and is currently evaluating the distribution and quality of deep coal resources in the Black Warrior basin. The GSA has cooperated with the NCRDS since 1978, and data collected for these mapping studies are submitted to the USGS, as well as being maintained by the GSA.

Alabama is the leader in CBM production in the Appalachian basin and is third in the Nation. Cumulative production exceeds 1.8 TCF, and combined CBM resources may exceed 3 TCF (Alabama State Oil and Gas Board, 2006). In 2005, 4,313 CBM wells operated in the State, producing 116.6 BCF of gas (J. Pashin, Geological Survey of Alabama, written commun., 2006; Milici and Polyak, this volume, chap. G.2).

The GSA has maintained an active research program in carbon dioxide sequestration since the year 2000, which is now being conducted as part of the Southeast Regional Carbon Sequestration Partnership (SECARB). This research includes assessing the potential of geologic formations (including unminable coal beds) as sequestration sites, identifying risks associated with geologic sequestration, and implementing sequestration technology.

Kentucky

Kentucky produces coal in both the eastern Kentucky coal field (part of the Appalachian basin) and the western Kentucky coal field (part of the Illinois basin). Kentucky is the third largest coal-producing State in the Nation; it produced 48.798 million short tons of coal in the eastern Kentucky coal field alone in 2012 from 137 underground and 193 surface mines (Energy Information Administration, 2013a). The Kentucky Geological Survey (KGS) conducts studies that cover the full extent of coal research topics, including resource calculation, coal-availability studies, coal-quality investigations, studies of CBM content and coal permeability (mostly in the western coal field), carbon dioxide sequestration, and environmental impacts of coal usage. See Greb and others (2006) for an excellent overview of these issues.

GIS files created for coal extent, coal thickness, structure, overburden, mined-out areas, and data locations are made available in the KGS Digital Coal Atlas and are published in the KGS Map and Chart Series and as electronic databases. These data were used by the USGS in the National Coal Resource Assessment of 2000 in the Appalachian basin. The KGS has collaborated with the NCRDS since 1980. Stratigraphic information used to make these maps is accessible through searches at the KGS Web site on coal data (http://kgs.uky.edu/kgsweb/DataSearching/Coal/Borehole/boreholesearch.asp and http://kgs.uky.edu/kgsweb/DataSearching/Coal/KCRIS/thickness_search.asp). Nine coal-availability studies (scale of 1:24,000) and six regional coal assessments have been completed for the eastern Kentucky coal field, and fourteen coal-availability studies and five regional assessments have been done for the western coal field.

The KGS also collects and interprets coal-quality data (for both raw coal and coal washability) and participates in the Midwest Regional Carbon Sequestration Partnership (MRCSP). The MRCSP is a consortium of State geological surveys, universities, and nongovernment organizations within seven contiguous States (Indiana, Kentucky, Maryland, Michigan, Ohio, Pennsylvania, and West Virginia); it was established to assess the technical and economic potential for carbon dioxide sequestration within its region. It is partly funded by the U.S. Department of Energy. Most of the carbon dioxide sequestration research by the KGS is focused on the western Kentucky coal field.

Kentucky has great potential for commercial CBM production (Drahovzal, 2003). In 1957, two wells produced 75 to 80 MCF of methane from a single coal bed, the Lower Elkhorn. In 1990, a well in Letcher County initially produced a stimulated flow of 5,000 MCF from 11 coal beds (Chesnut and others, 1997). Although currently there are no active CBM wells in the State, recent work by Eble and Greb (2004) suggested that unmined coals below drainage (more than 2,000 ft below the ground surface) may contain large amounts of methane; the coals may have a median value for gas in place of 324 cubic feet of methane per short ton (CF/ton). Currently, the KGS is working with companies to evaluate the potential for commercial CBM production in the eastern Kentucky coal field.

Maryland

Maryland produced 2.283 million short tons of coal in 2012 from 3 underground and 18 surface mines (Energy Information Administration, 2013a). In late 2006, a major mine (Metiki) ceased operations, and production will likely continue to decrease.

Maryland recently joined the MRCSP. The current investigation focuses on depleted or nearly depleted natural gas reservoirs and also on deep unminable coal seams in Garrett and Allegany Counties (western Maryland). Initial work focused on characterizing the suitability of the thick and minable Pittsburgh and Upper Freeport coal seams for carbon dioxide sequestration.

Maryland has no reported commercial CBM production.

Ohio

Ohio produced 26.328 million short tons of coal in 2012 from 10 underground and 29 surface mines (Energy Information Administration, 2013a). The Ohio Division of Geological Survey, informally called the Ohio Geological Survey (OGS), participates in the USGS NCRDS cooperative program and annually encodes a portion of its measured-section and drill-hole stratigraphic descriptions for the database. Since the start of the cooperative program in 1989, over 23,000 measured-section and drill-hole stratigraphic descriptions have been entered. In addition, using these data as a base, the OGS has conducted eight coal-availability quadrangle studies at a scale of 1:24,000 (for all beds present) and a statewide study for two coal beds, the Upper Freeport and Middle Kittanning.

The OGS leads the geologic team in the MRCSP. The OGS collaborates with the State geological surveys of Indiana, Kentucky, Maryland, Pennsylvania, and West Virginia and with Western Michigan University to study possible sites for the sequestration of greenhouse gases in geologic formations, including coal. Researchers from the seven participating States have developed an interactive GIS for the region available online at http://www.MRCSP.org. The MRCSP geologic team also participates in the NATional CARBon database and geographic information system (NATCARB), which is building a national interactive GIS housing information on carbon sources and potential sinks (http://www.netl.doe.gov/research/coal/carbon-storage/natcarb-atlas). The GIS is designed to allow users to estimate the amount of carbon dioxide emitted by sources (such as powerplants, refineries, and other fossil-fuel-consuming industries) and relations to possible geologic sequestration reservoirs.

Currently, there is no reported commercial CBM production in Ohio, but desorption analyses of shallow coals (less than 500 ft below the surface) in eastern Ohio show gas-in-place volumes of up to 115 CF/ton. Deeper coals may contain larger volumes of methane that could be commercially viable.

Pennsylvania

The Commonwealth of Pennsylvania is currently ranked third of the Appalachian States in coal production, behind West Virginia and Kentucky, and it produced a total of 54.719 million short tons in 2012 from 49 underground and 186 surface mines (Energy Information Administration, 2013a). Bituminous coal production accounted for 96 percent of the total.

During the 1980s and into the early 1990s, the Pennsylvania Bureau of Topographic and Geologic Survey (also called the Pennsylvania Geological Survey, PAGS) produced a series of county reports containing maps of major coal-bed outcrops, structure contours, and mined areas. Tewalt and others (2001) and Ruppert and others (2001) used these reports to create digital 1:24,000-scale maps of the areal extent of the Pittsburgh and Upper Freeport coal beds in Pennsylvania. The PAGS continues to participate in its USGS NCRDS cooperative program, which started in 1978, correcting data and entering data into the database for use in coal resource estimation. The PAGS has conducted five 1:24,000-scale coal-availability studies, three of which are published (Lentz and Neubaum, 2005a,b; Dodge, 2006). PAGS digital Mineral Resource Reports are being developed for each quadrangle in the coal-bearing counties now under study; the reports are similar to the previous map series but have additional information not depicted on the older maps (Dodge, 2005).

Until about 1993, the amount of CBM produced in Pennsylvania was almost negligible. Currently, stratigraphic and production information on approximately 1,200 CBM wells in various stages of completion and commercial production from southwestern Pennsylvania (Cambria, Fayette, Greene, Indiana, Washington, and Westmoreland Counties) is tracked by the Pennsylvania Department of Environmental Protection's Bureau of Oil and Gas Management. In 2008, these wells produced 11.6 BCF of methane, an increase from the 1.64 BCF produced in 2003 (Pennsylvania Bureau of Topographic and Geologic Survey, 2014). Cumulatively, 9.5 BCF of methane has been produced, and production from coal beds in Pennsylvania is predicted to increase.

Tennessee

Tennessee's coal production of 1.090 million short tons (Energy Information Administration, 2013a) in 2012 was from 5 underground and 9 surface mines. All the recent production was bituminous coal from the Cumberland Plateau and Cumberland Mountains regions in eastern Tennessee.

The Tennessee Division of Geology (TDG) collects and encodes coal stratigraphic information for the NCRDS and has done so since 1988; the eventual goal is a statewide coal resources recalculation. In order to facilitate the encoding of stratigraphic information and to evaluate the regional relations of the various coal zones and formation members, several Mississippian and Pennsylvanian stratigraphic cross sections were constructed across the Northern Tennessee coal field and the Cumberland Block area of Tennessee and Kentucky (Miller, 2004). This study established consistent coal zone correlations that could be compared with information from drill holes, electric logs, and measured sections. Cross sections show the correlation of coal zones and strata from the Middle Pennsylvanian Breathitt Formation down to the Upper Mississippian Newman Limestone ("Big Lime") and were integrated with many type localities of formation members and coal zones. Regional horizons, such as tonsteins and beds containing marine invertebrate fossils, were used as marker beds. Work on similar cross sections for the Southern Tennessee coal field is planned.

Western Tennessee has a significant resource of lignite, estimated at more than a billion short tons (Luppens, 1979), but no lignite has been produced to date. The TDG has collaborated with the USGS to assess whether surface mining of this lignite would affect groundwater resources (Parks, 1981). The geology of the lignite-bearing section was summarized by Hackley and others (2006).

There are no wells producing CBM reported in Tennessee.

Virginia

Virginia produced 18.965 million short tons of coal in 2012 from 57 underground and 39 surface mines (Energy Information Administration, 2013a). Beginning in 2002, the Virginia Division of Mineral Resources (VDMR) conducted a program to acquire, digitally scan, catalog, and georeference every available map for underground mines in the Southwest Virginia coal fields. The results of this project include a searchable catalog that provides an index of historic map collections with scanned images. Digital mine outlines from the georeferenced scans of mine maps become GIS layers keyed to relevant coal beds. Combined with data on coal outcrop and extent, isopachs and structural contours, geophysical well log data and other geologic data, the mine-map GIS layers provide the basis for a three-dimensional model of the Virginia coal fields. Incorporating geochemical data and information on present and future restrictions to mining will facilitate assessments of remaining coal resources.

The occurrence of roof falls in Virginia coal mines has long been studied by geologists at the VDMR. A report by Byington (2004) described a technique called SOMA (Stress-field Orientation Mapping and Analysis), which may advance analytical methods for predicting the likelihood of roof falls. Continuing studies in Virginia's active underground coal mines will provide additional structural geologic information to enable safer conditions for miners.

Since 1979, the VDMR has participated in the NCRDS. It encodes stratigraphic information and conducts coal-availability resource studies.

Virginia is the second largest CBM-producing State in the Appalachians, after Alabama. Production occurs within the Pocahontas basin in Buchanan, Dickenson, Russell, Tazewell, and Wise Counties, Va. Milici and Polyak (this volume, chap. G.2) report that there are opportunities for additional growth in this basin. The Virginia Division of Gas and Oil (2006) reported that 2,753 operating wells produced more than 69 BCF of CBM in 2005.

West Virginia

West Virginia produced 120.425 million short tons of coal in 2012 from 160 underground and 104 surface mines, making it the top coal-producing State in the Appalachian basin and second only to Wyoming in the Nation (Energy Information Administration, 2013a). The West Virginia Geological and Economic Survey (WVGES) participates in a cooperative effort with the West Virginia Department of Tax and Revenue and the West Virginia University (WVU) Department of Geology and Geography in the GIS-based Mineral Lands Mapping Program. The WVGES conducts the Coal-bed Mapping Project, which is creating a GIS-based inventory of coal in the State. Coal-bed maps or GIS layers include structure-contour maps; outcrop maps; surface, auger, and underground mined area maps; coal-thickness maps; percent-parting maps; and coal-quality maps. Mapping is progressing by counties, but eventually, the statewide extent of each economically important bed will be mapped. A computer database will exist for each of the coal-bearing quadrangles at a scale of 1:24,000; to date, 130 quadrangles have been completed (B.M. Blake, WVGES, oral commun., 2008). Stratigraphic database work being accomplished under the current NCRDS cooperative, which began in 1975, directly benefits the Coal-bed Mapping Project and supports other cooperative Federal projects. The WVGES has produced a dozen coal-availability and coal-recoverability studies at a quadrangle scale.

For the Applied Coal Resources Investigations Program of the WVGES, researchers maintain and regularly enhance a computerized database of the chemical and physical characteristics of West Virginia coals. The database is one of the largest public databases of coal-quality information in the Nation. Stratigraphic database work accomplished under this effort directly benefits the Coal-bed Mapping Project and supports cooperative Federal projects. The WVGES actively supports exploration, assessment, and utilization of CBM within the State. In addition, the staff pursues biostratigraphic and lithostratigraphic studies to better understand the geology of coal and coal-bearing rocks in West Virginia.

Annual CBM production is increasing rapidly in West Virginia. In 2005, over 388 CBM wells produced more than 17.6 BCF of methane (K.L. Avary, WVGES, written commun., 2006). Permits for CBM drilling have been granted for areas located throughout the coal-bearing stratigraphic interval of the State (fig. 2).

Conclusions

The USGS, in partnership with the State geological surveys of Kentucky, Maryland, Ohio, Pennsylvania, Virginia, and West Virginia, digitally assessed six top-producing Pennsylvanian coal beds and coal zones (Pittsburgh coal bed, Upper Freeport coal bed, Lower Kittanning coal bed, Fire Clay coal zone, Pond Creek coal zone, and Pocahontas No. 3 coal bed) in the northern and central Appalachian basin coal regions in 2000. The total original amounts of coal resources were calculated for five of the coal beds and zones—the Pittsburgh, Upper Freeport, Fire Clay, Pond Creek, and Pocahontas No. 3 (table 1)—and are estimated at about 93 billion short tons, of which about 66 billion short tons remain. Much of the remaining coal in all five coal beds and zones is thinner (<3.5 ft) and deeper (>1,000 ft) than the coal that has been mined, but economic resources are still available, and mining in each coal bed and coal zone will continue for several decades, given current market conditions.

Significant coalbed-methane resources occur throughout the coal-producing States in the Appalachian basin. The basin produces over 1 TCF of CBM annually. Much of the CBM research occurs within the State geological surveys and the USGS. In addition, the surveys conduct research in mapping and correlating coal beds and coal zones and assessing the potential for carbon dioxide sequestration in unmined coal beds and other geologic reservoirs. The State surveys provide coal stratigraphic data to the National Coal Resources Data System.

The Nation is dependent on, and will remain dependent on, coal-burning electric powerplants for much of its electricity for at least the next few decades. Coal-quality issues, especially sulfur content, play an increasingly important role in Appalachian basin coal production trends. The sulfur-dioxide-emission requirements mandated by Phase II of the Clean Air Act Amendments of 1990 (Public Law 101–549) took effect in 2000 and limit maximum emissions to 1.2 pounds of sulfur dioxide per million Btu. This limit has caused companies to favor production of coal from the central Appalachian basin coal region because it has generally lower mercury and sulfur contents than coal from the northern Appalachian basin coal region. However, the use of scrubbers may increase the mining and utilization of coal from the northern Appalachian basin coal region.

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