Stripping-Coal Resources of the United States

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By PAUL AVERITT

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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A review and analysis by States of data available on the stripping-coal potential of the United States

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By PAUL AVERITT

ABSTRACT

The amount of coal mined and potentially minable by strip-mining methods has increased steadily throughout the years, concomitantly with an impressive increase in the size and efficiency of strip-mining machinery. An analysis by States of the geologic and technologic sources of information on stripping coal indicates that as of January 1, 1967, the remaining recoverable stripping-coal resources in the United States in the 0- to 100-foot-thick overburden range totaled about 108 billion tons. This figure is 28 times the cumulative strip-coal production from the beginning of mining to January 1, 1967, and it is 600 times the 1966 strip-coal production of 179 million tons. These convenient comparisons are an aid in appreciating the magnitude of the stripping-coal resources, but they do not represent life expectancy because the rate of production and the estimated size of stripping-coal resources will surely change in the future.

The total estimated recoverable stripping-coal resources are widely distributed in 26 States as tabulated herein, but significantly large amounts are concentrated in North Dakota and eastern Montana, the Illinois basin, and the north half of the Appalachian basin.

INTRODUCTION

Since World War II, coal has been in intense competition with petroleum and natural gas and has lost many former markets to these more generally convenient fuels. Throughout this period of competition, coal has maintained a competitive advantage in areas where it can be mined on a large scale at very low cost by strip-mining methods. The electric utilities have fostered the development of strip mining because the demand for electricity has increased greatly over the years and because the huge generating plants are equipped to use the most economical fuel available; they are not deterred from using coal because of its bulk, its rank, or its moderate ash content provided the unit cost per Btu is satisfactorily low. In many areas, therefore, the utilities have demanded and have received large amounts of strip-mined coal as the lowest cost fuel available, and this increased demand has been accompanied by a steady increase in strip-coal production.

The anticipated future needs for low-cost strip-mined coal for use by the still-growing electric utility industry and possibly by an embryonic synthetic liquid fuels industry has brought about an increased demand for information about potential strip-mining localities.

Although strip-mining localities cannot be defined accurately, except in terms of the present technology, scale of mining, the time and place of use of the coal, methods of transportation, and other purely economic factors, a certain amount of information about potential strip-mining sites and about the strip-mining potential of the United States is widely scattered in geologic and technologic reports published over the years. This short report is intended to provide a summary of this information.

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THE STRIP-MINING INDUSTRY

In strip mining, output per man-day is roughly 100 percent higher, overall recovery is 60 percent higher, and operating costs are 25–30 percent lower than in underground mining. Because of these significant economic advantages the amount of coal produced by strip mining has increased steadily over the years. In 1917, strip mining accounted for only 1 percent of total United States production of bituminous coal and lignite as compared to 33.7 percent in 1966 (U.S. Bur. Mines, 1967, p. 9). By the end of 1966, strip and auger mining had accounted for about 10 percent of the total cumulative United States production. During 1966 almost the entire coal production of eight States—Alaska, Kansas, Missouri, Oklahoma, Texas, Wyoming, North Dakota and South Dakota—was obtained by stripping methods.

In 1966 Illinois was the leading State in strip-coal production with a total of 36.1 million tons. Kentucky was second with a total of 32.5 million tons, derived mostly as a result of increased strip production in western Kentucky. Pennsylvania was third with 30 million tons, derived from operations in both the bituminous coal and anthracite regions. These leaders were followed in order by Ohio, Indiana, and West Virginia.

During the period 1941–64, Pennsylvania was the leading State in strip-coal production and in 1947–48 attained alltime record highs

of nearly 50 million tons annually. Following the 1947–48 peak, strip-coal production in Pennsylvania declined markedly and during the period 1956–66 held almost constant at or near 30 million tons annually. In marked contrast, the strip-coal production of Illinois and western Kentucky increased significantly over the same period and in 1965 both States surpassed Pennsylvania for the first time.

The increased production by strip mining has been accompanied by continued improvement in the size and efficiency of earth-moving machinery. In 1917 the largest steam shovel in operation had a capacity of only a few cubic yards. By 1957 the largest shovel in operation had a capacity of 70 cubic yards, or 105 tons. In succeeding years larger shovels were constructed, and in 1965 the largest shovel in operation had a capacity of 180 cubic yards, or 265 tons, and was capable of removing 16,000 tons of overburden an hour. In 1966, shovels of 200-cubic-yard capacity were in the planning and construction stages. A shovel of 300-cubic-yard capacity is regarded as being technically feasible (Coal Age, 1966a). A walking dragline with a bucket of 220-cubic-yard capacity and a 310-foot boom is also in the planning stage (Mining Engineering, 1966). An even larger dragline with a 500-foot boom is regarded as being technically feasible.

Wheel excavators of the type used for many years in the brown coal areas of Western Germany have been used on a limited scale in the United States since 1944 (Huey, 1964). These wheels are highly efficient for the removal of soft and unconsolidated overburden, and they are technologically appealing because the operation is continuous and the broken-down overburden can be delivered by conveyor belt to any point desired. The most successful use of wheels in the United States has been in the removal of glacial drift in Illinois and of unconsolidated overburden in North Dakota. The most recent wheel excavator in the United States was installed in North Dakota in 1965; it was manufactured in Germany and has a capacity of 2,800 cubic yards an hour.

The increase in size and efficiency of strip-mining machinery has permitted a steady increase in the average maximum thickness of overburden that can be removed and a parallel increase in the ratio of average overburden thickness to average coal thickness. This trend is shown in table 1.

The averages presented in table 1 include several noteworthy extremes. In Alaska, for example, the average thickness of overburden removed in 1965 was nearly 67 feet, and the average thickness of coal recovered was nearly 43 feet; these figures yield a very favorable Statewide ratio of 1.4:1. In marked contrast, the average thickness of overburden removed in Oklahoma in 1965 was 43 feet, and the aver-

TABLE 1.—*Average thickness (in feet) of overburden removed and of bituminous coal and lignite recovered by strip mining in the United States for selected years*

[Modified from Young (1967, p. 18)]

	1946	1950	1955	1960	1965
Average thickness of overburden removed	32	39	42	46	50
Maximum thickness of overburden removed	------	------	70+	100	125
Average thickness of coal recovered	5.2	5.1	4.9	5.1	5.2
Ratio of average overburden thickness to average coal thickness	6:1	8:1	8.5:1	9:1	10:1

age thickness of coal recovered was 1.5 feet; these figures yield a Statewide ratio of 29 : 1 (Young, 1967, p. 18). In at least one operation in Kansas, 45 feet of overburden was removed to obtain 1.5 feet of high-quality coal; these figures yield a ratio of 30 : 1. In Illinois ratios larger than 30 : 1 have been handled and are being planned in parts of large-scale stripping projects where the coal is 28–36 inches thick.

These examples suggest that the 30 : 1 ratio is technically feasible as a maximum for present and near-future strip mining. However, in the present highly competitive energy market, the success of each strip-mining operation depends on many economic factors other than thickness of the overburden. These factors include thickness and quality of the coal, density and hardness of the overburden, capacity of machinery, size of property, selling price of coal from competing sources, distance to transportation facilities and markets, and availability of electric power, labor and supporting facilities. Because of the continued availability of coal with more favorable overburden ratios, the average nationwide ratio will continue to be less than 30 : 1 for many years, as may readily be seen by an examination of the average ratios for recent years as shown in table 1.

The very large shovels mentioned previously are designed with the increased lift and swing required to handle overburden as much as 125 feet thick, a maximum met in 1965 in parts of large stripping projects. Anticipating the trend toward stripping to greater depths, the Illinois and Indiana Geological Surveys, in outlining areas suitable for strip mining, are including beds with overburden thicknesses of as much as 150 feet. Investigators in other areas have presented data on overburden to maxima of 90 and 120 feet.

Some of the most spectacular coal-mining operations in the United States are those in which the coal is being recovered by stripping methods. The thickest bed mined by stripping is at Wyodak, Wyo., where the coal is 90 feet thick; the overburden is generally less. The deepest strip pits in the United States are in the Pennsylvania anthracite fields where two major types of strip mining, termed "outcrop

stripping" and "basin stripping," are in progress. In outcrop stripping, operations proceed linearly and downdip along a steeply dipping outcrop. These outcrops were first mined many years ago by underground methods, which recovered about one-third of the coal. Later, during the 1920's and 1930's, they were stripped out along a very narrow shallow belt with small shovels. In the current operations the partly mined coal just below the older stripped-out zone is being recovered with large draglines and shovels. These pits are as much as 200 feet deep. In basin stripping, the entire canoe-shaped end of a syncline is mined out and backfilled on a massive scale. In one such operation where the 20-foot-thick Mammoth bed lies in the syncline, the block of ground being strip mined is 800 feet wide and 290 feet deep at the deepest place on the synclinal axis (Coal Age, 1965, p. 79).

Strip mining greatly increases the amount of ultimately recoverable coal in the United States, for the method yields an average recovery of about 80 percent as compared to 50 percent for underground mining. Strip mining also adds to total recoverable coal by making possible the mining of coal under shallow overburden, in thin beds, in multiple beds, in badly faulted areas, or in small isolated pockets where underground mining would not be practicable.

In many individual operations, where strip mining has been terminated for reasons of economy and practicality, additional coal is being recovered by use of horizontal, power-driven augers that bore into the coal bed at the base of the highwall. The diameter of an auger is generally a little less than the thickness of the coal bed. The largest single auger thus far constructed is 84 inches in diameter. To avoid engineering problems caused by the use of large augers, some manufacturers have recently constructed augers consisting of two paired bits and shafts that operate simultaneously. In a typical operation, auger holes are drilled about 200 feet under the highwall. The method permits a maximum recovery of about 75 percent in the block of ground being mined, but actual recovery is generally much less because the diameter of the augers is generally less than the full thickness of the bed being mined, and because the holes are usually spaced several inches apart. In 1966 about 15 million tons, or 2.8 percent of the total bituminous coal and lignite produced, was mined by the auger method (U.S. Bur. Mines, 1967, p. 4).

Mining of a coal bed at the outcrop or under the highwall is in process of being greatly extended through use of remote-controlled, continuous mining machines similar to those now in common use in underground mining. These "highwall miners" have revolving cutting heads, or drums, or oscillating arms that break down the coal at the face and move it continuously to the rear as the machines advance. A

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remote-controlled, continuous mining machine now in an advanced state of experimental use for outcrop mining is capable of penetrating as much as 1,100 feet into the coal outcrop.

STRIPPING-COAL SITES DESCRIBED IN PUBLISHED REPORTS

The delineation of a stripping-coal deposit requires detailed information in three dimensions. The basic, two-dimensional information on the thickness, continuity, and dip of coal beds at the outcrop is readily obtained through routine geologic surveys. Information on the third dimension—the thickness of the overburden and the contour of the overlying land surface—can be obtained in a preliminary way from topographic maps, which are available for considerable parts of most coal-bearing areas and have done much to facilitate study and use of coal in the United States. However, the precise information on overburden composition, thickness, and tonnage needed for strip-mine development requires closely spaced test drilling, which is time-consuming and expensive, and, in fact, is rarely carried out until mining of the coal is contemplated. A few selected stripping-coal sites have been mapped and described, and other potential sites noted during the course of geologic surveys have been mentioned in published reports. A summary of this and related information follows.

ALABAMA

In the Fabius-Flat Rock area, Jackson County, Shotts and Riley (1966) described a strippable deposit containing 40 million tons of coal in a bed averaging about 28 inches in thickness with 60 feet or less of overburden.

ALASKA

In the Nenana coal field, Wahrhaftig and Birman (1954) mapped an area of about 25 square miles extending from the Nenana River 6 miles up the valley of Lignite Creek, which is underlain by 95 million tons of coal in six beds ranging in thickness from 5 to 60 feet and at depths generally less than 200 feet.

In the Beluga River coal field, Warfield (1963) described a drilling program that delineated 20 million tons of coal within reach by stripping methods. This coal is reasonably convenient to Anchorage.

In the Homer district of the Kenai coal field, Barnes and Cobb (1959, p. 243) described an area of 28 acres on lower Deep Creek that is underlain by 200,000 tons of coal in a 4-foot-thick bed with less than 25 feet of overburden.

ARKANSAS

As part of a summary study of the coal resources of Arkansas determinable from existing mapping and exploration, Haley (1960, p. 814) concluded that the original resources of low-volatile bituminous coal and semianthracite within 60 feet of the surface totaled 231 million tons, or 10 percent of the total of such coal in Arkansas. His maps (pls. 59, 60) show the 60-foot overburden line on the Lower and Upper Hartshorne coal beds. Haley (1960, p. 824, 825) also reported on 32 million tons of strippable lignite in beds generally more than 2½ feet thick and generally less than 100 feet below the surface. The two figures combined yield a substantial total of 263 million tons as the strippable coal resources of Arkansas.

ILLINOIS

A considerable amount of information on stripping coal in Illinois has been published by the Illinois Geological Survey. In the period 1925–37, many potential stripping-coal sites were described by Culver (1925), Cady (1927, 1937), and Henbest (1929) based on the capacities of the small shovels then in use. Subsequently, Cady (1952, p. 43–48) provided important summary information on the economics of strip mining in Illinois and on certain coal beds and localities of potential interest to strip miners. In 1955 the Illinois Geological Survey began a new program of study of stripping coal that has yielded five reports to date (Smith, 1957, 1958, 1961; Smith and Berggren, 1963; Reinertsen, 1964). On the basis of work completed and in progress, J. A. Simon (written commun., Sept. 28, 1966) has concluded that the remaining stripping-coal resources of Illinois as of January 1, 1966, in beds 18 inches or more thick and at a maximum depth of 150 feet, total 21,223 million tons. Simon also concluded that the original resources within the same parameters totaled about 23,000 million tons.

A map of the Illinois coal field recently prepared by Simon (1966) shows major operating strip and underground mines and provides subsidiary data on 1965 production, beds being mined, railroad lines, and freight rate districts.

INDIANA

The Indiana coal field contains large resources of stripping coal because of its location on the east edge of the large Illinois coal basin. As part of a study of Indiana coal resources, Spencer (1953, p. 7) concluded that the original stripping-coal resources with a maximum overburden of 40 feet for coal 14–28 inches thick, 60 feet for coal 28–42 inches thick, and 90 feet for coal more than 42 inches thick totaled 3,524 million tons. This figure is 9.4 percent of the total for the State as estimated by Spencer. In 1966 the Indiana Geological Survey was

engaged in a detailed study of selected stripping-coal sites, which included deposits with overburden to a maximum of 150 feet thick.

KANSAS

In a report on the coal resources of Kansas, Abernathy, Jewett, and Schoewe (1947, p. 3, 13) stated that the proved resources of stripping coal in the ground as of January 1, 1946, totaled 60 million tons. This estimate is based on an assumed weight of 1,500 tons per acre-foot and is restricted to coal with less than 60 feet of overburden, or with an overburden ratio of not more than 35 cubic yards per ton of coal. The distribution of this tonnage is given in cited reports of the State Geological Survey of Kansas. Additional information on stripping coal is given by Schoewe (1955, 1959). The distribution and extent of areas mined out by stripping methods as of 1945 are shown on a map by Abernathy (1946). Mined areas of the important Weir-Pittsburg bed are shown on a similar map by Abernathy (1944).

KENTUCKY

Since the late 1950's the U.S. Geological Survey and the Kentucky Geological Survey have been engaged in a cooperative program of geologic mapping in Kentucky. As of January 1, 1967, this program had yielded about 90 geologic maps covering parts of the eastern and western Kentucky coal fields. These maps are printed on topographic base maps at the scale of 1 inch to 2,000 feet. The geologic maps show outcrops of main coal beds, the range in thickness of coal beds, structure contours, and locations of underground mine adits and strip mines and thus provide the basic data needed to delineate potential strip-mining sites. It is not feasible to cite all these maps in this short summary, but they are listed in various bibliographies of geologic reports.

MISSOURI

In a study of the mineral commodities of Putnam County, Gentile (1965, p. 24–26) discussed the strip-mining potential of an area of 130 square miles in eastern Putnam County, where the Lexington coal is 30 inches thick on the average and the overburden is generally less than 150 feet.

MONTANA

In eastern Montana 59 potential strip-mining localities, underlain at shallow depth by 5 billion tons of coal, have been described in 10 reports of the U.S. Geological Survey (Baker, 1929; Bass, 1932; Brown and others, 1954; Collier and Knechtel, 1939; Culbertson, 1954; Kepferle, 1954; May, 1954; Parker, 1936; Pierce, 1936; Warren, 1959).

The information on stripping coal in these reports was summarized by Averitt (1965, p. 18–20, table 4, fig. 5). The figure of 5 billion tons is 2.4 percent of the total coal resources in eastern Montana as determined by mapping and exploration. It is obviously less than the total strippable coal present in Montana, because the 59 areas selected for mention or study were the best noted in each locality. Other potential stripping-coal sites should be present in all parts of the Montana coal fields, particularly in northeast Montana where the coal-bearing rocks are concealed by glacial deposits. The total potential stripping coal resources of Montana should be at least three times the total described in published reports, or 15,000 million tons. This estimated figure would be much larger, except for the fact that in southeastern Montana, where the total resources are very large, the topographic relief tends to reduce the size of strippable areas; also many of the higher and more accessible beds are burned out along the outcrops.

NORTH DAKOTA

The strippable lignite resources of North Dakota are very large as evidenced by the great number and thickness of lignite beds, the gentle dip of the enclosing rocks, and the general low topographic relief. Brant (1953) has supplied data from which an estimate of the potential strippable resources may be deduced. According to Brant (1953, p. 1, 4), the original resources of lignite in North Dakota as determined by mapping and exploration totaled 350, 910 million tons, of which 70 percent, or 250,000 million tons, is within 500 feet of the surface. For reasons previously suggested, this large tonnage should be evenly distributed by 100-foot overburden categories. If so, one-fifth of the total, or 50,000 million tons, is 100 feet or less below the surface. Brant also (1953) presented planimetric maps of individual counties showing lignite outcrops and locations of many strip mines.

North Dakota's modest annual lignite production of less than 3 million tons is obtained from a few large, readily accessible strip-mining localties, most of which have developed resources adequate for many years of continuous operation. Ball (1966, p. 11) estimated that operating strip-mining companies in North Dakota control, or have developed, properties containing about 1,850 million tons of strippable lignite in thick beds generally less than 90 feet below the surface. Ball also estimated that the total strippable resources of such lignite in North Dakota probably ranges from 7,000 to 10,000 million tons. This is admittedly a conservative figure based on present and near-future mining practices and commercial needs.

Because of the abundance of strippable lignite in all parts of western

North Dakota, only a few of the larger and more conspicuous deposits have been mapped and described. They are summarized as follows:

In the Wibaux area, which extends into Montana, May (1954) mapped and described 10 possible strip-mining areas. The largest of these covers about 55 square miles and is underlain by lignite 10–40 feet thick. A part of this large area selected for special study contains 339 million tons of lignite in a bed 24 feet thick and generally less than 60 feet below the surface.

In Slope and Bowman Counties, Kepferle and Culbertson (1955) mapped and described two areas underlain by 1,370 million tons of lignite in a bed 20–30 feet thick. About half of the total is 60 feet or less below the surface.

On a detailed geologic map of the Square Buttes coal field in Oliver and Mercer Counties, Johnson and Kunkel (1959, p. 50, pl. 1) delineated seven potential strip-mining localities in which the lignite is 6 feet thick or more, and the overburden is generally less than 60 feet.

Van Sant and Ellman (1959) provided mining costs and other data on six strip mines that in 1955 supplied 70 percent of North Dakota's production.

OKLAHOMA

The bulk of Oklahoma's annual coal production, which in 1966 totaled 850,000 tons, is obtained by strip mining. The distribution and extent of strip-mined areas as of 1960 are shown on a map by Doerr (1961, p. 27). Many of these areas were mined with small shovels and could possibly be mined deeper with larger equipment. In the Henryetta district, Okmulgee County, Dunham and Trumbull (1955, p. 211) discussed four areas of potential value for strip mining.

PENNSYLVANIA

Pennsylvania has been a major producer of strip-mined coal for many years. As a consequence, the outcrops of all the thicker and better known beds have been extensively stripped. The outcrop of the Pittsburgh bed, in particular, is largely mined out. Deasy and Griess (1960, p. 14) prepared a map showing the few remaining unstripped areas along the outcrop of the Pittsburgh bed; earlier they (1958, p. 112) prepared maps showing original outcrops and remaining unmined outcrops of the Lower Freeport coal in Clearfield County and the Upper Freeport coal in Armstrong County. Deasy and Griess (1960, facing p. 68) also prepared a map showing the cumulative strip-mined bituminous coal lands of Pennsylvania and more detailed maps of selected smaller areas (1958, p. 120; 1959, p. 4, 8). These maps demonstrate the widespread extent of strip mining, and they will aid in finding unmined areas.

In a summary study of the coal resources of Beaver County, Patterson (1963, p. A19, A20, A22, A23) estimated that the original resources with less than 60 feet of overburden totaled 147 million tons, or about 7 percent of the total original resources estimated for the county.

In a summary study of the coal resources of Lawrence County, Van Lieu and Patterson (1964, p. B17–B19) estimated that the remaining resources as of January 1, 1957, with less than 60 feet of overburden totaled 67 million tons, or about 9 percent of the total remaining resources estimated for the county.

SOUTH DAKOTA

Although South Dakota contains adequate resources of lignite suitable for strip mining, at least for local use, annual production is very small because of competition from coal in the adjoining States of Wyoming and North Dakota where the beds are thicker and more economical to mine. Most of past and present production in South Dakota has come from strip mines in the Isabel-Firesteel district, in Dewey and Ziebach Counties, advantageously located on a branch line of the Milwaukee Railroad. Summaries of information available on the Isabel-Firesteel district have been provided by Denson (1950) and by Brown (1952, p. 16). Brown (1952) also provided a summary of information available on the remainder of the South Dakota lignite field and cited three additional areas potentially suitable for strip mining.

TEXAS

In a summary study of lignite resources in Texas, Perkins and Lonsdale (1955, p. 28–36) reported strippable resources totaling 3,282 million tons in beds 5 feet thick or more and 90 feet or less below the surface. This tonnage is classed as measured and indicated and is demonstrably conservative.

WASHINGTON

The stripping-coal resources of Washington are very small, because in most areas the coal-bearing rocks are folded, faulted, and steeply dipping. Nevertheless, mapping and exploration to date have revealed three areas of relatively gentle dips and thin overburden.

In the Centralia-Chehalis district, Lewis and Thurston Counties, Snavely, Brown, Roberts, and Rau (1958, p. 111) delineated areas in the Tono basin that are suitable for strip mining. A 1-million-kilowatt steam-powered generating plant designed to use this low-cost strip-mined coal is under construction by the Pacific Power and Light Company and the Washington Water Power Company.

In the Toledo-Castle Rock district, Cowlitz and Lewis Counties,

Roberts (1958, p. 49, 50, 52, 53; pls. 15, 16) described a small strip-mining area that contains 8 million tons of lignite in two beds ranging in thickness from 5 feet to more than 20 feet and generally less than 60 feet below the surface. (See also Toenges and others, 1947.)

In the Roslyn field, Kittitas County, Beikman, Gower, and Dana (1961, p. 21) mentioned three areas in T. 20 N., R. 15 E., where the dip of the Big Dirty bed and the slope of the topography are approximately the same and where the Big Dirty bed is probably generally less than 120 feet below the surface.

WYOMING

Wyoming contains substantial resources of stripping coal around the edges of the Powder River Basin, in the Hanna basin, and in the Kemmerer area of Lincoln County. The bulk of annual coal production in Wyoming is obtained from a few large strip mines in these areas. As in North Dakota, the amount of strippable coal already known and potentially present in Wyoming is so much larger than annual production that incentive to delineate additional areas has been lacking. Several potential stripping-coal localities are described, however, in two reports of the U.S. Geological Survey. In the Buffalo–Lake De-Smet area, Johnson and Sheridan Counties, Mapel (1959, p. 93, 94) discussed eight potential strip-mining areas. Three of these areas are underlain by coal locally as much as 224 feet thick in the Healy(?) bed. (See also Mapel and others, 1953.) In the Crazy Woman Creek area, Johnson County, Hose (1955, p. 84–87) presented resource data by individual beds and townships in an overburden category of 0–150 feet. This information used in conjunction with his geologic map will be helpful in delineating potential strip-mining areas.

The modern strip-mining operation of the Kemmerer Coal Co. at Elkol, Lincoln County, is described in a recent article in Coal Age (1963).

OTHER POTENTIAL SITES

Many additional strip-mining sites are undoubtedly present in the States mentioned and in other coal-bearing States not mentioned. These sites can be located by study of the relation between coal outcrops, dip of beds, nature of overlying rock, and the terrane. This study will be facilitated by the availability of geologic reports of various agencies for substantial parts of most coal-bearing areas and by the increased availability of modern topographic maps. The topographic map coverage of the United States coal field areas has increased steadily through the years and is virtually complete for most coal areas in the Eastern United States. Since the mid 1950's most topographic maps of coal field areas have been prepared on the improved scale of 2,000 feet to the inch,

which is ideal for study and planning. For the United States as a whole, these maps are being published at the rate of about 1,500 per year.

ESTIMATED TOTAL STRIPPING-COAL RESOURCES

From data summarized in the preceding paragraphs it is obvious that the stripping-coal resources of the United States are very large. In six States alone, where State-wide estimates of stripping-coal resources based on factual data have been prepared, the total is 95,069 million tons, as shown in table 2.

TABLE 2.—*Estimated original resources of stripping coal in six States*

[Figures are for resources in the ground, of which about 80 percent may be considered recoverable]

State	*Millions of short tons*	*Range of overburden (feet)*
Arkansas	263	0– 60; 0–100
Illinois	23, 000	0–150
Indiana	3, 524	0– 90
Montana	15, 000	Various
North Dakota	50, 000	0–100
Texas	3, 282	0– 90
Total	95, 069	

Accepting the figures in table 2 as a frame of reference, one can derive comparable figures for adjoining and intervening States and a total for the United States by a crude process of extrapolation, using for each State the following critical factors: (1) Size of the total resource, (2) tonnage in the major 0- to 1,000-foot overburden category, (3) average topographic relief, and (4) average dip of the coal-bearing rocks.

As figures for five of the six States in table 2 are for resources in overburden categories generally less than 100 feet, the extrapolation based on these figures is intended to include coal in the 0- to 100-foot overburden category, which represents most coal of present interest for strip mining. It would, of course, be possible to modify the figures in table 2 so that they would apply more closely to the 0- to 100-foot overburden category, but this process would substitute extrapolated estimates for figures arrived at by more accurate methods of calculation and would not improve the extrapolation in surrounding States. Furthermore, the smaller figures in table 2 are compensated by the larger figure for Illinois, which represents coal in the 0- to 150-foot overburden category.

The figures for the States listed in table 2 and the extrapolated figures for adjoining and intervening States are presented in table 3. The total of these figures—139,969 million tons—represents the estimated total original stripping-coal resources of the United States.

TABLE 3.—*Estimated original resources of stripping coal in the United States in beds generally less than 100 feet below the surface*

[Figures are for resources in the ground, of which about 80 percent may be considered recoverable]

State	Millions of short tons	State	Millions of short tons
Alabama	800	North Dakota	50, 000
Alaska	2, 000	Ohio	5, 000
Arizona	100	Oklahoma	500
Arkansas	263	Pennsylvania	8, 000
Colorado	1, 200	South Dakota	400
Illinois	[1] 23, 000	Tennessee	200
Indiana	3, 524	Texas	3, 282
Iowa	600	Utah	300
Kansas	600	Virginia	1, 000
Kentucky	6, 000	Washington	100
Maryland	100	West Virginia	6, 000
Missouri	1, 000	Wyoming	10, 000
Montana	15, 000		
New Mexico	1, 000	Total	139, 969

[1] Overburden, 0–150 feet thick.

Although a great deal of subjectivity is inherent in the figures determined by extrapolation, the total of 139,969 million tons reflects control by estimates for the six States mentioned previously where subjectivity was at a minimum. This figure can be further evaluated by a second line of reasoning. Continuing study of United States coal resources has shown that of the total resources known through mapping and exploration to date, about 1,450 billion tons is in the 0- to 1,000-foot overburden category. The figure for stripping-coal resources is 9.6 percent of this larger total, which suggests that it is a reasonable maximum.

The estimated total of 139,969 million tons is, of course, for original resources in the ground. Subtracting 4,850 million tons, representing cumulative past strip production of bituminous coal and anthracite of 3,876 million tons to January 1, 1967, plus estimated past losses of 974 million tons, and assuming future recoverability of 80 percent, the total is reduced to 108,095 million tons. This figure is too large to be appreciated except by comparison with smaller and more meaningful numbers. It is, for example, 28 times the cumulative strip-coal production of 3,876 million tons, from the beginning of mining to January 1, 1967, and it is 600 times the 1966 strip-coal production of 179 million tons. These comparisons do not represent the life expectancy of stripping-coal resources because the rate of production and the estimated size of the resources will surely change in the future.

PREVIOUS ESTIMATE OF STRIPPING-COAL RESOURCES

An estimate of 230,670 million tons as the stripping-coal resources of the United States has been presented previously (Coal Age, 1966b). For a few States where data were obtained from common sources,

the figures are identical in the Coal Age estimate and in the present estimate. Where figures were obtained by extrapolation, those in Coal Age are, in general, higher than those in the present estimate. For some States this increase is explained by the inclusion of coal with overburden to maxima of 120 and 150 feet. For others, the difference is too great to be satisfactory to the writer. The Coal Age figures for Kansas (6,807 million tons), Missouri (18,085 million tons), and West Virginia (30,400 million tons) seem to be too high for the stated 150-foot overburden range. When the Coal Age estimate of 230,670 million tons is compared to the total estimated United States resources as determined by mapping and exploration, it is about 16 percent of such resources in the 0- to 1,000-foot overburden category. This total and percentage are both somewhat high for the stated parameters.

RECLAMATION OF STRIP-MINED LANDS

The thousands of stripped-over areas in the United States cover about 1,500 square miles. The present rate of increase in strip mining is adding ever-increasing annual increment to this total, and the increase in size of strip-mining machinery will result in ever higher and wider spoil banks. Recognizing this threat to the beauty of the land and to the utility of other resources, many States have enacted legislation to require reclamation of future strip-mined lands.

Existing spoil banks present serious problems to conservationists. In mountainous areas where contour stripping is practiced, the spoil banks may initiate landslides, which devastate larger areas than the original piles, and contribute excessive amounts of silt to the local drainage; in these areas, conservation objectives are directed toward reducing the possibility of slides and improving the opportunities for reforestation.

In areas of low relief, spoil banks are more stable, and conservation objectives vary according to the composition, texture, height, and slope of the banks. Many spoil banks are high in sulfuric acid, derived from sulfur in the coal and associated rock. A few are low in sulfuric acid. All are low in organic material and in available trace elements needed to support plant life. Highly acidic spoil banks will support little plant life; moderately acidic banks will support trees and plants adapted to an acidic soil; other less acidic banks will support a wider variety of plant life. The degree of reclamation and future utility thus depends on physical and chemical factors that require a great deal of preliminary study and experimentation. Within limits imposed by chemical and physical characteristics, spoil banks have been used as tree farms, recreational areas, grazing lands, game and fish preserves,

city dumps, and sewage disposal ponds. A few of high calcareous content support orchards and other suitable forms of agriculture. Deasy and Griess (1963) provided an excellent summary and bibliography on the status of thought and effort thus far devoted to reclamation.

CONCLUSIONS

The information summarized permits several broad and perhaps self-evident generalizations that are worthy of emphasis:

1. The largest concentration of strippable coal in the United States is in North Dakota and eastern Montana. Relatively little mining is carried on in this area, however, because of the small population and lack of industrialization.
2. The second largest concentration of strippable coal is in the Illinois basin, which embraces the coal-bearing parts of Illinois, Indiana, and western Kentucky. In 1964 the Illinois basin became the leading area in strip-coal production in the United States with an output of 66 million tons. This lead was increased in 1965 with an output of 72 million tons and further increased in 1966 with an output of 79 million tons—the maximum thus far recorded for the Illinois basin.
3. The third largest concentration of strippable coal is in the north half of the Appalachian basin, which embraces the coal-bearing parts of Pennsylvania, including the Pennsylvania anthracite fields, West Virginia, and Ohio. Because this area is near centers of population and industrial activity, it was the leading area in strip-coal production for many years. It attained a maximum of 89 million tons in 1947. Since that date, however, strip-coal production in the north half of the Appalachian basin has declined, and during 1956–65 it ranged from 57 to 68 million tons annually. The 1964 production of 63 million tons was for the first time in many years less than that of the Illinois basin. The increased 1965 production of 68 million tons was also less than that of the Illinois basin.

   The fact that strip-coal production in Pennsylvania and West Virginia is falling behind the national trend suggests that much of the readily accessible, low-cost strip coal has been mined out. Because of the substantial resources of strip coal remaining in these States, a resurgence in strip and related production is in prospect through use of larger equipment, augers, and highwall miners.
4. If the cumulative past production of 3,876 million tons of strip coal has resulted in spoil banks covering 1,500 square miles, then the removal of the remaining recoverable resources of 108,095 million tons could result in spoil banks covering 42,000 square miles—an

area larger than the entire State of Ohio. This prospect is repugnant to public opinion, and future strip mining is likely to be more closely controlled by State and Federal laws. Nine or ten States have enacted or have under legislative consideration fairly stringent reclamation laws, and the stripping-coal industry is actively supporting research on reclamation methods. The future of the strip-mining industry is obviously strongly dependent on an effective nation-wide program of reclamation of stripped-over lands.

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