Stripping-Coal Resources of the United States—January 1, 1970

GEOLOGICAL SURVEY BULLETIN 1322

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By PAUL AVERITT

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A review and analysis by States of data available on the stripping-coal potential of the United States. Supersedes Bulletin 1252–C

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1970

UNITED STATES DEPARTMENT OF THE INTERIOR

WALTER J. HICKEL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

Library of Congress catalog-card No. 71-607887

**For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 25 cents (paper cover)**

CONTENTS

ILLUSTRATION

TABLES

STRIPPING-COAL RESOURCES OF THE UNITED STATES—JANUARY 1, 1970

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, 1970, the remaining recoverable resources of stripping coal in the United States in the 0- to 150-foot-thick overburden category totaled 128 billion tons. This figure is 29 times the cumulative strip-coal production from the beginning of mining to January 1, 1970, and it is 690 times the 1969 strip-coal production of about 185 million tons. These convenient simplified 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 the resource 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 (1) Northern Great Plains region of western North Dakota, eastern Montana, and northeastern Wyoming, (2) the Illinois basin, and (3) the north half of the Appalachian basin.

INTRODUCTION

The marked increase in production of strip-mined coal in the United States in recent years has been fostered primarily by the electric utilities, who have taken over the position in the coal economy formerly occupied by the railroads and by household heating. Since World War II, the utilities have experienced a strong upward trend in growth caused by increased population, increased use of manufactured products, and increased use of electrical appliances, particularly air conditioning.

The huge steam-powered electric generating plants constructed to meet this burgeoning demand are designed to use the most economical fuel available. They are not deterred from using coal because of its bulk or its physical and chemical properties, provided only that the unit cost per Btu is satisfactorily low. In and near coal-field areas, therefore, the utilities provide a large, ever-increasing market for large amounts of strip-mined coal as the lowest cost fuel available, and this assured market has been responsible not only for increased strip-coal production, but also for the improvement in strip-mining technology.

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, have brought about an increased demand for information about potential strip-mining localities.

Although strip-mining localities can be defined only in terms of the present technology, or an assumed future technology, scale of mining, methods and distance of transportation, and other purely economic and technologic factors, a modest amount of information about possible 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. Much of this information is summarized in subsequent paragraphs, and additional information will be found in reports cited in the accompanying bibliography.

This report is a revision and an updating of Bulletin 1252–C (Averitt, 1968).

ACKNOWLEDGMENTS

The author is indebted to F. F. Barnes, E. C. Beaumont, Helen M. Beikman, Henry L. Berryhill, Jr., Russell A. Brant, W. C. Culbertson, K. J. Englund, Boyd R. Haley, A. L. Hornbaker, E. R. Landis, Edward T. Luther, Robert E. Matson, Avery H. Reed, Walter V. Searight, Jack A. Simon, Joseph B. Smith, W. H. Smith, Arthur A. Socolow, James V. A. Trumbull, and Charles E. Wier, for contribution and review of data used in this report.

THE STRIP-MINING INDUSTRY

In strip mining, output per man-day is roughly 100 percent higher than in underground mining, average recovery is 60 percent higher, and operating costs are 25–30 percent lower. 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 U.S. production of bituminous coal and lignite as compared to 34.1 percent in 1968 (U.S. Bur. Mines, 1969, p. 4). By the end of 1969, strip mining had accounted for 11 percent of total cumulative U.S. production. During 1969, almost the entire coal production of 10 States—Alaska, Kansas, Missouri, Montana, New Mexico, Oklahoma, Texas, Wyoming, North Dakota and South Dakota—was obtained by stripping methods.

In 1968, the following six States accounted for the bulk of U.S strip-coal production:

State	*Production (millions of short tons)*
Illinois	36
Kentucky	34
Ohio	31
Pennsylvania	25
Indiana	16
West Virginia	12

During the period 1941–64, Pennsylvania was the leading State in strip-coal production, and in 1947 and 1948 attained alltime record highs of nearly 50 million tons annually. Following these record highs, strip-coal production in Pennsylvania declined markedly, but during the period 1956–66 it held almost constant at or near 30 million tons annually. In 1967 and 1968, the decline in strip-coal production in Pennsylvania resumed, and the 25 million tons produced in 1968 was the lowest recorded since 1954.

In 1947, West Virginia attained an alltime record high in strip-coal production of 22 million tons. Since that date, annual production has ranged generally between 6 million and 12 million tons.

In spite of lower strip-coal production in Pennsylvania and West Virginia, the northern Appalachian basin, which comprises Pennsylvania, Ohio, West Virginia, and Maryland, maintained generally high strip-coal production throughout the 1950's and 1960's, primarily because of a steady increase of strip-coal production in Ohio, from 17 million tons in 1947 to 31 million in 1968.

During this same period, however, the strip-coal production of the Illinois basin, which comprises Illinois, Indiana, and western Kentucky, increased steadily and rapidly. Indiana surpassed West Virginia in 1958; Illinois surpassed Pennsylvania in 1965; and western Kentucky surpassed Pennsylvania in 1967. As a result of these changes, the strip-coal production of the Illinois basin surpassed that of the northern Appalachian basin in 1964, and the spread between these two major producing areas has increased during succeeding years. (See fig. 1.)

The decline in strip-coal production in Pennsylvania and West Virginia and the increase in Ohio and in Illinois basin States are related in part to differences in topographic relief. In Pennsylvania and West Virginia, the land surface is moderately to highly dissected, and many stream valleys are V-shaped. In this topographic setting, strip mining must follow the sinuous outcrops of

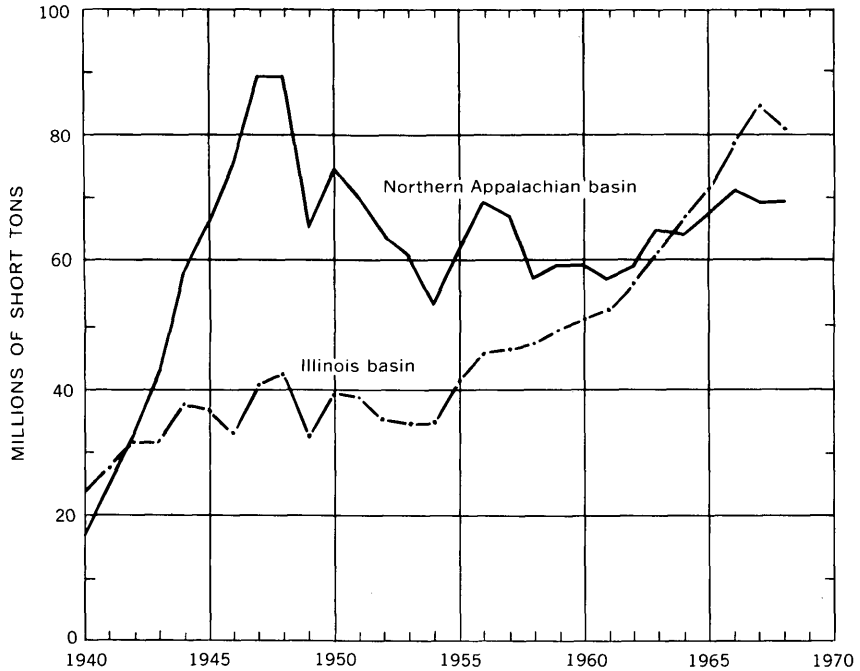

FIGURE 1.—Strip-coal production of the northern Appalachian basin (Pennsylvania, Ohio, West Virginia, and Maryland) versus that of the Illinois basin (Illinois, Indiana, and western Kentucky). Source: U.S. Bureau of Mines (1940–1968).

coal beds on hillsides. This pattern of mining is not conducive to the use of large-scale machinery, and it adds to the difficulty of spoil bank reclamation. In Ohio and in the Illinois basin States, the land surface is much less dissected and is gently rolling to nearly flat over large areas. This topographic setting permits large-scale unit operations and the use of very large machinery. It also presents fewer problems in the reclamation of mined-out areas.

The increase in 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, still 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 in the future (Coal Age, 1966a). In 1968, a walking dragline with a 145-

cubic-yard bucket of 215 tons capacity and a 250-foot boom was placed in operation in Indiana. This dragline can handle overburden to a maximum depth of 96 feet (Coal Age, 1968b). In 1969, a walking dragline with a 220-cubic-yard bucket of 325 tons capacity and a 310-foot boom was placed in operation in southern Ohio. This dragline can handle overburden to a maximum depth of 185 feet. An even larger dragline with a 500-foot boom is regarded as being technically feasible in the future (Coal Age, 1966a).

The increase in size of shovels and draglines has been accompanied by a parallel increase in the size of coal-hauling trucks. In late 1968, trucks of 200 tons capacity were in use in several large-scale stripping operations, and an off-road tractor-trailer combination capable of handling 240 tons was successfully demonstrated.

Wheel excavators of the type used for many years in the brown coal areas of Western Germany have 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 appealing from a technological viewpoint because the operation is continuous and because 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 unconsolidated overburden in North Dakota and in the removal of glacial drift in Illinois. A wheel of German manufacture installed in North Dakota in 1965 had a rated capacity in unconsolidated material of 2,800 cubic yards an hour. This wheel was moved to Illinois in 1968. A wheel of American manufacture installed in Illinois in 1968 had a rated capacity of 2,400 cubic yards an hour (Roman, 1968).

The increase in size and efficiency of strip-mining machinery has permitted a steady increase in the average and in the maximum thickness of overburden removed, and as a result the ratio of average overburden thickness to average recovered coal thickness has also increased. This trend is shown in table 1.

The averages presented in table 1 include several noteworthy extremes. In the famous Wyodak mine, Wyoming, for example, a 90-foot bed of coal is recovered by removing 25–40 feet of overburden. In Alaska, 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 average thickness

TABLE 1.—*Average and maximum thickness (in feet) of overburden removed and average thickness 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	1970 (estimated)
Average thickness of overburden removed	32	39	42	46	50	55
Maximum thickness of overburden removed	--	--	70+	100	125	185
Average thickness of coal recovered	5.2	5.1	4.9	5.1	5.2	5.0
Ratio of average overburden thickness to average coal thickness	6:1	8:1	8.5:1	9:1	10:1	11:1

of coal recovered was 1.5 feet; these figures yield a statewide ratio of 29:1 (Young, 1967, p. 18). In one outstanding operation in Alabama, overburden ranging in thickness from a few feet to nearly 100 feet, and averaging about 60 feet, is removed to recover a bed of high-quality metallurgical coal 22 inches thick (Coal Age, 1968a). These figures yield a ratio of 22:1. In at least one operation in Kansas, 45 feet of overburden was removed to recover 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 in addition to the ratio between thickness of overburden and thickness of coal. 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 much less than 30:1 for many years, as may readily be seen by an examination of the average ratios for recent years shown in table 1.

The very large shovels and draglines mentioned above are designed with the increased lift and swing required to handle, in one cut, overburden as much as 185 feet thick. Overburden 180–185 feet thick will be removed in parts of large-scale stripping projects already in the advanced planning stage.

Older investigators of stripping-coal resources, thinking in terms of smaller equipment, presented data on coal with overburden 40, 50, 60, 90, 100, and locally 120 feet thick, depending on the thickness of the coal; and coal in these overburden ranges is still of greatest economic importance. In later studies, the Illinois and Indiana Geological Surveys included beds with overburden as much as 150 feet thick. In a recent study of strip coal in Montana, Ayler, Smith, and Deutman (1969) presented data on coal beds with overburden locally as much as 200 feet thick. The increase in size and capacity of strip-mining machinery is being matched by the advanced thinking of investigators of stripping-coal resources. Both trends are still upward.

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 beds mined by stripping are at Kemmerer and Wyodak, Wyo., where the coal beds are about 90 feet thick. 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 primitive underground methods, which recovered only one-third of the coal. Later, during the 1920's and 1930's, the outcrops were strip mined along very narrow shallow belts with small shovels. In current operations, the partly mined coal just below the older stripped-out zone is being recovered by use of large draglines and shovels. These pits are as much as 400 feet deep. By 1980 maximum depths will be greatly increased, possibly to as much as 1,000 feet.

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 coal bed was removed from the end of a syncline, the strip-mined block of ground was 800 feet wide and 290 feet deep at the deepest place on the synclinal axis (Coal Age, 1965, p. 79).

The Kemmerer Coal Co., which operates a large strip mine on inclined beds in southwestern Wyoming, is making preliminary plans and estimates for an enormous strip pit 1 mile long and 1 mile wide, with a highwall 1,600–2,000 feet high. This pit would permit recovery of coal from 13 beds with an aggregate thickness of about 200 feet (Consalus, 1967, p. 41).

RECOVERABILITY IN STRIP MINING

In some individual strip-mining operations, recoverability is as high as 90 percent of the coal in the block being mined. In many individual operations, recoverability is 80 percent of the coal in the block being mined, and this figure is usually accepted as a fair average for most strip-mining operations. However, in other operations, particularly those in heavily populated areas in the Illinois and Appalachian basins, overall recoverability is likely to be less than 80 percent because of areas that must be left under towns, roads, railroads, streams, protective areas around oil and gas fields, and areas withheld for esthetic reasons. Because of these factors, Simon and Smith (1968) have suggested that of the coal potentially recoverable by strip-mining in Illinois, only about half may actually be recovered by future strip-mining operations.

In this report, the stripping coal resources are reported as original resources in the ground, and the conventional 80 percent recoverability factor is used to suggest a maximum order of magnitude of recoverability, with the qualification that average recoverability for the United States as a whole may be somewhat less.

AUGER MINING

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 1968, 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, 1969, 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 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 which 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 in detail. Other potential sites noted during the course of geologic surveys have been mentioned in various published reports. A summary of this and related information follows under State headings. A few recent or planned individual strip-mining operations in Arizona, Montana, New Mexico, Washington, and Wyoming are discussed briefly because they will represent major changes in the production patterns of the States.

ALABAMA

About one-third of Alabama's annual coal production is obtained by strip mining, mostly in the Warrior basin, along the Warrior River. Coal available by strip-mining methods in Alabama is estimated to total about 800 million tons.

In the Fabius-Flat Rock area, Jackson County, Ala., 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.

In Bibb County, Shotts (1969) delineated 19 million tons of low-sulfur coal that is recoverable by stripping methods.

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; this area is underlain by 95 million tons of coal in six beds ranging in thickness from 5 to 60 feet at depths generally less than 200 feet.

In the Beluga River coal field, Warfield (1963) described a drilling program that delineated 21 million tons of coal in a bed 48 feet thick with overburden ranging in thickness from a few feet to 225 feet. 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 bed 4 feet thick with less than 25 feet of overburden.

ARIZONA

The stripping-coal resources of Arizona in beds 4 feet or more thick and to a maximum overburden depth of 100 feet are here estimated to total 400 million tons. This figure is based primarily on the results of an exploratory drilling program by the Peabody Coal Co. in the northeastern part of the Black Mesa field, which disclosed 387 million tons of coal in four beds, 4 to 22 feet thick, with overburden 20–130 feet thick (Arnold, 1969). This coal is soon to be strip mined on a large scale. In a summary of the geology and coal resources of Arizona, which includes a comprehensive bibliography, Averitt and O'Sullivan (1969, p. 64) stated:

> In 1966, the Peabody Coal Co. announced plans to open a large modern strip mine on a block of ground * * * leased from the Navajo and Hopi Indian Tribes. * * * The mine will supply coal to the projected 1,500,000 kilowatt Mohave electric powerplant to be located below Davis Dam on the Colorado River in southernmost Clark County, Nev. The plant is to be financed and built by a group of 17 private and public utilities known as the Western Energy Supply & Transmission Associates (WEST Associates), and is scheduled for completion in 1970 or 1971. The contractual agreement between the Peabody Coal Co. and WEST Associates calls for the delivery over a period of 35 years of at least 117 million tons of coal at a delivered cost of $500 million, which will include $30 million in royalty payments to the Navajo and Hopi Tribes. This is the largest long-term coal mining and delivery contract ever signed.

In the summer of 1969, work was in progress on a 273-mile 18-inch coal slurry pipeline, which will be used to move coal from the mine to the powerplant. This will be the longest coal slurry pipeline ever built.

Early in 1970, construction will begin on a 2.3-million-kilowatt electric generating plant at Page, Ariz., near the Glen Canyon Dam. This plant will also be fired by strip-mined coal from the Black Mesa field. The plant will be financed by a group of four major power producing and distributing companies in the southwest. The first of three 770,000-kilowatt generating units is scheduled for operation in 1974. The coal will be transported from Black Mesa to Page over an 80-mile-long railroad, which will be constructed as part of the project (Pay Dirt, 1969). By the early 1970's, strip-coal production in Arizona should be about 4 million tons annually; by the late 1970's it should be about 10 million tons annually.

ARKANSAS

As a 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 coal determinable from mapping and exploration 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 total of 263 million tons as the original strippable coal resources of Arkansas within the stated overburden ranges.

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 from which coal could be recovered by the small shovels and draglines then in use were described by Culver (1925), Cady (1927, 1937) and Henbest (1929). 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 seven reports to date. (See Searight and Smith, 1969; Smith, 1957, 1958, 1961, 1968; Smith and Berggren, 1963; Reinertsen 1964.) Work is in progress on two additional areas that will complete coverage of the State. In the areas covered by the seven published reports, the remaining strippable resources in beds 18 inches or more thick and to a maximum depth of 150 feet totaled 19 billion tons as of about January 1, 1968. It seems likely that an additional 2 billion tons of stripping coal will be delineated by mapping still in progress, which will increase the estimate of remaining resources to 21 billion tons. As past cumulative production and losses of strip coal in Illinois to January 1, 1970, total about 2 billion tons, the original stripping-coal resources in beds 18 inches or more thick and to a maximum depth of 150 feet totaled about 23 billion tons.

The distribution of the 19 billion tons described in the seven published reports of the Illinois Geological Survey has been presented in many categories by thickness of beds and thickness of overburden in a summary report by Simon and Smith (1968, p. 60–63). On the basis of this distribution analysis, the 23 billion tons representing the original resources can be divided into 15.5 billion tons with overburden of 100 feet or less, and 7.5 billion tons with overburden of 100–150 feet. The 15.5-billion-ton figure is selected for use in table 2.

A map of the Illinois coal field prepared by Simon (1966), which complements the reports cited above, shows major active strip and underground mines, and provides subsidiary data on 1965 production, beds being mined, railroad lines, and freight rate districts. The Illinois Geological Survey also has available a series of maps on the scale of 1:62,500 showing areas mined out by strip-mining methods through 1968.

INDIANA

The Indiana coal field contains substantial resources of stripping coal because of its favorable location on the eastern 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 totaled 3,524 million tons, 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. This figure is 9.4 percent of the total for the State as estimated by Spencer.

The Indiana Geological Survey has published a series of 13 preliminary county coal maps that show thickness, structure, and mined areas for all important coal beds. These maps provide almost complete coverage of the Indiana coal field. The most recent map by Powell (1968) covers Parke County and the southern part of Vermillion County. It contains a small index map showing areas covered by previous maps in the series. A mimeographed list of these and other coal maps is available from the Indiana Geological Survey, 611 North Walnut Grove, Bloomington, Ind. 47401. A map of the entire Indiana coal field prepared by Powell (1967) shows all areas strip mined for coal as of June 1967. Powell (1970) has also prepared a more definitive report on strip mining in Indiana.

KANSAS

In a report on the coal resources of Kansas, Abernathy, Jewett, and Schoewe (1947, p. 3, 13) provided data on proved resources of stripping coal totaling 60 million tons. This estimate is based on an assumed weight of 1,500 tons per acre-foot to allow for future losses in mining. It included coal in the ground as of January 1, 1946, with overburden not exceeding 60 feet, or with a ratio of not more than 35 cubic yards of overburden 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 as of the mid-1950's 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).

In a study of the fuel supply available for steam electric-generating plants in the northeastern part of Kansas within the drainage area of the Missouri River, Stroup and Falvey (1969, p. 16–17) tabulated areas of strippable coal totaling 215 million tons with maximum overburden ratios of 20–25 cubic yards per ton of coal.

If allowance is made for the strip-mining potential of coal-bearing areas in southeastern Kansas not included in the Stroup and Falvey study, for slightly larger ratios of overburden thickness to coal thickness, and for past strip-mine production and losses, the original stripping-coal resources of Kansas with overburden not exceeding 100 feet should total about 500 million tons.

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, 1970, this program has yielded 134 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 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 shown on an index map titled "Status of Kentucky areal geologic mapping program," which is revised from time to time, and which is available free on request to the Kentucky Geological Survey, 307 Mineral Industries Building, University of Kentucky, Lexington, Ky.

40506, or to the U.S. Geological Survey, Washington, D.C. 20242. They are also listed in various bibliographies of geologic reports.

In a study of the coal resources in the Princess No. 3 and No. 7 beds, Greenup County, Ky., Johnson (1969) delineated remaining recoverable strippable resources totaling 41 million tons in beds 28 inches or more thick, and 120 feet or less below the surface; and 11.5 million tons in beds 14–28 inches thick, and 60 feet or less below the surface.

In a pilot study of parts of the Beaver Creek basin, McCreary County, Ky., Musser (1963) and Collier and others (1964) discussed the influence of strip mining on the hydrologic environment of the basin, and their conclusions may be applicable in studies of the effects of strip mining in similar areas.

In western Kentucky, 2.5 billion tons of coal in beds 2 feet or more thick, and 150 feet or less below the surface have been tabulated in categories according to thickness of beds and thickness of overburden in three reports of the Tennessee Valley Authority and the Kentucky Geological Survey (Mullins, Hodgson, Avery, and Wilson, 1963; Hodgson, 1963; Mullins, Lounsbury, and Hodgson, 1965).

A map accompanying the report by Mullins, Lounsbury, and Hodgson (1965, pls. 2, 3) shows the structure of the important No. 9 coal, and areas depleted by underground and strip mining. Supplementary maps by the Tennessee Valley Authority (1969, pls. 2, 3, 4) present comparable information for the No. 9 coal in other parts of the western Kentucky coal field, and show (pl. 1) outcrop areas of beds Nos. 4, 6, 11, 12, 13, and 14. Copies of the coal maps at the compilation scale of 1 inch to 2,000 feet are on open file and may be inspected by appointment at the office of the Tennessee Valley Authority, Fuel Planning Staff, 516 Chattanooga Bank Building, Chattanooga, Tenn. 37401.

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.

In a study of the fuel supply available for steam electric-generating plants in the northwestern part of Missouri within the drainage area of the Missouri River, Stroup and Falvey (1969, p. 18–21) tabulated areas of strippable coal totaling 449 million tons with maximum overburden ratios of 20–25 cubic yards per ton of coal. They included a choice part of the area in eastern Putnam County cited above.

If allowance is made for the strip-mining potential of coal-bearing areas not included in the Stroup and Falvey study, for the larger strip potential of the area in eastern Putnam County, for slightly larger ratios of overburden to coal, and for past strip-mine production and losses, then the original stripping-coal resources of Missouri with overburden not exceeding 100 feet should total about 1 billion tons.

MONTANA

The stripping-coal resources of Montana in beds 5 feet or more thick total about 23 billion tons according to an analysis by Matson (1969). He tabulated 17 billion tons in 47 deposits delineated by mapping and exploration and estimated that an additional 6 billion tons would be found by extension of known deposits and by mapping and exploration in new areas. In an earlier report, Ayler, Smith, and Deutman (1969) provided detailed descriptions of 37 deposits that contain 12.7 billion tons. In these deposits, the coal beds are 5 feet or more thick, and the overburden is generally less than 120 feet thick, but in a few deposits where the coal is very thick, the overburden is locally as much as 200 feet thick.

Other reports on stripping coal in Montana by Gilmour and Williams (1969), Matson, Dahl, and Blumer (1968), and by the Montana Bureau of Mines and Geology (1969) supply detailed information on deposits included in the tabulation by Matson (1969). Previous summary studies of stripping coal in eastern Montana by Groff (1968) and by Averitt (1965) may supply data and citations of subsidiary value.

The figure of 23 billion tons is 10 percent of the total original coal resources in eastern Montana as determined by exploration, and it is 14 percent of the total estimated to be 1,000 feet or less below the surface, which suggests that it is of an order of magnitude commensurate with the selected limits of coal and overburden thickness. The stripping-coal resources of Montana would be larger were it not for the fact that in southeastern Montana, where the total resources are very large, the topographic relief tends to reduce the size of the strippable areas, and many of the higher and more accessible beds are burned out along the outcrops.

Although Montana contains large resources of strippable coal, annual production is small compared with that of surrounding States, primarily because of Montana's small population and geographic position. In 1968, for example, the coal production of

Montana totaled only 519,000 tons, of which 483,000 tons, or 93 percent, was strip mined. Most of the strip-mine production was from the Breezy Flat deposit (Ayler and others, 1969, p. 51) in Richland County, which was used to fire a 54,000-kilowatt electric generating plant of the Montana-Dakota Utilities Co. at Sidney, Mont.

In 1968, the Western Energy Co., a subsidiary of the Montana Power Co., began a new operation at the site of the old Colstrip mine, Rosebud County, for the purpose of supplying coal to the Billings generating plant of Montana Power. In September 1969, the Peabody Coal Co. began operations at a new strip mine near Colstrip for the purpose of supplying coal on a long-term contract to an enlarged electric generating plant of the Minnesota Power and Light Co. at Cohasset, north-central Minnesota. This plant is expected to require about 2 million tons annually by 1973. The two operations at Colstrip will represent a substantial increase in Montana's strip-coal production, which should continue for many years.

NEW MEXICO

The stripping-coal resources of New Mexico are concentrated along the west and northwest sides of the San Juan basin in a narrow belt extending roughly from Gallup, N. Mex., to Durango, Colo. The strippable resources in this belt to an overburden depth of 100 feet are here estimated to total about 3 billion tons. This figure is based on consideration of data contained in 16 reports of the U.S. Geological Survey, which are cited in a bibliography of publications of the U.S. Geological Survey (1962) and need not be cited here. The availability of strip coal in this area and the growing need for electric power in the southwest have resulted in the recent development of two major strip mines and the planned development of a third.

In 1962, the McKinley mine of the Pittsburg and Midway Coal Mining Co., located about 20 miles north of Gallup, N. Mex., went into operation to supply coal on a long-term contract to the Cholla generating plant of the Arizona Public Service Co., near Joseph City, Ariz. The mine produces about 380,000 tons annually, which is moved by unit train to Joseph City (Coal Age, 1966b, p. 83).

In 1963, the Navajo mine of the Utah Construction and Mining Co. near Farmington, N. Mex., went into operation to supply coal on a long-term contract to the newly constructed Four Corners electric generating plant of the Arizona Public Service Co. located nearby (Coal Age, 1963b). As reported by Curry (1969), the mining property of 31,000 acres contains in excess of 1.1 billion tons of strippable coal. In the period 1963–67, this mine produced 2–2.5 million tons annually. In 1967, work was in progress to increase the size of the Four Corners generating plant from 575,000 kilowatts to 2,085,000 kilowatts. When the enlarged plant is in full operation in the mid-1970's it will require about 8.5 million tons of coal annually.

North of the Navajo mine, an area suitable for strip mining has been acquired by the Public Service Company of New Mexico for the purpose of supplying fuel to a nearby 1-million-kilowatt generating plant, now in the planning stage. When completed in 1976, the plant will require about 4 million tons of coal annually.

In the late 1970's, the strip coal production of New Mexico should be about 13 million tons annually.

NORTH DAKOTA

North Dakota's modest lignite production of about 4 million tons annually is obtained from a few large readily accessible strip-mining localities, most of which have resources adequate for many years of continuous operation. Because of this fact, only a few of the larger and more conspicuous deposits of strippable coal have been mapped and described. Nevertheless, the strippable lignite resources of North Dakota must be very large, as evidenced by the number and thickness of lignite beds, the gentle dip of the enclosing rocks, and the generally low topographic relief.

Brant (1953) presented planimetric maps of individual counties in North Dakota showing lignite outcrops and locations of many strip mines. He also supplied data from which an estimate of the total potential strippable resources of North Dakota may be deduced. According to Brant (1953, p. 1, 2, 4), the original resources of lignite in North Dakota totaled nearly 351 billion tons. Of this huge total, 30 percent is in beds 5 feet or more thick, and 70 percent is 500 feet or less below the surface. Therefore, 30 percent of the 70 percent—that is, 21 percent—should be in beds 5 feet or more thick, and 500 feet or less below the surface. When this 21-percent factor is applied to the total of 351 billion tons, the product is 74 billion tons. If one assumes an even distribution of this tonnage by overburden categories, which is justified because of the low dips and the low topographic relief, then 20 percent of this statistically derived amount, or roughly 15 billion tons, is in beds 5 feet or more thick, and 100 feet or less below the surface.

By this same method of analysis, 70 percent of the 70 percent—that is, 49 percent—should be in beds 2½ to 5 feet thick and 500 feet or less below the surface. When this 49-percent factor is applied to the total of 351 billion tons, the product is 172 billion tons. If one assumes an even distribution of this tonnage by overburden categories, then 10 percent, or 17 billion tons, is in beds $2\frac{1}{2}$ to 5 feet thick, and 50 feet or less below the surface. The total of 15 billion tons in thicker beds plus 17 billion tons in thinner beds, or 32 billion tons, is, therefore, the potential stripping-coal resources of North Dakota within the assumed overburden categories.

The estimated 15 billion tons in the thicker beds is, of course, of much greater current interest than the comparable tonnage in the thinner beds, and this figure is inserted in table 2. Ball (1966, p. 11) estimated that operating strip-mining companies in North Dakota have developed or control properties containing 1.2 billion tons of strippable lignite in thick beds generally less than 90 feet below the surface, and that the total strippable resources of such lignite in North Dakota probably ranges from 7 to 10 billion tons. This is admittedly a conservative figure based on present and near-future mining practices and commercial needs. It does, however, suggest that the 15-billion-ton figure derived above for tonnage in the thicker beds is of the proper order of magnitude for the stated parameters.

In the Wibaux area, Montana and North Dakota, May (1954) mapped and described 10 possible strip-mining areas. The largest and best 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, N. Dak., Kepferle and Culbertson (1955) mapped and described two areas underlain by 1.4 billion 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, Oliver and Mercer Counties, N. Dak., Johnson and Kunkel (1959, p. 50 and pl. 1) delineated seven potential strip-mining localities in which the lignite is 6 feet or more thick and the overburden generally less than 60 feet.

In a review of all data on strippable lignite in North Dakota, including data in the reports cited above, data from operating mines, and drill records in the files of holding companies, Smith (1969) concluded that 4.2 billion tons of strippable lignite has been delineated by mapping and exploration.

Van Sant and Ellman (1959) analyzed mining procedures and costs for 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 1968 totaled a little more than 1 million tons, is obtained by strip mining. The distribution and extent of areas mined out by stripping to about 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.

OREGON

In a report on the Coos Bay quadrangle, Oregon, Allen and Baldwin (1944, p. 102–105) described an exploratory drilling project near the town of Riverton that disclosed about 50,000 tons of subbituminous coal in a bed 3.7 feet thick, with overburden 2–34 feet thick and averaging about 19 feet thick.

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 coal 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, and Griess and Deasy (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. (See Deasy and Griess, 1958, p. 120; 1959, p. 4, 8.) These maps demonstrate very effectively the widespread extent of strip mining, and they will aid in finding remaining 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 competing coal in the adjoining States of North Dakota and Wyoming is in thicker beds and is more economical to mine. Most of the past and present production in South Dakota has come from strip mines in the Isabel-Firesteel district, 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 also provided a summary of information available on the remainder of the South Dakota lignite field and described three additional areas potentially suitable for strip mining.

TEXAS

In a summary study of Texas lignite resources, 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. Mapping and exploration to date have, however, revealed areas of relatively gentle dips and thin overburden in three districts.

In the Centralia-Chehalis district, Lewis and Thurston Counties, Snavely, Brown, Roberts, and Rau (1958, p. 111) delineated three areas in the Tono basin that are suitable for strip mining. The availability of this coal led to the selection of the Centralia area as the site for the construction of a 1.4-million-kilowatt coal-fired electric utility plant owned jointly by the Pacific Power and Light Co. and the Washington Water Power Co. When completed about 1973, the plant will require about 5 million tons of coal annually, and Washington will be added to the list of strip-coal-producing States.

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 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 four areas in T. 20 N., R. 15 E., where the dip of the Big Dirty coal 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.

WEST VIRGINIA

The original stripping-coal resources of West Virginia in beds 28 inches or more thick, and to an overburden depth of 100 feet are estimated by Avery H. Reed (U.S. Bur. Mines, oral commun., Nov. 21, 1969) to total about 9,500 million tons. A detailed report in preparation by Reed will include consideration of coal to an overburden depth of 120 feet.

WYOMING

Wyoming contains substantial resources of stripping coal around the edges of the Powder River basin, northeastern Wyoming; in the Hanna basin, Carbon County; and in the Evanston-Kemmerer area, Uinta and Lincoln Counties. Smith (1969) delineated 13 billion tons of strippable coal to a maximum overburden depth of 120 feet in these areas.

The amount of strippable coal in Wyoming is limited by the fact that most of the coal-bearing rocks lie in deep structural basins, but this is offset by the fact that several very thick beds crop out in the northeastern part of the Powder River basin. The D-Anderson, Roland, and Felix coal beds each contain substantial amounts of strippable coal.

In the Buffalo-Lake DeSmet 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 1966 and subsequent years, the Reynolds Mining Corp., a subsidiary of the Reynolds Aluminum Co., was engaged in test drilling and analytical studies of coal from the Lake DeSmet deposit.

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 an article in Coal Age (1963a).

OTHER POTENTIAL SITES

Many additional potential strip-mining sites are undoubtedly present in the States mentioned above and in other coal-bearing States not specifically mentioned. These sites can be located by study of the relation between coal outcrops, dip of beds, nature of overlying rock, and the terrain. This study will be facilitated by the availability of geologic reports of the U.S. Geological Survey, State geological surveys, and other agencies for substantial parts of most coal-bearing areas, and by the increased availability of modern topographic maps. The topographic map coverage of U.S. coal-field areas has increased steadily through the years, and although far from complete at modern scales, it is virtually complete at scales of 1 inch to the mile or larger 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 1 inch to 2,000 feet, 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. Index maps of individual States showing topographic map coverage are available free on request to the U.S. Geological Survey, Washington, D.C. 20242.

ESTIMATED TOTAL STRIPPING-COAL RESOURCES

RESOURCES IN THE 0- TO 100-FOOT OVERBURDEN CATEGORY

From data summarized in the preceding paragraphs it is obvious that the stripping-coal resources of the United States in the 0- to 100-foot overburden category are very large. For the 10 States shown by figures in boldface type in table 2, statewide estimates of stripping-coal resources based on mapping and exploration, or reasonable documentation, have been prepared, and in these States alone the total is 84 billion tons.

Accepting these 10 documented figures as a frame of reference, one can derive comparable figures for adjoining and intervening States and an approximate total for the United States by a crude process of extrapolation, using for each State the following 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 the bulk of the tonnage in the estimates for the 10 States is 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.

The two classes of figures shown in table 2 yield a total of 114,619 million tons as the estimated original stripping-coal resources of the United States in the 0- to 100-foot overburden category. This figure may be appropriately rounded to 115 billion tons. Although a great deal of subjectivity is inherent in the figures determined by extrapolation, the total of 115 billion tons reflects control by estimates for the 10 states where subjectivity was at a minimum. This figure can be further evaluated by a second line of reasoning. Continuing study of U.S. coal resources has shown that of the total original resources known through mapping and

TABLE 2.—*Estimated original resources of stripping coal in the United States in beds generally less than 100 feet below the surface*

[Figures in boldface type are based fully or in considerable part on detailed mapping and exploration. Other figures are obtained by extrapolation by methods explained in text. All figures are for resources in the ground, of which about 80 percent may be considered recoverable. See page 7]

State	Millions of short tons	Range of overburden thickness (ft)
Alabama	800	0–100
Alaska	2,000	0–100
Arizona	400	0–100
Arkansas	**263**	0–60; 0–100
Colorado	1,200	0–100
Illinois	[1] **15,500**	0–50; 50–100 [1]
Indiana	**3,524**	0–40; 0–60; 0–90
Iowa	600	0–100
Kansas	500	0–100
Kentucky	6,000	0–100
Maryland	150	0–100
Missouri	1,000	0–100
Montana	**23,000**	0–120 [2]
New Mexico	3,000	0–100
North Dakota	**15,000**	0–100
Ohio	5,000	0–100
Oklahoma	500	0–100
Oregon	([3])	
Pennsylvania	8,000	0–100
South Dakota	400	0–100
Tennessee	200	0–100
Texas	**3,282**	0–90.
Utah	300	0–100
Virginia	1,000	0–100
Washington	500	0–100
West Virginia	**9,500**	0–100
Wyoming	**13,000**	0–120 [2]
Total	114,619	

[1] Illinois contains an additional 7,500 million tons with 100–150 feet of overburden.
[2] Maximum of 200 feet on very thick or multiple beds.
[3] Less than 1 million tons. (See p. 19.)

exploration, about 1,445 billion tons is in the 0- to 1,000-foot overburden category (Averitt, 1969, p. 11, 35). The figure of 115 billion tons is 8.0 percent of the larger total, which suggests that it is of a proper order of magnitude.

RESOURCES IN THE 100- TO 150-FOOT OVERBURDEN CATEGORY

If the potential stripping-coal resources in the 0- to 100-foot overburden category total 115 billion tons, then the additional resources in the 100- to 150-foot overburden category can be approximated by further extrapolation.

The amount in the 100- to 150-foot overburden category must be less than half of the amount in the 0- to 100-foot overburden category, or less than 57.5 billion tons, for the following reasons: (1) thinner beds that are recoverable in the 0- to 100-foot overburden category are not recoverable in the 100- to 150-foot overburden category, (2) in areas of pronounced topographic relief where contour stripping is practiced, the disposal of overburden becomes increasingly difficult as the thickness of overburden increases, (3) locally, on the edges of structural basins, the topography rises counter to the dip, so that the amount of available stripping coal decreases with each incremental increase in overburden. These factors will be offset in part by the trend toward larger machinery, multiple-bed stripping, and unit development of larger tracts; so, the reduction in quantity below 57.5 billion tons will be small. The figure of 50 billion tons is, perhaps, the best that can be selected to represent total stripping coal resources in the 100- to 150-foot overburden category.

This tonnage is of less economic interest than the larger tonnage presented in table 2, but it is available and within reach by present machinery and technology. A small amount of coal in the 100- to 150-foot overburden category is already being strip mined as part of operations on large tracts, and the amount mined will increase annually.

The sum of 115 billion tons plus 50 billion tons, or 165 billion tons, is therefore the general order of magnitude of the original stripping-coal resources of the United States with overburden of 150 feet or less.

The estimated total of 165 billion tons is, of course, for original resources in the ground. Subtracting 5.5 billion tons, representing cumulative past strip production of bituminous coal and anthracite of 4.4 billion tons, to January 1, 1970, plus estimated past losses of 1.1 billion tons, and assuming future recoverability of 80 percent, the total is reduced to 128 billion tons. This figure is too large to be appreciated except by comparison with smaller and more meaningful numbers. It is, for example, 29 times the cumulative strip-coal production of 4.4 billion tons, from the beginning of strip mining to January 1, 1970; and it is 690 times the 1969 strip-coal production of about 185 million tons. These simplified comparisons do not represent life expectancy of stripping-coal resources because the rate of production and the estimated size of the resources will surely change in the future.

RECLAMATION OF STRIP-MINED LANDS

The annual increase in the rate of strip mining, the steady increase in the size and capacity of strip-mining machinery, and the enormous amount of coal potentially recoverable by strip-mining methods pose a threat to the future utility and beauty of the land. The end product of a strip-mining operation is a ridge, or many closely spaced parallel ridges of loose rock resting at the angle of repose, which is about 33°. These piles of rock, usually termed "spoil banks," present a Pandora's box of economic and esthetic problems for which there are no simple solutions.

In mountainous regions where contour stripping is practiced, the overburden removed on the first cut is thrown down the mountain side, where it may form an oversteepened slope. In this setting, spoil banks may initiate landslides, which devastate areas larger than the areas of the original piles, and they contribute excessive amounts of silt to the local drainage. In mountainous areas, therefore, conservation objectives are directed toward reducing the angle of slope of the downhill spoil bank and of the vertical highwall to reduce the problems posed by steep slopes, and to improve changes for reforestation. In areas of low relief, spoil banks are more stable and conservation objectives are more varied and depend somewhat on the texture, height, slope, and chemical composition 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 plantlife. Highly acidic spoil banks will support little plantlife. Moderately acidic banks will support trees and plants adapted to an acidic environment. Other, less acidic, banks will support a wider variety of plantlife.

The degree of reclamation and future utility thus depends on physical and chemical factors that require a great deal of study and experimentation. Within limits imposed by physical and chemical characteristics, spoil banks have been used as tree farms, recreational areas, grazing land, game and fish preserves, city dumps, and sewage disposal ponds. A few banks of high calcareous content support orchards and other higher forms of agriculture.

Deasy and Griess (1963) and the U.S. Department of the Interior (1966, 1967) provide extended discussions and comprehensive bibliographies on the status of thought and effort thus far devoted to reclamation objectives in the United States.

The value of the coal removed from most strip-mined sites is many times the agricultural value of the land before strip mining (Brock and Brooks, 1968; Brock, 1969). According to a report of the U.S. Department of the Interior (1967, p. 113), the minimum cost of strip-mine reclamation is about $100 per acre, and the national average cost is about $230 per acre. These costs allow for only a minimum level of reclamation in which slope angles are reduced, drainage is improved, and a cover crop of some sort is planted. They do not contemplate restoration of the original contour of the land, or of a natural-appearing contour. Regrading for this objective would require costs ranging from $900 to $2,700 per acre (Griffith and others, 1966). The cost of reclamation is obviously more than the value of the reclaimed land for agricultural and most other purposes.

The problems of strip-mine reclamation have received wide recognition, and many constructive actions have been taken by Government, industry, and conservationists:

1. In a study of strip and surface mining in the Appalachian coal basin, the U.S. Department of the Interior (1966) assembled much useful information on the size of the area disturbed in Appalachia, methods and costs of reclamation, and recommendations for legislation to control future strip mining. In a later report, the U.S. Department of the Interior (1967) presented comparable data for the United States as a whole. This study showed (p. 110) that as of January 1, 1965, the land disturbed by strip mining for coal totaled 1,301,430 acres, or 2,033 square miles. If production from 1965 through 1969 is taken into account, the total disturbed land as of January 1, 1970, should total about 2,450 square miles. About one-third of this total, or about 850 square miles, has been reclaimed by man or nature, or has been put to some minimal beneficial use, and about two-thirds, or about 1,600 square miles, has not been reclaimed.

2. In January 1969, a bill (S. 524) to provide for cooperation between the Secretary of the Interior and the States with respect to the future regulation of surface mining operations was introduced in the Senate. This bill was identical in substance to a pre-

vious bill (S. 3132), introduced in March 1968, on which no action was taken. The published hearings on S. 3132 (U.S. Cong., Senate Comm. on Interior and Insular Affairs, 1968) are a useful compendium of information on all aspects of the strip mine reclamation problem. Like its predecessor, S. 524 empowers the Secretary of the Interior to establish minimum standards for reclamation objectives that would become effective in States not adopting and enforcing comparable standards.

3. Partly as a result of the introduction of S. 3132 and S. 524 and partly as a result of prior concern, at least 17 States have enacted laws requiring reclamation of strip-mined land. In at least six States, older laws no longer fully applicable have been revised and updated. The National Coal Association (1969) has prepared a summary of existing State strip-mining laws. It is estimated that compliance with these laws will increase the price of coal to the consumer 1–2 percent.

4. In 1963, the Mined-Land Conservation Conference, a division of the National Coal Association, was organized for the purpose of disseminating information on strip-mine reclamation activities and findings and the promotion of reclamation practices. The conference publishes a periodic newsletter. According to the newsletter for January–February 1969 (Mined-Land Conserv. Conf., 1969), reclamation processes in 1967, and presumably those in 1968 and 1969, were applied to areas larger than the areas disturbed by strip mining during those years.

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 the Northern Great Plains region of western North Dakota, eastern Montana, and northeastern Wyoming. Relatively little mining is carried on in this area however, because of the small population, isolated geographic position, 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 subsequent years. The 1967 production of nearly 85 million tons (fig. 1) was an alltime record for the 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 production 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 1956–68 ranged from 57 million to 69 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 production in subsequent years has also lagged behind 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. Risser (1969) suggested that a peak in the percentage (not tonnage) of strip coal mined in the eastern States may be approaching because of increase in depth and volume of overburden, increased costs of larger equipment, increased costs of assembling tracts large enough to justify purchase of larger equipment, and more stringent reclamation and air pollution laws. With substantial resources of strip coal remaining in the eastern States, it is likely that these problems will be countered by an increase in the selling price of strip-mined coal, a decrease in the number of individual operations, and a significant increase in the size and scale of individual operations.

4. Because the cost of spoil-bank reclamation is more than the value of the reclaimed land for agriculture and most other purposes, part of the costs of reclamation must be borne either by the owners of coal royalties, coal operators, purchasers of the mined coal or by the users of electricity, steel, and other coal-based products, which includes the entire population. As preservation of the environment is a national objective, it seems probable that these costs will be added to the cost of coal and passed on to the users of both the reclaimed land and the coal-based products.

5. If the cumulative past production of 4.4 billion tons of strip-mined coal has resulted in disturbed land covering 2,450 square miles, then removal of the remaining recoverable resources of 128 billion tons could result in disturbed land covering 71,000 square miles—an area larger than the combined areas of the States of Pennsylvania and West Virginia. This prospect is unacceptable to the Nation and is not likely to occur. Instead, strip-mine reclama-

tion requirements are likely to become more stringent than those now contemplated. In both England and Germany, for example, reclamation requirements are far more advanced than those in the United States. At places in each country the topsoil is first removed and stored. During and after strip mining, the land is returned to a pleasing contour and the topsoil is replaced. Future strip mining in the United States obviously should be accompanied by an effective, progressive nationwide program of reclamation of stripped-over lands.

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