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COAL RESOURCES OF THE UNITED STATES

(A progress report, October 1, 1953)

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By Paul Averitt, Louise R. Berryhill, and Dorothy A. Taylor

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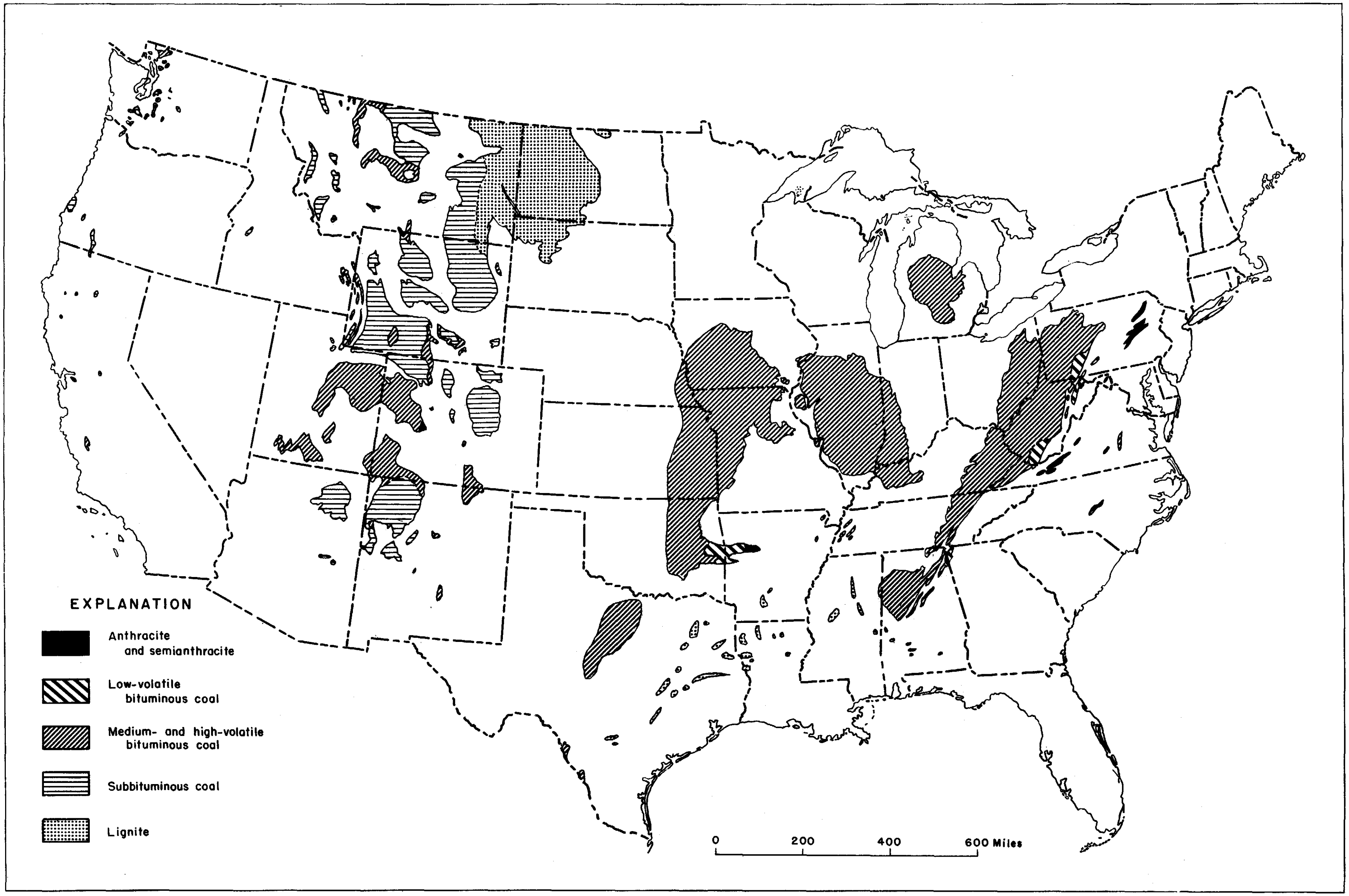

Figure 1. —Coal fields of the United States.

COAL RESOURCES OF THE UNITED STATES

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ABSTRACT

As estimated in this second progress report, the coal reserves of the United States remaining in the ground on January 1, 1953, total 1,899,739 million tons. This figure is about a 20 percent reduction of the total estimate published in the first progress report (Averitt and Berryhill, 1950). The new total is based on new, detailed, conservative estimates of reserves in Indiana, Michigan, Montana, New Mexico, North Carolina, North Dakota, South Dakota, Virginia, and Wyoming, prepared since 1947 by the U. S. Geological Survey; on new provisional, but equally conservative estimates of reserves in Colorado, Maryland, and Georgia, based on previous work of the U. S. Geological Survey and other agencies; on estimates of reserves in Illinois, Kansas, Pennsylvania, and West Virginia, prepared by the geological surveys of those States; and on older and incompletely documented estimates for the remaining states.

The older estimates were prepared on a highly generalized basis and were intended to represent total possible reserves in both thick and thin beds and under both light and heavy overburden. The recent estimates have been prepared on a more conservative basis than the older estimates and tend to be considerably smaller. New conservative estimates have now been prepared for 16 coal-bearing States, which include about two-thirds of the total estimated reserves of the United States. As new estimates are prepared for the remaining States a further reduction of the total reserve figure is in prospect, though the reserves still will be large.

The estimated recoverable reserves of the United States as of January 1, 1953, total 949,870 million tons, based on the assumption that half of the coal reserves in the ground will be lost in mining, and half will be recovered. The distribution of the remaining and recoverable reserves by rank is shown in the accompanying table.

The reserves in 10 States have been classified in considerable detail according to thickness of beds, thickness of overburden, and relative abundance of reliable information available for making estimates. In these States, which are representative of several coal provinces, and contain about 40 percent of the total reserves, and are thus typical of the United States as a whole, 5 percent of the total is measured reserves in beds 28 inches or more thick, and less than 1,000 feet below the surface; and 20 percent is indicated reserves within the same limit of thickness and less than 2,000 feet below the surface. The remaining 75 percent is inferred reserves, reserves in thin beds, and reserves 2,000 to 3,000 feet below the surface.

The large percentage of inferred reserves obviously includes some coal in thick beds, which for lack of detailed information cannot be appraised quantitatively. Although accurately based on the data now available, the distribution percentages are subject to considerable change as new work is completed, particularly in the transfer of reserves from the indicated and inferred categories to the measured category. The figures serve, however, to indicate the present state of knowledge of the Nation's coal reserves, and they point to the need for additional geologic mapping and exploration.

Remaining coal reserves of the United States, January 1, 1953

Rank	Estimated total reserves remaining in the ground, January 1, 1953 (In millions of short tons)	Estimated recoverable reserves, January 1, 1953, assuming 50 percent recovery	
		(In millions of short tons)	(In quadrillions of Btu)
Bituminous coal	1,049,457	524,729	13,643
Subbituminous coal	372,934	186,467	3,543
Lignite	463,356	231,678	3,105
Anthracite and semianthracite	13,992	6,996	178
Total	1,899,739	949,870	20,469

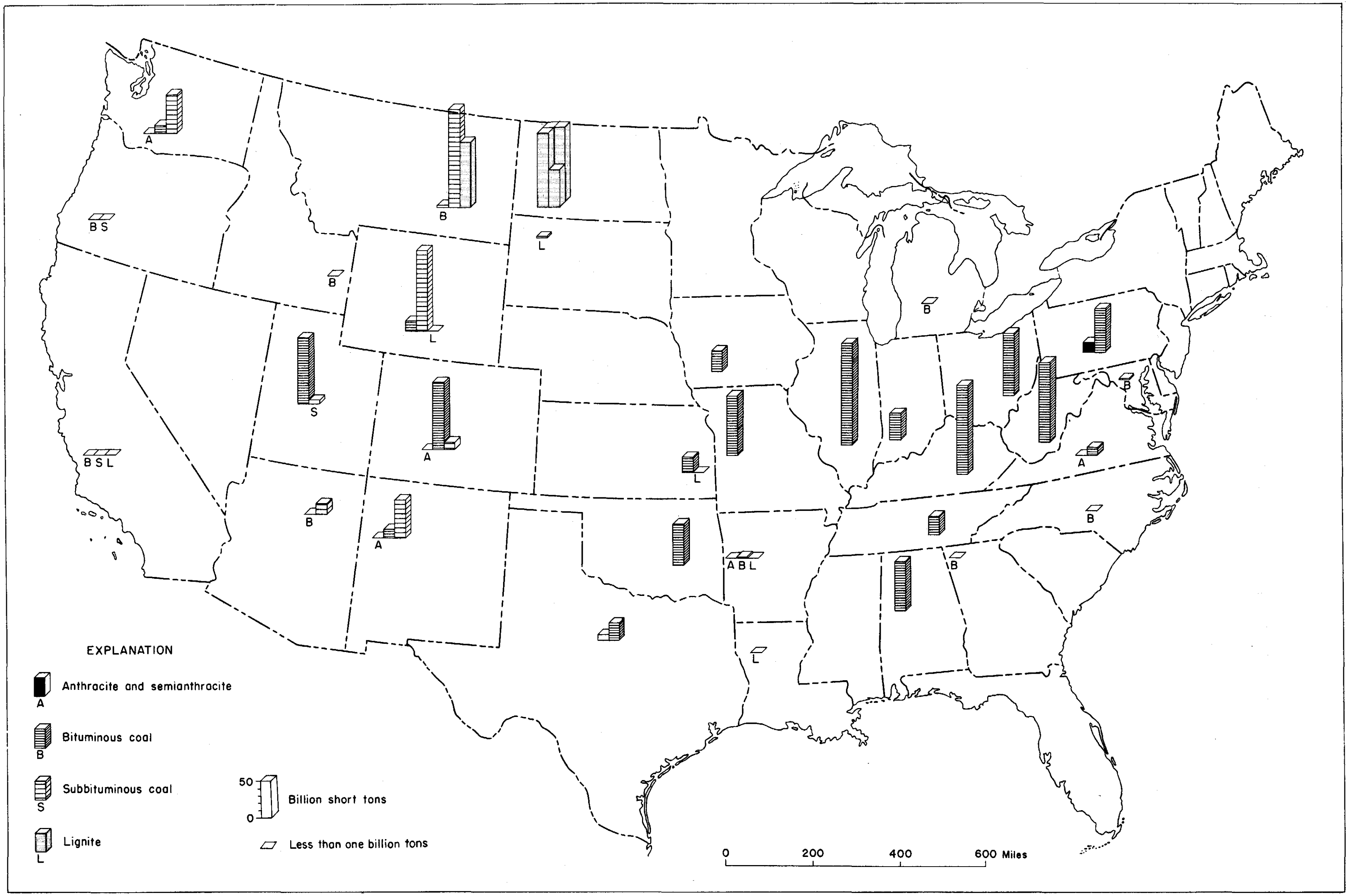

Figure 2. —Remaining coal reserves of the United States, January 1, 1953.

A comparison on a uniform Btu basis of reserves of coal and other fuels shows that coal constitutes 84 percent of the total estimated recoverable fuel reserves, and that petroleum and natural gas each constitute about 2 percent. The remaining 12 percent is oil in oil shale, which is not currently used as fuel. The disparity in reserves is further emphasized by the fact that petroleum and natural gas together are being produced and consumed at a rate about equal to that of coal.

The total recoverable reserves of coal as of January 1, 1953, are 1,279 times the recent average annual production. Even assuming a great increase in the rate of coal production, these reserves still will last many generations. On any basis of analysis the coal reserves of the United States are very large and give comforting assurance that the fuel needs of the Nation can be met in any contingency for many decades to come.

INTRODUCTION

The industrial supremacy of the United States is based largely on the abundance and accessibility of the three mineral fuels, coal, petroleum, and natural gas, of which coal is by far the most abundant. Although the total reserves of coal in the United States are known only in a general way and the total reserves of petroleum and natural gas are largely undefined, and may ultimately prove to be much larger than present estimates suggest, it appears on the basis of information currently available that the recoverable reserves of coal are of the order of 22 times greater than the combined reserves of petroleum and natural gas. In spite of this marked difference in relative magnitude of reserves, petroleum and natural gas do not at present differ greatly in cost from coal, and they are generally more convenient to use. As a result, the four-fold increase in use of energy in the United States that has taken place during the last 50 years has been met largely by an increase in the use of petroleum and natural gas. The increase has been accelerated in recent years by the extraordinary demands of World War II, and by a considerable increase both in population and in per capita use of energy, to such an extent that the present use of petroleum and natural gas now exceeds anything contemplated only a few years ago.

With the increase in use of petroleum and natural gas has come a growing realization that the ultimate reserves of these fuels have finite limits, and that regardless of where the limits may be established, the inevitable day of depletion is being approached at an accelerating rate. At some time in the future, therefore, the far larger reserves of coal must be drawn upon in increasing quantities to supply some of the needs now served by petroleum and natural gas. The growing interest in coal is based largely on the general belief in our ultimate dependence on coal as a fuel, and on the assurance that coal can be adapted to meet practically all fuel requirements.

Although coal-bearing rocks cover 14 percent of the total area of the United States (fig. 1), and contain enormous reserves, it is apparent that reserves of coal also have limits. In the extensively mined eastern coal fields, it is becoming increasingly difficult to locate new areas containing thick beds of high-rank and high-quality coal to replace areas that have been mined out. This is particularly true in areas containing low-volatile bituminous coal, which is so important in the manufacture of coke, and which constitutes only about 1 percent of the total reserves. Furthermore, a considerable part of the total reserves of the United States consists of coal of lignite and subbituminous ranks, or of thin coal beds that can be mined only with great difficulty and expense, or of reserves that must be classed as inferred for want of sufficient information about their occurrence and extent.

Considering the importance of coal in the present and future fuel economy, it is apparent that much more information is needed about the distribution of coal in the United States than has been available in the past. Recognizing this need, the U. S. Geological Survey began in 1947 to expand the program of detailed geologic mapping in coal field areas, and simultaneously started the preparation of new state by state summary estimates of coal reserves. Several state geological surveys have embarked on reserve programs in the individual states. The increasing volume of geologic data available on the occurrence of coal, and the detailed and careful methods now employed in calculating and classifying coal reserves, already permits a much more reliable and useful estimate for the coal reserves of the United States than has previously been available, although much detailed and summary work remains to be done to improve the accuracy and completeness of the estimate.

This second report of progress on the results of the program to reappraise the coal reserves of the United States supersedes "Coal resources of the United States, a progress report, November 1, 1950," published as U. S. Geological Survey Circular 94 in December, 1950.

STATUS OF AVAILABLE INFORMATION

Summary estimates of coal reserves are based largely on detailed geologic maps showing the outcrops and correlations of the individual coal beds, and on accompanying geologic reports giving detailed measurements of the coal thickness. This information is augmented locally by data from exploratory and development drilling and from operating mines. Unfortunately, many coal-bearing areas in the United States have not been mapped geologically; many others have been mapped only in reconnaissance; and few have been prospected other than along the outcrops of the beds. In states where recent reserve appraisals have been prepared, many large areas known to be coal-bearing have been omitted from consideration for want of information. In Wyoming, for example, 53.5 percent of the coal-bearing areas was thus omitted, and in Montana, 9.3 percent was omitted. Even in the eastern fields where information generally is considered to be more abundant, much of the geologic mapping dates from the period 1900-1920 and does not provide the data necessary for a modern inventory of reserves. Progress toward full knowledge of the coal reserves of the United States depends, therefore, upon an active program of detailed geologic mapping and exploratory drilling. Such detailed work is in progress on a modest scale by the U. S. Geological Survey and several State agencies.

Based as they are upon the accumulated detailed information that is obtained only by the laborious processes of mapping outcrops of coal beds and drilling holes to test the coal thickness, summary estimates of coal reserves are only provisional estimates and

Table 1.—Coal reserves of the United States, January 1, 1953, by rank
(In millions of short tons)

State	Estimated original reserves	Reserves depleted to Jan. 1, 1953		Remaining reserves Jan. 1, 1953	Recoverable reserves Jan. 1, 1953, assuming 50 percent recovery
		Production[1]	Production plus loss in mining, assuming past losses equal production		
Bituminous coal					
Alabama[2]	67,570	861	1,722	65,848	32,924
Arkansas	1,396	84	168	1,228	614
COLORADO[3]	90,258	367	734	89,524	44,762
GEORGIA	100	12	24	76	38
ILLINOIS	[4] 137,321	[5] 156	[5] 312	137,009	68,504
INDIANA	37,293	1,039	2,078	35,215	17,607
Iowa	29,160	348	696	28,464	14,232
KANSAS	[4] 20,774	[5] 6	[5] 12	20,762	10,381
Kentucky	123,327	2,177	4,354	118,973	59,487
MARYLAND	[4] 1,200	[5] 2	[5] 4	1,196	598
MICHIGAN	297	[6] 46	[7] 77	220	110
Missouri	79,362	267	534	78,828	39,414
MONTANA	2,363	32	64	2,299	1,149
NEW MEXICO	10,948	90	180	10,768	5,384
NORTH CAROLINA	112	1	2	110	55
Ohio	86,584	1,806	3,612	82,972	41,486
Oklahoma	54,951	166	332	54,619	27,309
PENNSYLVANIA	75,093	7,718	15,436	59,657	29,829
Tennessee	25,665	340	680	24,985	12,493
Texas	8,000	11	22	7,978	3,989
Utah	88,184	215	430	87,754	43,877
VIRGINIA	11,696	599	1,198	10,498	5,249
Washington	11,413	126	252	11,161	5,581
WEST VIRGINIA	116,618	5,428	10,856	105,762	52,881
WYOMING	13,235	247	494	12,741	6,371
Other states[8]	820	5	10	810	405
Total	1,093,740	22,149	44,283	1,049,457	524,729
Subbituminous coal					
COLORADO	9,437	111	222	9,215	4,607
MONTANA	132,151	131	262	131,889	65,945
NEW MEXICO	50,801	32	64	50,737	25,368
Utah	5,156	3	6	5,150	2,575
Washington	52,442	19	38	52,404	26,202
WYOMING[9]	108,319	136	272	108,047	54,024
Other states	15,500	4	8	15,492	7,746
Total	373,806	436	872	372,934	186,467
Lignite					
Arkansas	90	0	0	90	45
KANSAS	(11)	0	0	(11)	(11)
MONTANA	87,533	1	2	87,531	43,766
NORTH DAKOTA	350,910	77	154	350,756	175,378
SOUTH DAKOTA	2,033	1	2	2,031	1,015
Texas	23,000	51	102	22,898	11,449
WYOMING[9]	---	---	---	---	---
Other states[12]	50	(11)	(11)	50	25
Total	463,616	130	260	463,356	231,678
Anthracite and semianthracite					
Arkansas	230	10	20	210	105
COLORADO	713	6	12	701	350
NEW MEXICO	6	1	2	4	2
PENNSYLVANIA	22,805	5,043	10,086	12,719	6,360
VIRGINIA	355	10	20	335	168
Washington	23	0	0	23	11
Total	24,132	5,070	10,140	13,992	6,996
Total, all ranks	1,955,294	[13] 27,785	55,555	1,899,739	949,870

[1]Production, 1800 through 1885, from *The first century and a quarter of American coal industry*, by H. N. Eavenson, privately printed, Pittsburgh, 1942; production, 1886 through 1952, from U. S. Geol. Survey Mineral Resources volumes and U. S. Bureau of Mines Minerals Yearbooks, unless otherwise indicated.
[2]Reserve estimates of states in lowercase letters were prepared by, or under the direction of, M. R. Campbell prior to 1928.
[3]Reserve estimates of states in capital letters supersede earlier estimates by M. R. Campbell.
[4]Remaining reserves, January 1, 1950.
[5]Production, 1950 through 1952.
[6]Production, 1860 through 1949, Michigan Geological Survey Division, as cited in U. S. Geol. Survey Circular 77, p. 56, 1950.
[7]Past losses assumed to be 40 percent of coal originally in the ground.
[8]Includes Arizona, California, Idaho, and Oregon.
[9]Small reserves and production of lignite included under subbituminous coal.
[10]Includes Arizona, California, and Oregon.
[11]Negligible, (for Kansas see discussion in text).
[12]Includes California and Louisiana.
[13]Somewhat less than total recorded production. See footnote 5.

Table 2.—Coal reserves of the United States, January 1, 1953, by states
(In millions of short tons)

State	Estimated original reserves					Reserves depleted to Jan. 1, 1953		Remaining reserves Jan. 1, 1953	Recoverable reserves Jan. 1, 1953 assuming 50 percent recovery
	Bituminous coal	Subbituminous coal	Lignite	Anthracite and semianthracite	Total	Production[1]	Production plus loss in mining, assuming past losses equal production		
Alabama[2]	67,570	---	---	---	67,570	861	1,722	65,848	32,924
Arkansas	1,396	---	90	230	1,716	94	188	1,528	764
COLORADO[3]	90,258	9,437	---	713	100,408	484	968	99,440	49,719
GEORGIA	100	---	---	---	100	12	24	76	38
ILLINOIS	[4] 137,321	---	---	---	[4] 137,321	[5] 156	[5] 312	137,009	68,504
INDIANA	37,293	---	---	---	37,293	1,039	2,078	35,215	17,607
Iowa	29,160	---	---	---	29,160	348	696	28,464	14,232
KANSAS	[4] 20,774	---	(6)	---	[4] 20,774	[5] 6	[5] 12	20,762	10,381
Kentucky	123,327	---	---	---	123,327	2,177	4,354	118,973	59,487
MARYLAND	[4] 1,200	---	---	---	[4] 1,200	[5] 2	[5] 4	1,196	598
MICHIGAN	297	---	---	---	297	[7] 46	[8] 77	220	110
Missouri	79,362	---	---	---	79,362	267	534	78,828	39,414
MONTANA	2,363	132,151	87,533	---	222,047	164	328	221,719	110,860
NEW MEXICO	10,948	50,801	---	6	61,755	123	246	61,509	30,754
NORTH CAROLINA	112	---	---	---	112	1	2	110	55
NORTH DAKOTA	---	---	350,910	---	350,910	77	154	350,756	175,378
Ohio	86,584	---	---	---	86,584	1,806	3,612	82,972	41,486
Oklahoma	54,951	---	---	---	54,951	166	332	54,619	27,309
PENNSYLVANIA	75,093	---	---	22,805	97,898	12,761	25,522	72,376	36,189
SOUTH DAKOTA	---	---	2,033	---	2,033	1	2	2,031	1,015
Tennessee	25,665	---	---	---	25,665	340	680	24,985	12,493
Texas	8,000	---	23,000	---	31,000	62	124	30,876	15,438
Utah	88,184	5,156	---	---	93,340	218	436	92,904	46,452
VIRGINIA	11,696	---	---	355	12,051	609	1,218	10,833	5,417
Washington	11,413	52,442	---	23	63,878	145	290	63,588	31,794
WEST VIRGINIA	116,618	---	---	---	116,618	5,428	10,856	105,762	52,881
WYOMING	13,235	[9] 108,319	([9])	---	121,554	383	766	120,788	60,395
Other states	[10] 820	[11] 15,500	[12] 50	---	16,370	9	18	16,352	8,176
Total	1,093,740	373,806	463,616	24,132	1,955,294	[13] 27,785	55,555	1,899,739	949,870

[1] Production, 1800 through 1885, from *The first century and a quarter of American coal industry*, by H. N. Eavenson, privately printed, Pittsburgh, 1942; production, 1886 through 1952, from U. S. Geol. Survey Mineral Resources volumes and U. S. Bureau of Mines Minerals Yearbooks; unless otherwise indicated.
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[4] Remaining reserves, January 1, 1950.
[5] Production, 1950 through 1952.
[6] See discussion in text.
[7] Production, 1860 through 1949, Michigan Geological Survey Division, as cited in U. S. Geol. Survey Circular 77, p. 56, 1950.
[8] Past losses assumed to be 40 percent of coal originally in the ground.
[9] Small reserves and production of lignite included under subbituminous coal.
[10] Includes Arizona, California, Idaho, and Oregon.
[11] Includes Arizona, California, and Oregon.
[12] Includes California and Louisiana.
[13] Somewhat less than total recorded production. See footnote 5.

are subject to change as mapping, prospecting, and development are continued. Such estimates are valuable, however, in showing the quantitative distribution of reserves, in selecting areas favorable for further exploration or development, and in planning industrial expansion.

The first considered estimate of the total coal reserves of the United States was prepared by M. R. Campbell of the Geological Survey, and published at various times in the period prior to 1928. For more than 20 years this estimate served as the principal reference on our National coal reserves and was republished with only minor modifications by other individuals and organizations. Campbell's generalized estimate was necessarily based on many assumptions concerning the thickness and lateral extent of coal beds in areas for which little geologic data were then available. The estimate included all coal in the ground in beds more than 14 inches thick under less than 3,000 feet of overburden, without attempting to distinguish between reserves of thick, easily-accessible coal and reserves of thin, deeply buried coal.

In the period 1928 to 1947 summary reappraisals of the coal reserves in Pennsylvania, West Virginia, and Kansas were prepared by the Geological Surveys of the respective States.[1] These estimates were more conservative and more detailed than the older estimates, and were correspondingly more useful.

In the current U. S. Geological Survey program to reappraise the coal reserves of the United States, primary emphasis is being placed on the amounts of coal in separate categories according to rank, thickness of beds, thickness of overburden, and relative abundance of reliable data available for preparing the estimates, because of the obvious need for such classified information in the proper utilization of our reserves. Prepared as part of this program to date are detailed reappraisals of the coal reserves in Indiana, Michigan, Montana, New Mexico, North Carolina, North Dakota, South Dakota, Virginia, and Wyoming, which have been presented previously in separate publications; and new provisional appraisals of reserves in Colorado, Maryland, and Georgia, based on previous work of the U. S. Geological Survey and other agencies. In this same period the Illinois Survey has prepared a new and detailed appraisal of Illinois reserves; and the Bureau of Mines began a program to appraise the minable reserves of coking coal, which to date has yielded reports on reserves in 11 counties in Pennsylvania, West Virginia, and eastern Kentucky.

The tables included in this circular are based on reserve figures from these varied sources, which are not strictly comparable. (See tables 1 and 2, and fig. 2.) In particular, the Campbell estimates and those for Missouri and Ohio, prepared under Campbell's direction during the same period,[2] were based on more generous assumptions than the recent estimates, and allowance should be made for this fact in considering them. Although the figures presented for individual states are not strictly comparable, they are cited as originally given by the authors, for, to alter them arbitrarily by some purely mathematical method for use in this progress report would be unnecessarily confusing, particularly in view of the fact that revision of the estimates in some of these states is now in progress or contemplated for the immediate future.

[1] References cited under discussion of reserves in individual states.
[2] These estimates are opposite state names in lowercase letters in tables 1 and 2 and figure 4.

METHODS OF PREPARING AND REPORTING COAL RESERVE ESTIMATES

In preparing state-wide summary estimates of coal reserves, all available information is first gathered together and recorded on individual coal bed maps. Sources of information include the publications and records of the U. S. Geological Survey and state geological surveys, maps and drill records of coal mining companies, information in the files of state mine inspectors and railroad companies, records of exploration for petroleum and natural gas, records of water-well drilling companies, and occasionally, private records obtained from individuals. To translate this information accumulated from geologic observation, mining, and drilling into estimates of tonnage a series of definitions, procedures, and assumptions must be employed.

For practical purposes, two cut-off points must be established in calculating coal reserves—one at the minimum thickness of coal included in the estimate, and another at the maximum thickness of overburden allowed above the coal. A very conservative estimate may include only the original reserves in thick beds and under slight overburden—in other words, reserves that could be recovered profitably under current mining conditions. A more inclusive estimate, on the other hand, may consider thinner, more impure, and more deeply buried coal as recoverable by improved methods when more easily mined deposits have been exhausted.

Other factors, in addition to those involving thickness of coal beds and of overburden, must be established in calculating coal reserve estimates. The weight or specific gravity of the coal must be determined or assumed, and where the continuity of a coal bed is unknown, a method must be selected to estimate its probable extent, based on the available outcrop, mine, or drill data.

The way in which these factors are treated can vary greatly with individual estimators, and the results of such varied treatment are apparent in the estimates for several states. For this reason, an estimate of coal reserves has meaning only when considered in relation to the methods used in obtaining it.

In order to produce reasonably uniform results in preparing coal reserve estimates, the U. S. Geological Survey has adopted a set of definitions, procedures, and assumptions for use by Survey coal geologists. These definitions, procedures, and assumptions, which are discussed in paragraphs below, were prepared jointly by members of the Geological Survey and the Bureau of Mines, and include recommendations of the National Bituminous Coal Advisory Council.

Classification according to characteristics of the coal

Rank of coal. —Coal is classified by rank according to percentage of fixed carbon and Btu content, calculated on a mineral-matter-free basis. As shown in figure 3, the percentage of fixed carbon and the Btu content, except in anthracite, increase from the lowest to the highest rank of coal as the percentages of volatile matter and moisture decrease. The decrease in volatile matter and moisture, and the accompanying increase in fixed carbon took place progressively during the slow process by which plant material deposited in swamps and marshes in the geologic past was transformed into coal. The lower layers of plant material in the swamps were first compacted under successive layers of vegetation. Later, as the sea covered the coal swamps, the weight of sediments deposited on the sea floor further compressed the plant material and caused successive reductions in the amounts of volatile matter and moisture. That these changes are profound is evidenced by the fact that a foot of bituminous coal may contain the accumulated plant growth of several centuries. Locally, deformation of the coal-bearing sediments by movements of the earth's crust speeded up the coal-forming process.

Rank of coal is thus a function of age and deformation, and is a way of expressing successive stages in the formation of coal. It is quite independent of grade, or quality, which is in part a function of the ash and sulfur in the coal.

The standard classification of coal by rank in use in the United States is that established by the American Society for Testing Materials (1939). This classification, which is reproduced as table 3, is used uniformly in classifying all coal reserve estimates. As coals of different rank are adaptable to different uses, rank is the major basis of differentiation shown in figures 1 and 2 and in tables 1 and 2.

Most of the tables and illustrations in this report show reserves of all ranks of coal in short tons as computed. In terms of ultimate usefulness, however, comparison of the reserves of lignite and subbituminous coal, which have relatively low heat values, with reserves of bituminous coal and anthracite, which have higher heat values, can best be made on a uniform Btu basis. Such a comparison is presented in figure 4, which shows the remaining reserves in each state as of January 1, 1953, on both a tonnage and a Btu basis.

Grade of coal. —Coal is classified by grade, or quality, largely according to the content of ash, sulfur, and other deleterious constituents. Thus far in work on coal reserves it has not been possible to report on reserves in categories according to grade because the number of available coal analyses is small compared to the total reserves, and because the analyses are concentrated for the most part in areas of active mining and limited to the line of outcrop of certain key beds.

Although the definitions and procedures used in calculating coal reserves generally permit the inclusion of beds containing as much as 33 percent ash, very little coal of such high ash content is included in modern estimates, in part, because of the natural conservatism of the estimators, and, in part, because all layers of parting and bone more than 3/8-inch thick are excluded in determining the thickness of the beds. On the other hand, reserve estimates do include beds containing somewhat higher ash contents than beds now being mined, and the average ash content in the total estimated reserves probably is higher than the average ash content of existing analyzed samples.

Fieldner and others (1942) have prepared a list of 642 typical mine, tipple, and delivered samples of coal from beds in all parts of the United States. In this list the ash contents range from 2.5 to 32.6 percent, and the average ash content is 8.9 percent. The sulfur contents range from 0.3 to 7.7 percent, and the average sulfur content is 1.9 percent.

It is thus apparent that the average ash and sulfur contents of the estimated reserves could be markedly higher than the average ash and sulfur contents of existing analyses, and still be significantly lower than the maximum amounts permitted in coal included in reserve estimates.

Weight of coal. —The weight of coal in the ground varies significantly with rank and with differences in ash content. The following values, however, conform closely to the average of the recorded specific gravities of coal in each of the four major rank categories:

Rank	Specific gravity	Tons per acre-foot	Tons per sq. mile-foot
Anthracite and semianthracite-----	1.47	2,000	1,280,000
Bituminous coal------	1.32	1,800	1,152,000
Subbituminous coal---	1.30	1,770	1,132,560
Lignite--------------	1.29	1,750	1,120,000

Where more precise data are not available, these values are assigned as the weight of the coal in the ground in all recent U. S. Geological Survey estimates of coal reserves.

Persons closely associated with individual mining operations often employ lower weight factors to allow for anticipated losses in mining. Such a practice is not suitable for use in a general report, however, for recoverability may vary greatly in different areas, in different beds, and with different methods of mining. The selected weight factors, therefore, are intended to yield reserves of coal in the ground without regard to ultimate recoverability.

Thickness of beds. —According to the present procedures of the U. S. Geological Survey, coal reserves are calculated and reported by beds in categories of thickness as follows:

Rank	Thickness categories
Anthracite, semianthracite, and bituminous coal----------	More than 42 inches. 28 to 42 inches. 14 to 28 inches.
Subbituminous coal and lignite------------------	More than 10 feet. 5 to 10 feet. $2\frac{1}{2}$ to 5 feet.

A few of the recent estimates are classified into thickness categories of 14 to 24 inches, 24 to 36 inches, and more than 36 inches for bituminous coal. Other estimates made at various times have used 18 inches as the minimum thickness of bituminous coal. Such differences are noted under the discussion of reserves in individual states as an aid in making comparisons between estimates.

The thickness of a coal bed is evaluated wherever possible by the use of isopach lines. Generally, however, the data are insufficient for this purpose, and average figures, which are weighted according to the

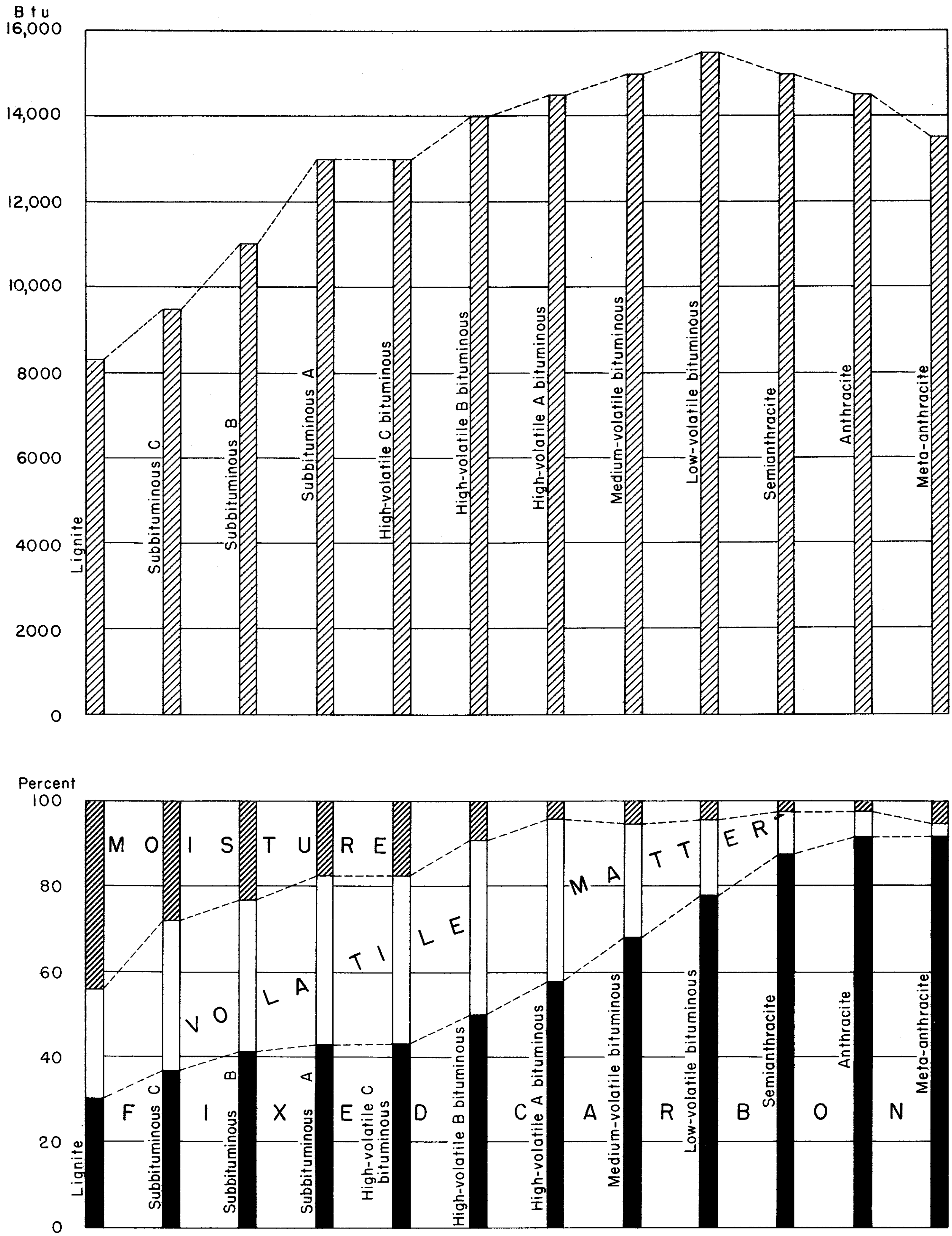


Figure 3.—Heat value of coal of different ranks compared to proximate analyses.

Table 3. Classification of coals by rank[a]

Legend: F.C. = Fixed Carbon. V.M. = Volatile Matter. Btu. = British thermal units.

Class	Group	Limits of Fixed Carbon or Btu. Mineral-Matter-Free Basis	Requisite Physical Properties
I. Anthracitic	1. Meta-anthracite	Dry F.C., 98 per cent or more (Dry V.M., 2 per cent or less)	Nonagglomerating[b]
	2. Anthracite	Dry F.C., 92 per cent or more and less than 98 per cent (Dry V.M., 8 per cent or less and more than 2 per cent)	
	3. Semianthracite	Dry F.C., 86 per cent or more and less than 92 per cent (Dry V.M., 14 per cent or less and more than 8 per cent)	
II. Bituminous[d]	1. Low volatile bituminous coal	Dry F.C., 78 per cent or more and less than 86 per cent (Dry V.M., 22 per cent or less and more than 14 per cent)	
	2. Medium volatile bituminous coal	Dry F.C., 69 per cent or more and less than 78 per cent (Dry V.M., 31 per cent or less and more than 22 per cent)	
	3. High volatile *A* bituminous coal	Dry F.C., less than 69 per cent (Dry V.M., more than 31 per cent); and moist[c] Btu., 14,000[e] or more	
	4. High volatile *B* bituminous coal	Moist[c] Btu., 13,000 or more and less than 14,000[e]	
	5. High volatile *C* bituminous coal	Moist Btu., 11,000 or more and less than 13,000[e]	Either agglomerating or nonweathering[f]
III. Subbituminous	1. Subbituminous *A* coal	Moist Btu., 11,000 or more and less than 13,000[e]	Both weathering and nonagglomerating
	2. Subbituminous *B* coal	Moist Btu., 9500 or more and less than 11,000[e]	
	3. Subbituminous *C* coal	Moist Btu., 8300 or more and less than 9500[e]	
IV. Lignitic	1. Lignite	Moist Btu., less than 8300	Consolidated
	2. Brown coal	Moist Btu., less than 8300	Unconsolidated

[a] This classification does not include a few coals which have unusual physical and chemical properties and which come within the limits of fixed carbon or Btu. of the high-volatile bituminous and subbituminous ranks. All of these coals either contain less than 48 per cent dry, mineral-matter-free fixed carbon or have more than 15,500 moist, mineral-matter-free Btu.

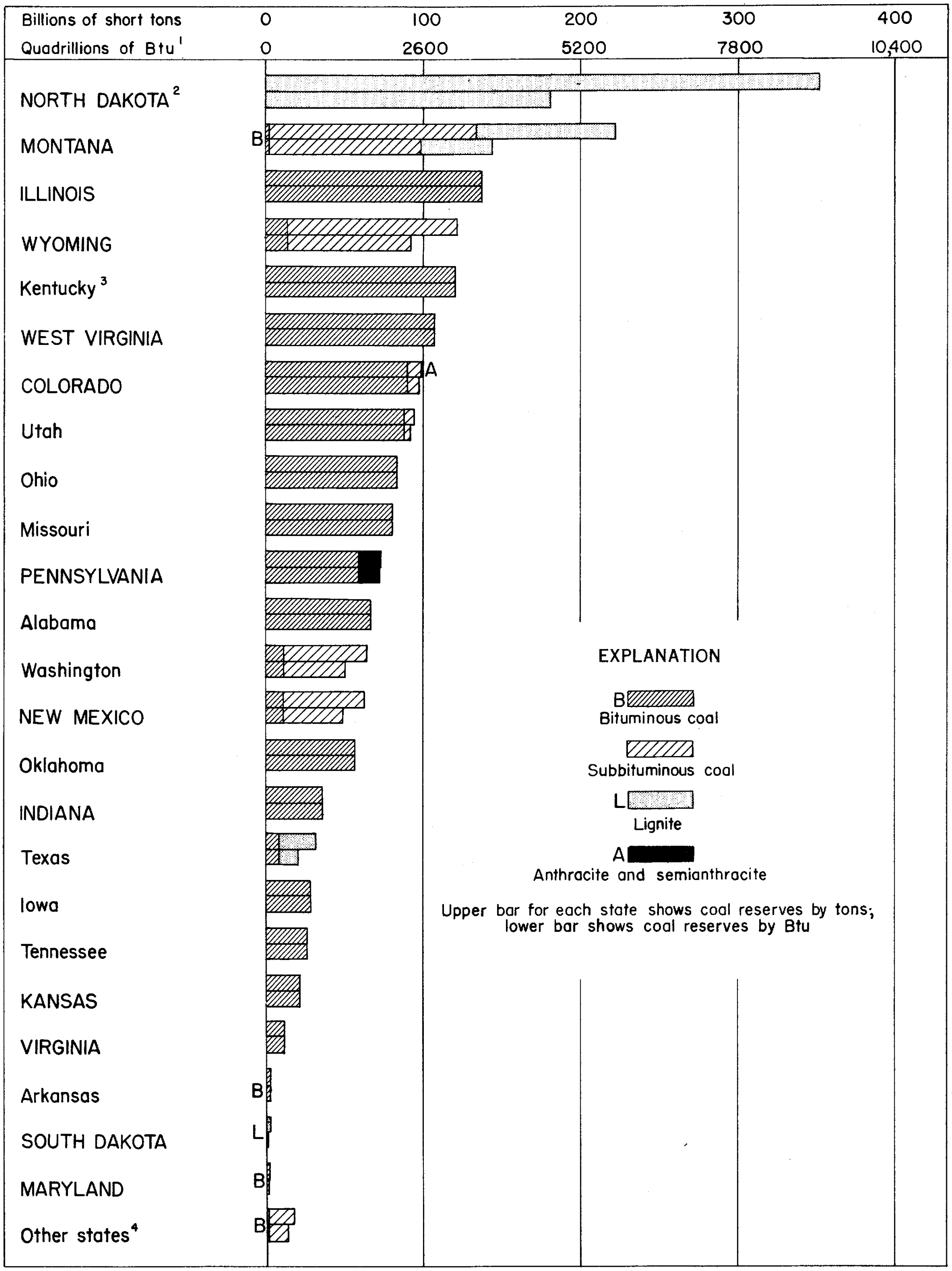
[b] If agglomerating, classify in low-volatile group of the bituminous class.

[c] Moist Btu. refers to coal containing its natural bed moisture but not including visible water on the surface of the coal.

[d] It is recognized that there may be noncaking varieties in each group of the bituminous class.

[e] Coals having 69 per cent or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of Btu.

[f] There are three varieties of coal in the high-volatile C bituminous coal group, namely, Variety 1, agglomerating and nonweathering; Variety 2, agglomerating and weathering; Variety 3, nonagglomerating and nonweathering.



1/ Conversion factors: anthracite, 12,700 Btu per pound; bituminous coal, 13,000 Btu per pound; subbituminous coal, 9500 Btu per pound; and lignite, 6700 Btu per pound

2/ Reserve estimate of States in capital letters supersede earlier estimates by M. R. Campbell

3/ Reserve estimate of States in lower case letters were prepared by, or under the direction of M. R. Campbell prior to 1928

4/ Includes Arizona, California, GEORGIA, Idaho, Louisiana, MICHIGAN, NORTH CAROLINA, and Oregon

Figure 4.—Remaining coal reserves of the United States, January 1, 1953, by states, according to tonnage and heat value.

approximate area of bed represented by each observation, are used. If the points of observation are not evenly spaced, the weighting is accomplished by assigning intermediate values for the thickness at places where data are needed to fill out a system of evenly spaced points. Where this procedure is followed to obtain the weighted average thickness along the outcrop of a persistent bed, the two end points of minimum thickness are also included in the average. Where the points of observation are fairly evenly spaced, as in an exploratory or development drilling program, a simple average is deemed sufficient.

Partings more than three-eighths of an inch thick are omitted in determining the thickness of individual beds. Beds and parts of beds made up of alternating layers of thin coal and partings are omitted if the partings make up more than one-half the total thickness, or if the ash content exceeds 33 percent. Benches of coal of less than the minimum thicknesses stated, which lie above or below thick partings, and which normally would be left in mining, are also omitted.

Occasionally, in older coal-reserve estimates, the "modulus of irregularity" has been used to determine the probable minimum thickness of a coal bed. According to this formula, the probable minimum thickness is obtained by multiplying the average of the measurements of bed thickness by $(1-\frac{SD}{S})$, in which S is the sum of all the thickness measurements and SD is the sum of the differences between each individual thickness measurement and the average of all the thickness measurements.

The modulus of irregularity was originally adopted by the U. S. Geological Survey as a mechanism in establishing the value of coal lands (Smith and others, 1913), but it is no longer used for this purpose. It was devised as a safeguard for the buyer of coal lands in areas where the coal beds range in thickness within wide limits. Computation of the thickness of the coal by using the modulus of irregularity permitted the "thickness of the coal under any tract of land to be considered as less than the average of the measurements. For while the coal is as likely to be just above the average as just below, and mathematically, is more likely to be just the average thickness than any other, yet a cautious buyer bargaining for coal would always want to discount the probability a little as a matter of safety." The modulus of irregularity is cumbersome and inappropriate for use in preparing estimates of coal reserves.

Areal extent of beds. —The areal extent of coal beds included in recent U. S. Geological Survey reserve estimates is determined in several ways. Where the continuity of the bed is well known from maps of the outcrop, mine workings, and drill holes, the entire area of the known occurrence of the bed is taken, even though points of observation are widely spaced. Persistent beds that have been traced around a basin or spur are considered to underlie the area enclosed by the outcrop. Otherwise, the length of outcrop within the thickness limits listed is considered to determine the presence of coal in a semicircular area having a radius equal to one-half the length of the outcrop. The total area of coal is considered to extend beyond such a semicircle if mine workings or drill holes so indicate, in which case coal is considered to extend only 1 mile beyond the limits of the mine workings. An isolated drill hole too far removed to be incorporated in the area thus defined is considered to determine the area of coal extending for a maximum radius of half a mile around the hole.

Recent estimates of other agencies follow these or very similar procedures. Minor points of difference are noted under discussions of the various states.

The older estimates assumed much wider continuity for the individual beds, and, in general, this is the major reason why the older estimates tend to be larger than the recent estimates.

Thickness of overburden. —Wherever possible, the reserve data are reported by the U. S. Geological Survey in three classes according to thickness of overburden, as follows:

0 to 1,000 feet
1,000 to 2,000 feet
2,000 to 3,000 feet

In some areas where the overburden is thin the reserves have been calculated in several sub-categories within the 0 to 1,000-foot category, whereas in other areas one or more major categories have been omitted. The tabulation of the reserves according to the thickness of overburden in Indiana and Michigan, for example, is in more detail than is suggested in the above table. In Indiana all of the estimated reserves are less than 1,000 feet below the surface, and strippable coal is classified into one of three overburden categories, as follows:

0 to 40 feet
0 to 60 feet
0 to 90 feet

The remainder is considered to be non-strippable coal. In Michigan all of the estimated reserves are less than 400 feet below the surface. Here the measured reserves are divided according to thickness of overburden as follows:

50 to 100 feet
100 to 200 feet
200 to 300 feet
300 to 400 feet

The indicated and inferred reserves in Michigan are not classified into sub-categories. In two states, Montana and North Carolina, the estimation of reserves in the 0 to 1,000-foot class of overburden was not practicable and, therefore, a 0 to 2,000-foot class was used.

Classification according to relative abundance of information

On the basis of the relative abundance of reliable data on which the calculations are based, coal reserves are reported by the U. S. Geological Survey in three classes, known as measured, indicated, and inferred.

Measured reserves. —Measured reserves are reserves for which tonnage is computed from dimensions revealed in outcrops, trenches, mine workings, and drill holes. The points of observation and measurement are so closely spaced, and the thickness and extent of the coal are so well defined that the computed tonnage is judged to be accurate within 20 percent or less of the true tonnage. Although the spacing of the points of observation necessary to demonstrate continuity of coal varies in different regions according to the character of the coal beds, the points of observation are, in general, about half a mile apart.

Indicated reserves. —Indicated reserves are reserves for which tonnage is computed partly from specific measurements and partly from projection of visible data for a reasonable distance on geologic evidence. In general, the points of observation are approximately 1 mile apart, but they may be as much as $1\frac{1}{2}$ miles apart for beds of known geologic continuity.

Inferred reserves. —Inferred reserves are reserves for which quantitative estimates are based largely on broad knowledge of the geologic character of the bed or region and for which few measurements of bed thickness are available. The estimates are based on an assumed continuity for which there is geologic evidence. In general, inferred coal lies more than 2 miles from the outcrop.

Distinction between original, remaining, and recoverable reserves

Coal reserves may be calculated and presented according to one or all of three quite different points of view as defined below:

Original reserves. —Original reserves are reserves in the ground before the beginning of mining operations. In the calculation of original reserves no allowance is made for past production and losses in mining or for future losses. Most older estimates are for original reserves only.

Remaining reserves. —Remaining reserves are reserves in the ground as of the date of appraisal and may be obtained by subtracting past production and losses from original reserves.

Recoverable reserves. —Recoverable reserves are reserves in the ground as of the date of appraisal that can actually be produced in the future. Much coal thus classified can be mined at or near present prices, measured in man-hours and equipment. The remainder, presumably, can be mined at gradually increased prices as the thicker and more accessible beds are exhausted. Recoverable reserves are obtained by subtracting estimated future losses in mining from remaining reserves.

The preparation of an estimate of original reserves is essential to the successful determination of remaining and recoverable reserves because it provides a base figure from which other figures can be derived. An estimate of original reserves, although subject to revision with new mapping and exploration, is essentially a constant, needing no date nor explanation to make it understandable. From this estimate the figures for remaining and recoverable reserves, which must be dated, can be determined annually, if desired, from available information on production and losses or from surveys of mined-out areas.

Coal reserves can be calculated successfully without reference to original reserves only in virtually mined-out areas where remaining reserves are small and clearly defined. In most coal areas in the United States, however, the estimates of remaining reserves still closely approximate those of original reserves. This is particularly true in the West, where relatively little mining has been done.

In tables 1 and 2, estimates are presented for original, remaining, and recoverable reserves as a means of emphasizing the distinction between these terms.

Percentage of coal recovered in mining

For calculating remaining and recoverable reserves, reasonably accurate figures for the past production of coal can be obtained from statistics on annual production. The figures for past and estimated future losses of coal in mining, also needed in these calculations, are not so easily obtained. In localities covered by detailed mine maps, past losses in mining can be determined by comparing production figures with measurements of areas known to be mined out. The necessary detailed maps are not available, however, for many of the coal-mining areas in the United States, and the estimates of individuals familiar with local mining operations provide, in general, the only indication of the relative tonnages of coal that are recovered and lost in mining.

The percentage of coal recovered in mining also differs greatly in different areas, depending upon such factors as the nature of the roof rock and the methods used in mining. In calculating remaining and recoverable reserves on a regional or national scale, therefore, an average figure for the estimated percentage of recovery in the past and in the future must be derived from a consideration of the relatively few detailed studies available.

Underground mining. —Most studies of recoverability in underground mining involve consideration of individual mines or small areas, and typically indicate a higher recoverability than studies of larger areas. In some individual mines, for example, as much as 80 or 90 percent of the coal in the block actually being mined may be recovered. From the total-resource point of view, however, recoverability appears to be only about 50 percent of the coal in the ground. This marked difference is due to the fact that studies of recoverability in larger areas include consideration of coal that is left in barrier pillars, in restricted areas around oil and gas wells, under towns, railroads, roads, and streams, in rider beds, in thin and impure beds, and in areas of faulting and folding, as well as the more conspicuous losses in the block or blocks of coal actually being mined.

The results of an investigation by Cady (1949) of the coal resources of Franklin County, Illinois, for example, have shown a recovery of less than 50 percent of the coal originally present in the No. 6 bed in that county. A similar study by Flint (1951) has indicated that the recovery of coal in Perry County, Ohio, between 1838 and 1948 was only 43 percent of the amount originally present. In Michigan the recovery of coal has averaged about 60 percent of the total coal in the ground, according to the estimates of individuals familiar with mining operations in the State (Cohee and others, 1950, p. 5). B. W. Dyer has stated in a personal communication that, in his opinion, mining operations in Utah have not been able to recover more than 50 percent of the total coal in the ground.

Eavenson (1946) has estimated that the actual recovery from the Pittsburgh bed in Pennsylvania is not more than 50 to 60 percent because of the large amount of coal that is left in the barriers, in reservations for oil and gas wells, under buildings, and in the rider above the main bed. In calculating the remaining reserves of bituminous coal in Pennsylvania, Ashley (1944) assumed a recovery of 50 percent for all coal in the State with the exception of that in the Pittsburgh bed, for which he assumed a recovery of 66-2/3 percent. Ashley's figures were based on the percentage recovery of coal in Fayette County, Pennsylvania, as determined by Moyer (Hickok and Moyer, 1940).

The weighted average recovery of bituminous coal in 11 counties of the Appalachian Region as determined by Dowd and others (1950-52) is as follows:

	Recovery (percent)
Pennsylvania:	
Cambria Co.	48.77
Indiana Co.	48.95
Armstrong Co.	46.24
Westmoreland Co.	58.25
Fayette Co.	55.41
Jefferson Co.	51.53
Kentucky:	
Pike Co.	55.08
Floyd Co.	53.23
Knott Co.	53.13
West Virginia:	
Raleigh Co.	57.71
McDowell Co.	62.1

The average of these figures is 53.67 percent.

As the results of these recently completed studies seem to be in accord, the estimated remaining and recoverable reserves of coal shown in tables 1 and 2 are based on the assumption that past mining operations have recovered only 50 percent of the coal in the ground and that this rate will be maintained in the future. Many individual operations recover more than 50 percent of the coal in the ground, however, and it is to be hoped that the general introduction of more efficient mining methods will result in a higher average recoverability in the future than the 50-percent factor assumed in the preparation of tables 1 and 2.

As production statistics of separate states generally include only the output of the larger mines, the recorded production figures used in tables 1 and 2 are somewhat less than actual production. Thus the past losses in mining, which are assumed in tables 1 and 2 to be equal to past production, are also somewhat less than actual losses. Therefore, the remaining and recoverable reserves as reported in tables 1 and 2 are somewhat higher than they would be if full and complete data were available for the amounts of coal mined and lost in mining. From a practical point of view, a considerable amount of the coal recovered in mining is ultimately lost in the process of mechanical cleaning. In 1951, for example, 45 percent of the bituminous coal produced was cleaned mechanically, and an average of 17 percent of this amount was discarded as refuse (U. S. Bur. Mines, 1952, p. 51).

Strip mining.--According to Koenig (1950, p. 28) recoverability in strip mining may, under favorable conditions, be as high as 90 percent of the coal originally in the ground. Other operators agree that the average recoverability in strip mining is of the order of 80 percent, and this figure is used in many appraisals of strip mining reserves. Because strippable coal constitutes only a small part of the total reserves, and only a modest part of past total production, the use in tables 1 and 2 of the 50 percent recoverability factor for all coal appears to be justified.

DISTRIBUTION OF RESERVES IN SELECTED CATEGORIES

Coal-bearing rocks underly about 14 percent of the surface area of the United States. (See table, p. 14, and figure 1.) These rocks are present in 35 different states, including a few, such as Mississippi, New York, and Nevada, in which the coal-bearing areas are small or the reserves insignificant, and others, such as Illinois and West Virginia, in which coal-bearing areas represent more than half the total area of the states.

The distribution of reserves on a tonnage basis is roughly proportional to the distribution of coal-bearing rocks, although a few large areas of coal-bearing rocks, like those in Michigan and Texas, contain relatively small reserves; and other areas, like some in the Rocky Mountain region, are deeply buried, and the contained coal is not included in current estimated reserves. The widespread distribution of accessible coal has contributed greatly to the industrial growth of the United States.

Distribution according to rank

Although coal is present in many parts of the United States, the distribution of reserves of the different ranks is quite unequal. About 60 percent of the reserves of the higher rank bituminous coal and anthracite is found east of the Mississippi River, although this part of the United States contains only 40 percent of the total estimated reserves. West of the Mississippi River, reserves of the higher ranks of coal are present only in comparatively small quantities, in Arkansas, Oklahoma, Colorado, and Washington. The 60 percent of the United States reserves west of the Mississippi River is mostly lignite, subbituminous coal, or high-volatile C bituminous coal.

The reserves of lignite and subbituminous coals in the West have only local value at present, though it is certain that they will have greater usefulness in the future. Coals of these ranks tend to crumble during transportation, and to ignite by spontaneous combustion if stored for too long a period without special precautions. They also have

Distribution of coal-bearing areas in the United States

State	Total area of state[1] (sq. miles)	Area underlain by coal-bearing rocks (sq. miles)	Percent underlain by coal-bearing rocks
Alabama	51,609	9,700	19
Arizona	113,909	3,040	3
Arkansas	53,104	1,600	3
California	158,693	230	0.1
Colorado	104,247	25,400	24
Georgia	58,876	170	0.2
Idaho	83,557	500	0.6
Illinois	56,400	37,700	67
Indiana	36,291	6,500	18
Iowa	56,290	23,100	41
Kansas	82,276	18,800	23
Kentucky	40,395	14,600	36
Louisiana	48,523	1,360	3
Maryland	10,577	440	4
Michigan	58,216	11,600	20
Mississippi	47,716	1,000	2
Missouri	69,674	24,700	35
Montana	147,138	51,300	35
Nevada	110,540	50	---
New Mexico	121,666	14,650	12
New York	49,576	10	---
North Carolina	52,712	155	0.3
North Dakota	70,665	32,000	45
Ohio	41,222	12,350	25
Oklahoma	69,919	14,550	21
Oregon	96,981	600	0.6
Pennsylvania	45,333	15,000	33
South Dakota	77,047	7,700	10
Tennessee	42,244	4,600	11
Texas	267,339	16,100	6
Utah	84,916	15,000	18
Virginia	40,815	1,940	5
Washington	68,192	1,150	2
West Virginia	24,181	16,800	69
Wyoming	97,914	40,055	41
Other states	383,634	0	0
United States total	3,022,387	424,450	14

[1]U. S. Bureau of the Census: Statistical abstract of the United States, p. 5, 1951.

lower heat value than other coals. On the other hand, the low rank coals are well suited for the synthetic production of gas and liquid fuels, and in many parts of the West they can be mined efficiently by stripping methods.

The geographic distribution of the different ranks of coal is due principally to differences in geologic age. Essentially all the coal in States east of the Mississippi River, and in Kansas, Iowa, Oklahoma, and in Arkansas, is of Pennsylvanian age; in the Western States, on the other hand, essentially all the coal is of Cretaceous or Tertiary age. The younger Western coal attains high rank only where it has been deformed and altered by the forces that accompanied mountain building and the intrusion of igneous rock.

Figure 5A, which shows the percentage distribution of original reserves in the four major categories of rank, is based on the estimated reserves in 16 states containing about two-thirds of the total estimated tonnage in the United States. These states, which are shown in capital letters in tables 1 and 2, are those in which detailed reserve estimates have replaced the earlier estimates of M. R. Campbell. Because so large a proportion of the total estimated reserves was used in constructing the diagram, it may be considered as being substantially correct for the United States as a whole. It should be noted that the comparisons shown in figure 5A are based on tons. A diagram based on heat value would show somewhat shorter columns for subbituminous coal and lignite.

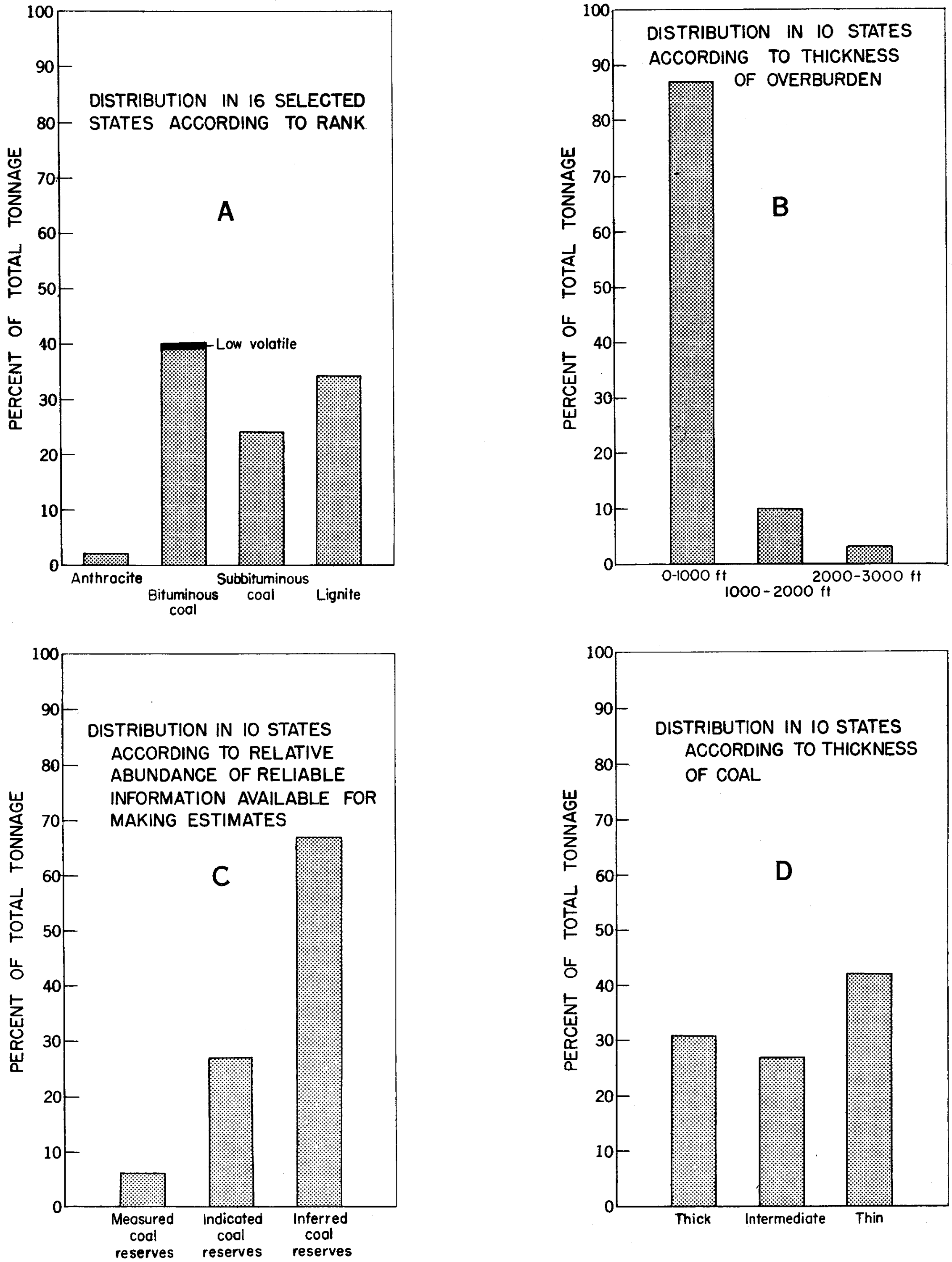


Figure 5.—Percentage distribution of estimated original coal reserves in 16 selected states, according to (A) rank; and in 10 states, according to (B) thickness of overburden, (C) relative abundance of reliable information available for making estimates, and (D) thickness of coal.

Distribution according to reserve categories other than rank

Figures 5B, 5C, 5D, and 6 show the percentage distribution of estimated reserves in categories other than rank in 10 states, which contain about 40 percent of the total estimated reserves in the United States. These 10 states, Illinois, Indiana, Michigan, Montana, New Mexico, North Carolina, North Dakota, South Dakota, Virginia, and Wyoming, are the only ones in which the reserve information is classified in sufficient detail to permit conclusions about the distribution of reserves in these additional reserve categories. The sample presented by the 10 states is fairly large, however, and the observed distribution percentages should show the general order of magnitude of distribution for the United States as a whole.

Distribution according to thickness of overburden. —Figure 5B shows the percentage distribution of reserves in three categories according to the thickness of overburden 0 to 1, 000 feet, 1, 000 to 2, 000 feet, and 2, 000 to 3, 000 feet. It is noteworthy that 87 percent of the estimated reserves in the 10 states is less than 1, 000 feet below the surface, and that only 10 percent and 3 percent, respectively, are present in the 1, 000 to 2, 000 and 2, 000 to 3, 000-foot categories. The impressive concentration of reserves in the 0 to 1, 000-foot category is due in part to the fact that coal-bearing rocks lie near the surface in many places, and in part to the fact that less information is available for the more deeply buried beds. Most of the coal mined in the United States today, for example, is taken from beds less than 1, 000 feet below the surface, and only a small amount is mined from beds 1, 000 to 2, 000 feet below the surface. In the United States no significant amount of coal is mined from beds more than 2, 000 feet below the surface, though in Belgium mining has been carried to a depth of nearly 4, 000 feet below the surface. As exploration and development are carried to greater depths, it is certain that the total estimated reserves in the United States will be considerably increased by the addition of reserves in the deeper overburden categories.

Distribution according to relative abundance and reliability of information. —Figure 5C shows the percentage distribution of original reserves in the measured, indicated, and inferred categories, as defined in earlier pages of this report. Of the large tonnage of classified reserves present in the 10 states, only 6 percent can be classed as measured, and only 27 percent as indicated. The far larger figure of 67 percent for inferred reserves may be attributed in part to the conservative approach adopted in preparing the newer estimates of reserves, and in part to the fact that positive information about the thickness and continuity of coal beds is restricted to a zone a mile or so wide along the outcrops. The larger percentage of inferred reserves thus reflects the lack of precise data for many of the coal field areas. It is, however, a convenient method of expressing the amount of coal that can be inferred with confidence to be present in the fields on the basis of the present geologic information. Additional geologic mapping and exploration in any of the coal field areas included in this distribution study would undoubtedly serve to increase the tonnage of measured and indicated reserves, and might also increase rather than decrease the tonnage of inferred reserves.

Distribution according to thickness of coal. —The terms "thick", "intermediate", and "thin" as used in figure 5D refer to coal in three thickness categories, which differ for the different ranks of coal. Included as "thick" are bituminous coal and anthracite more than 42 inches thick, and subbituminous coal and lignite more than 10 feet thick. Included as "intermediate" are anthracite and bituminous coal 28 to 42 inches thick, and subbituminous coal and lignite 5 to 10 feet thick. Included as "thin" are anthracite and bituminous coal 14 to 28 inches thick, and subbituminous coal and lignite $2\frac{1}{2}$ to 5 feet thick. The smaller percentage of reserves in the "intermediate" category is due probably for the most part to the conservativeness of the appraisers. This is particularly true in the estimation of inferred reserves, where little information is available to determine the thickness satisfactorily, and the tendency is to assume minimum thicknesses.

Distribution in all categories. — Figure 6 summarizes the distribution of reserves in the three major categories presented in figures 5B, 5C, and 5D. The figure clearly shows the preponderance of reserves in the 0 to 1, 000-foot category, and the relatively small quantities of measured reserves in all categories. Reserves are present in each of the possible 27 categories allowed for in figure 6 except the one representing measured reserves in thin beds 2, 000- to 3, 000-feet below the surface. The amounts in several categories are less than 1 percent of the total, however, and they could not be shown on a diagram of this scale.

Like figures 5B, 5C, and 5D, figure 6 also shows the conservative character of the estimates for the reserves in the 10 selected states. The relatively large percentages of reserves in the indicated and inferred categories, and the small percentages in the measured category are due to a lack of data—not a lack of coal. Similarly, the relatively small percentage of coal in the 1, 000- to 2, 000-foot category as compared to the 0 to 1, 000-foot category suggests that the deeper overburden categories contain much larger reserves than the estimates show.

COKING-COAL RESERVES

Coke is a manufactured product, and in spite of the frequent use of the term "coking coal, " there is actually little coal that can be used alone to produce coke satisfactory for metallurgical processes. Coal of medium-volatile bituminous rank is best for use in coke production, but reserves of coal of this rank are small and are rapidly being depleted. Coke that is equally satisfactory, however, can often be produced by blending together two different ranks of coal. Generally, 15 to 30 percent of low-volatile bituminous coal is used in a blend with high-volatile bituminous coal that alone produces only an inferior coke. Weakly coking coal is sometimes improved by adding small amounts of such noncoking ingredients as anthracite fines, petroleum coke, or low-temperature char.

The nature of the original plant constituents of a coal seems to have an effect in determining the suitability of a coal for manufacturing coke, and such deleterious constituents as ash and sulfur must not be present in excessive quantities.

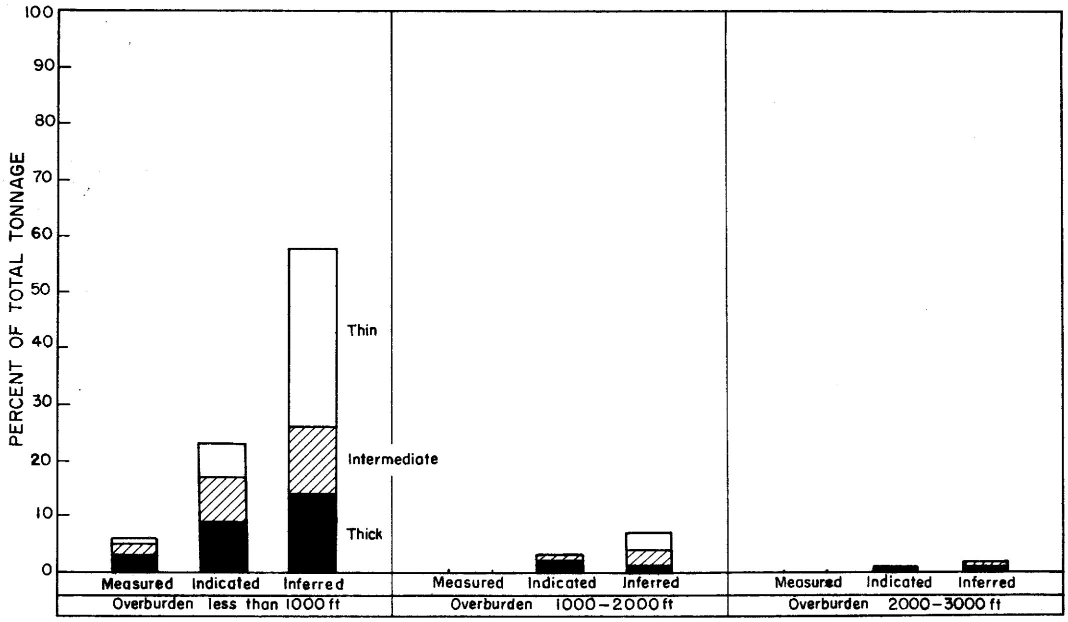


Figure 6. —Summary of percentage distribution of estimated original coal reserves in 10 selected states.

Most of the reserves of high-rank and high-quality coal best suited for the production of coke and coal chemicals are found in the East, principally in West Virginia, Pennsylvania, Kentucky, and Virginia. In a few areas in the West, principally in Colorado, Utah, Oklahoma, Arkansas, Washington, and New Mexico, coal is produced that is satisfactory for the manufacture of coke when used in blends. The most important areas in the West are the Raton Mesa region, Colorado-New Mexico; the Sunnyside field, Utah; and the Crested Butte field, Colorado. These areas stand out prominently in plans for the industrial development of the West. The available information about reserves of coking coal in the West is summarized in another report (Berryhill and Averitt, 1951).

Because of the almost limitless possibilities of blending coals and other hydrocarbons in the manufacture of coke, and because of the certainty that the acceptable amounts of impurities in coke will be allowed to increase and coking properties to decrease as the higher rank and higher grade coals are depleted, it is impossible to define coking coal in precise terms. It may be possible, however, to establish certain categories of coal based on coking properties, and ash and sulfur contents, conforming to ranges now regarded as acceptable for use in making coke, and to report coal reserves in these categories, but this has not as yet been done.

As low-volatile bituminous coal is a blending component that makes possible the use of vastly larger reserves of high-volatile bituminous coal for coke production, the reserves of low-volatile coal are important in regard to present and future supplies of coking coal. The original reserves of low-volatile bituminous coal in the United States are shown in the accompanying table, as estimated on the basis of information available about reserves in the several States.

Relation of original reserves of low-volatile bituminous coal to original coal reserves of all ranks in the United States.

State	Reserves of low-volatile coal (In thousands of short tons)	Percent of total coal reserves of all ranks
West Virginia	10,251,139	8.8
Pennsylvania	5,672,905	5.8
Maryland	700,000	40.7
Oklahoma	2,000,000	3.6
Arkansas	1,226,000	71.5
Virginia	300,000	2.5
Other states	50,000	---
United States total	20,200,044	1.0

The total estimated reserves of some of the states shown in the table will be reduced when new estimates are prepared according to modern, restrictive methods, and the reserves of low-volatile bituminous coal will be reduced accordingly. The ratio of low-volatile bituminous coal reserves to total coal reserves can be expected to remain approximately the same, however, as both the figures cited for low-volatile reserves and the figures for total reserves in tables 1 and 2 were obtained by the same methods. The value of the table lies, not in the figures cited, but in the percentages of total reserves that the figures represent.

On a tonnage basis the original reserves of low-volatile bituminous coal represent about 1 percent of the total original reserves of coal of all ranks in the United States. Mining has been carried on extensively in the areas containing low-volatile bituminous coal, however, because of the desirable qualities of this rank of coal. As a semismokeless fuel with a high heat value, it has many uses in addition to the production of coke. In 1947, for example, 84, 000, 000 tons of low-volatile bituminous coal was mined, of which only about 25 percent was used in manufacturing coke (Fieldner, 1950, p. 13-14).

In many areas of less desirable and less readily accessible coal in the United States, the remaining reserves are very nearly equal to the original reserves because little mining has been done. The areas containing low-volatile bituminous coal, on the other hand, are rapidly being mined out, and the remaining reserves of this coal are now much less than 1 percent of the total coal remaining in the United States, of which no more than half can be regarded as recoverable. With only a limited supply of low-volatile bituminous coal available, it is apparent that coking operations and metallurgical processes soon must be adjusted to permit increasing use of lower-rank coal, of which larger reserves still remain.

STRIPPING-COAL RESERVES

The great increase in strip mining in recent years has taken place largely because of the improvement in earth-moving machinery. A modern electric shovel that may remove as much as 35 cubic yards at a bite is, in fact, a very impressive advance over the small "steam" shovel of a few years ago. Because of the new efficient strip mining machinery, the amount of overburden that can be handled profitably has also increased, and many beds previously considered inaccessible for strip mining are now readily accessible. For overburden not exceeding about 60 feet, the maximum ratio of thickness of overburden to thickness of coal currently considered practicable is about 20 to 1, and for overburden exceeding 60 feet somewhat smaller ratios are also practicable, although the ratios decrease markedly with increase in the thickness of overburden above the limit of 60 feet, which represents the lifting capacity of most modern machinery.

In 1920, strip mining accounted for only 1. 5 percent of the total coal mined, whereas by 1949 strip mining accounted for 24. 2 percent of the total. The year 1949 represents the peak to date for percentage production of coal by strip mining. It was due in part to the normal growth of the industry and in part to several prolonged strikes affecting underground mining production. In 1950-51, however, the percentage contribution of strip-mined coal to total production decreased to 23. 9 and 22 percent respectively, thereby reversing the trend established prior to 1949. The decrease is of particular interest because it occurred during a time when total coal production declined, and when strip mining had reached a peak of efficiency, and should thus have been in a strong competitive position.

Some of the more spectacular coal mining operations are those where the coal is being recovered by stripping methods. The thickest bed now being mined by stripping in the United States is at Wyodak, Wyoming, where the coal is 90 feet thick. The deepest strip pits in the United States are in the Pennsylvania anthracite fields, where an overburden of 120 feet and more is being removed. A feature of the mining is this area is the fact that the outcrops are now being worked for the third time. The first time was by underground mining, which recovered only a small percentage of the coal near the outcrops. The second time was by stripping along the outcrop with small shovels. The third time is by stripping the so-called mined-out zone just below the older stripped zone with large drag-lines and shovels.

The total stripping coal reserves in the United States have not been estimated. That strippable reserves are large is suggested by the fact that 117, 618, 000 tons of coal was mined by stripping methods in 1951. Because of physical restrictions, however, strippable coal represents only a small part of the total reserves, particularly in the eastern states where most coal is mined and used.

The reserves of strippable coal have been calculated for Kansas and Indiana. The proved strippable reserves in Kansas, as of 1947, totalled 60, 000, 000 tons, based on an assumed weight of 1, 500 tons per acre-foot (Abernathy, 1947). This figure represents 0. 3 percent of the total estimated coal reserves in the State. In Indiana, the strippable coal reserves, as of 1950, totalled 3, 524, 170, 000 tons, based on an assumed weight of 1, 800 tons per acre-foot (Spencer, 1953). This tonnage is 9. 4 percent of the total coal reserves in the State.

Montana and North Dakota probably have larger reserves of strippable coal than any other states. In these two states, about half of the coal produced is mined by stripping methods. The U. S. Geological Survey has four reports in preparation on selected areas favorable for large scale strip mining in Montana and North Dakota (Kepferle, in preparation; May, in preparation; Culbertson, in preparation; Brown, A., and others, in preparation).

The use of stripping methods in mining serves in several ways to increase the total amount of coal that is ultimately recoverable. This is accomplished largely by the increase in recovery of coal inherent in the mining method, for strip mining recovers an average of 80 percent of the total coal in the ground, as compared with 50 percent for underground mining. Strip mining also adds to the total coal reserves by making possible the mining of coal under shallow overburden or in badly faulted areas where underground mining could not take place. Isolated pockets of coal that do not warrant the investment necessary for underground mining can often be recovered economically by strip mining.

In some individual operations, when stripping has been extended as far as is justified for reasons of economy and safety, additional coal is recovered by the use of a horizontal auger which bores into the coal bed at the base of the highwall. The large size coal auger has diameters up to 60 inches and penetrates a maximum of 200 feet into the bank. This method permits a theoretical recovery of 75 percent of the coal actually being mined.

Recently, mining at the outcrop of the coal bed has been further extended by the use of a continuous mining system in which a machine equipped with four overlapping cutting heads produces a hole approximately 10 feet wide and 3 feet high. The full height of the coal bed can be recovered by means of successive cuts. Currently, the depth of the hole is limited to 1, 000 feet, the length of the cable supplying power. The thickness of the pillar left between borings depends upon roof conditions, but, in general, recovery of coal by means of this continuous mining system is approximately 65 percent.

PRODUCTION OF COAL IN THE UNITED STATES

The United States now produces more than one-fourth of all the coal mined in the world. The accumulative recorded production in the United States to January 1, 1953, is about 31,405 million tons, half of which has been produced since 1923. In 1947, the year of all-time peak production, the United States produced 688 million tons. This amount would have filled about 28 continuous lines of coal cars extending from New York to San Francisco.[3] The accompanying map (fig. 7) shows the distribution of coal production in the United States in 1950. Most conspicuous on the map is the preponderance of production from the Appalachian Basin, and the fact that more than 90 percent of the production comes from coal fields east of the Mississippi River.

In the early 1800's production began to increase rapidly, and more than doubled during some decades in the first half of the century. Production continued to double every 10 years or so until about the time of World War I. An early peak in coal production was reached in 1918 when 678 million tons was mined; this amount was not exceeded until 1944, during World War II, when 683 million tons was mined. The long interval of no expansion in the coal industry came during the 1920's, when the use of oil and gas began to expand, and during the 1930's, when business was depressed. Nevertheless, considerable progress in mining methods was made during the period. In 1920, for example, less than 1 percent of the coal produced by underground methods was mechanically loaded, whereas by 1951 nearly 70 percent was mechanically loaded. In 1920 strip mining accounted for only 1.5 percent of the coal produced, whereas by 1951, strip mining accounted for 22 percent of the coal produced.

STATE ESTIMATES

As somewhat different assumptions and procedures were used to prepare many of the state reserve estimates presented in this report, comparison of the reserves in different states is facilitated by a consideration of the methods by which each estimate was obtained. Even in the recent appraisals of coal reserves prepared by the U. S. Geological Survey according to the basic outline already discussed, minor differences in procedures were necessary because of differences in the occurrence of the coal and in the amount of information available. Even greater differences in assumptions and procedures exist between estimates prepared by the state geological surveys of Illinois, Kansas, Pennsylvania, and West Virginia. The following summaries, arranged in alphabetical order according to the name of the state, describe and evaluate the various methods followed in preparing the individual state estimates. Wherever possible, the reserve figures for each state are further classified according to thickness of coal beds, amount of overburden, and abundance of reliable information, in order to give the estimates additional significance and usefulness. States for which no recent estimates are available, and for which the older estimates of M. R. Campbell are used, are included under the heading "Other states."

[3] This figure is based on the assumption that one mile of loaded coal cars contains 7,500 tons of coal.

Arkansas

The bituminous coal reserves of Arkansas have been estimated by Steel (1910) and by Campbell. On the basis used by Steel the estimated original reserves would total 1,095,168,000 tons, whereas, the original reserves as estimated by Campbell total 1,716,000,000 tons.

Steel based his estimate on the Hartshorne coal bed alone because it contains most of the reserves in Arkansas. He assumed the bed to average 3 feet in thickness over an area of 310 square miles, and to have an average specific gravity of 1.35, or a weight of 1,840 tons per acre-foot.

Campbell estimated the reserves in the Hartshorne and in other beds as thin as 14 inches over the entire coal-bearing area of 1,600 square miles. He assumed the coal to have an average specific gravity of 1.3, or a weight of 1,770 tons per acre-foot. The Campbell estimate is used in tables 1 and 2. The validity of both estimates needs to be checked, however, in the light of recent information available on the coal field in Arkansas.

Colorado

The original reserves of coal in Colorado, as provisionally estimated by Spencer and Erwin (1953), totaled 100,408 million tons. This figure, which is preliminary to a more detailed study, includes 713 million tons of anthracite, 90,258 million tons of bituminous coal, and 9,437 million tons of subbituminous coal.

Of the total 100,408 million tons of coal estimated to have been originally present in the State, 959 million tons has been mined out or lost in mining to January 1, 1952; the remaining reserves as of that date therefore total 99,449 million tons. Assuming 50 percent recoverability for the coal the recoverable reserves in Colorado total 49,725 million tons.

The estimate of original reserves, classified by counties and fields, was based on published and unpublished reports of the U. S. Geological Survey and on records made available by mining companies.

Of the 25,400 square miles of coal-bearing land believed to be present in the State only 5,277 square miles or 20 percent was included in the estimate. Although the coal probably almost completely underlies several large basin areas, such as the Denver basin and the Uinta Basin, the data used to compile the estimates were restricted for the most part to areas within six miles or less of the coal outcrops. No estimates were made for parts of the State where coal is perhaps present but specific information was lacking. As more mapping and exploratory drilling is carried on in the coal-bearing areas in Colorado, the estimate of reserves should be substantially increased.

No attempt was made in this preliminary estimate to classify the reserves according to thickness of overburden, thickness of beds, or other reserve categories.

In calculating the reserves, the minimum thickness of coal considered in the estimate was 14 inches for bituminous coal and anthracite and $2\frac{1}{2}$ feet for subbituminous coal.

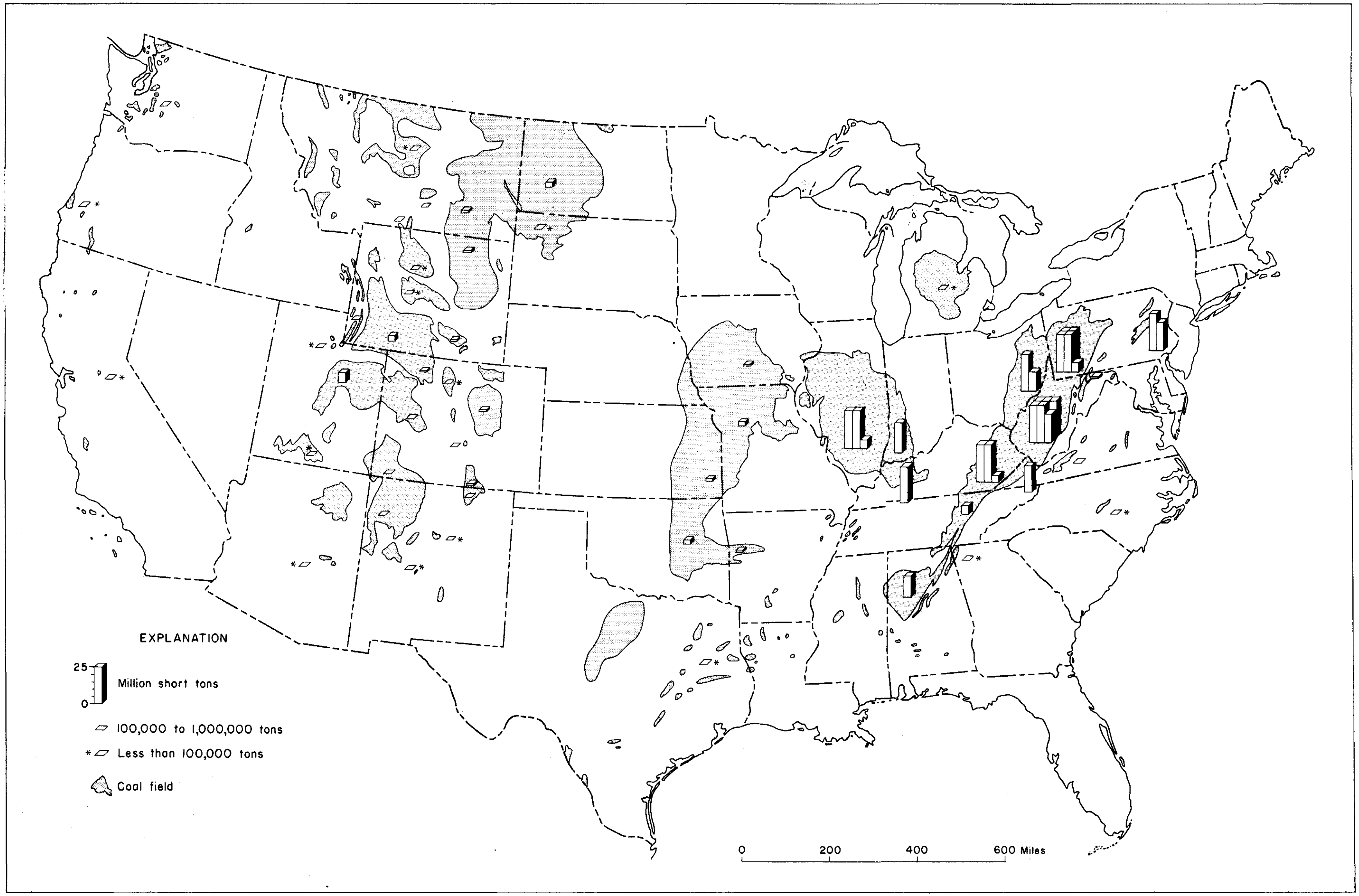


Figure 7.--Distribution of coal production in the United States during 1950.

The bituminous coal was assumed to weigh 1,800 tons per acre-foot; the subbituminous coal was assumed to weigh 1,770 tons per acre-foot; and the anthracite was assumed to weigh 2,000 tons per acre-foot.

Georgia

The original coal reserves of Georgia are here assumed to be 100 million tons on the basis of work by Sullivan (1942, p. 45-51), Johnson (1946), and Butts and Gildersleeve (1948, p. 109). This figure has been selected as a convenient way to reconcile the estimates of 198, 40, and 155 million tons, respectively, as published, or derived from the data published by the three workers. Most of the difference between the three estimates is due to differences in the assumptions on which they were based, and it can be shown by an analysis of the estimates that the selected figure of 100 million tons is fair as an approximation of the original reserves in all categories in all beds 14 inches or more thick, which is the basis on which reserves in most other states are compared.

The coal-bearing rocks in Georgia cover about 170 square miles in parts of Dade, Walker, and Chattooga Counties in the northwestern part of the State. The geology of this area is described in a report by McCallie (1904), which includes much useful information about the coal, but does not include estimates of reserves. Each of the three recent reports mentioned above describes only the Sand and Lookout Mountains area in Dade and Walker Counties, which covers about 120 square miles, or about 70 percent of the total coal-bearing area. At least 11 coal beds have been identified in the Sand and Lookout Mountains area, but mining on a commercial scale has been limited to 5 or 6 beds, which, in general, are considered to contain all of the reserves.

The area to the south, which is not considered in the three reports, covers about 30 percent of the total coal-bearing area in Georgia, but the coal beds are reported to be thinner and less extensive than those in the area to the north.

Sullivan (1942, p. 45-51) who prepared the first of the three reports on the Sand and Lookout Mountains area, calculated original reserves for 5 coal beds and arrived at a total of 197,585,000 tons. He omitted reserves in the Durham (No. 3) bed and the A (No. 1) bed which, although of small areal extent, have been computed in other estimates; but he included the Red Ash bed, which is reported to be generally less than 14 inches thick and is not included in other estimates. Other assumptions used in preparing the Sullivan estimate were not specified in the report.

Johnson (1946), who prepared the second report on the Sand and Lookout Mountains area, estimated that the remaining coal reserves as of 1945 totaled about 24 million tons, and that the original reserves totaled about 40 million tons (personal communication). This estimate includes the reserves in 5 beds with average thicknesses ranging from 1.3 to 3.3 feet.

Butts and Gildersleeve (1948, p. 109), who prepared the third report on the area, considered the reserves in 6 beds with average thicknesses ranging from 2.0 to 3.3 feet. They listed for each bed the average thickness, acreage, percentage of area worked out, and percentage of the area unworkable. Assuming that the coal weighs 1,800 tons per acre-foot, calculations based on their data show that the original workable reserves totaled 154,978,560 tons, of which 34,557,210 tons had been mined out as of the date of their estimate.

The estimates made by Sullivan and by Butts and Gildersleeve are considerably larger than the estimate made by Johnson. A large part of this difference may be attributed to different interpretations of the Dade and the Rattlesnake beds. Johnson considered Dade and Rattlesnake as local names for a single coal bed, the No. 9 bed of his report, which in his estimate accounts for about 1 percent of the total estimated reserves. Sullivan and Butts and Gildersleeve, however, considered them to be two separate beds, which in their estimates account for more than 70 percent of the estimated coal reserves. If only one bed is assumed to be present, in the interest of conservatism, the Butts and Gildersleeve estimate would be reduced to something between 89 to 103 million tons, and the Sullivan figure would range from 97 to 156 million tons.

Although the Johnson figure of 40 million tons is based conservatively on careful, detailed work, the fact that other later workers arrived at higher figures, and the fact that about 30 percent of the coal-bearing areas is not covered by recent detailed mapping suggest that a higher figure should be selected for the original reserves of the State. The 100 million figure selected to serve this purpose is intermediate between the published figures, and should be serviceable until further detailed work is done.

Illinois

As recently estimated by the Illinois Geological Survey (Cady, and others, 1953) the remaining reserves of Illinois on January 1, 1950, totaled 137,321,111,000 tons. In this new and detailed estimate the minimum thickness of coal considered was 28 inches, except for areas of strippable coal where an average thickness of 24 inches was used. Coal underlying large towns was not included in the estimate; nor was coal underlying known oil fields and areas of closely spaced rotary drilling, except for an area in Franklin County where such drilling was done in close cooperation with active mining. Approximately 90 percent of the estimated reserves is less than 1,000 feet below the surface; the remainder is between 1,000 and 1,200 feet below the surface.

A fourfold classification of reserves was used in the Illinois Geological Survey estimate as follows: I-A, Proved reserves; I-B, Probable reserves; II-A, Strongly indicated reserves; and II-B, Weakly indicated reserves. The Proved and Probable categories correspond approximately to the Measured and Indicated categories of the U. S. Geological Survey.

Class I-A, Proved reserves, includes coal extending no more than one-half mile from a mined-out area, diamond drill hole, or an outcrop.

Class I-B, Probable reserves, includes coal extending no more than two miles from a mined-out area, diamond drill hole, outcrop, or churn drill hole known to have been drilled for coal.

Class II-A, Strongly indicated reserves, includes coal extending no more than 4 miles from a mined-out area; diamond drill hole; outcrop; churn drill coal test hole; churn drill hole drilled for oil, gas, or water, if sufficiently detailed logs were available; and "control" rotary drill holes that were sampled and logged in the field by members of the Illinois Geological Survey.

Class II-B, Weakly indicated reserves, includes coal in areas not included in previous categories, where geologic information suggested that the coal was at least 28 inches thick. All reserves in this category were calculated on the assumed minimum thickness of 28 inches.

Where the strict application of the above definitions produced a number of closely spaced areas all in the same category, and the coal was known to be relatively uniform, the areas were joined.

In all calculations the coal was assumed to weigh 1,800 tons per acre foot. Where data permitted, isopach lines were drawn on the coal beds at 28 inches, 42 inches, and at succeeding one-foot intervals; and reserves were calculated in each of these categories. If the data were too widely spaced to permit the use of isopach lines, average thicknesses were estimated for each township.

The results of the Illinois Geological Survey study are summarized in the accompanying table, which presents the total remaining reserves in Illinois as of January 1, 1950, classified by beds and by reserve categories. The report by Cady and others (1953), gives the data in greater detail by beds, counties, reserve categories, and thickness categories, and includes maps of the individual coal beds.

It should be noted that the Illinois estimate, which is for remaining reserves as of January 1, 1950, in beds more than 28 inches thick, is markedly more conservative than estimates for some other states, which are for original reserves in beds more than 14 inches thick.

Indiana

As estimated by Spencer (1953) the original coal reserves of Indiana totaled 37,293,079,000 tons, all of bituminous rank. This figure includes remaining reserves as of January 1, 1951, totaling 35,805,776,000 tons, plus an estimate of coal mined and lost in mining to January 1, 1951, totaling 1,487,303,000 tons. The tonnage estimated as mined and lost in mining was computed from information on available maps of mined-out areas and is a minimum figure. The estimated recoverable reserves, based on an assumed 80 percent

Estimated remaining coal reserves of Illinois, January 1, 1950
(In thousands of short tons)

Coal bed	Reserve categories				
	I - A Proved	I - B Probable	II - A Strongly indicated	II - B Weakly indicated	Total
Trowbridge	8,396	7,873	---	---	16,269
Friendsville	---	24,449	70,018	5,388	99,855
Danville (Sparland) No. 7	1,003,028	3,413,502	2,924,154	499,698	7,840,381
Jamestown	42,147	191,363	367,425	---	600,935
Herrin No.6 (includes Grape Creek)	12,299,737	21,100,547	25,143,881	4,093,391	62,637,556
Harrisburg (Springfield) No. 5	4,168,131	9,593,325	19,776,703	4,971,819	38,509,978
Summum No. 4	51,592	62,359	67,585	---	181,536
Indiana IV	11,946	58,072	61,024	---	131,042
La Salle (Colchester) No. 2	1,359,365	3,622,676	6,216,399	6,287,748	17,486,188
Dekoven	92,150	845,075	1,548,149	---	2,485,374
Indiana III	167,452	687,898	965,550	---	1,820,900
Davis-Wiley	123,448	1,061,644	1,882,935	364,056	3,432,084
Stonefort	4,540	---	---	---	4,540
Bald Hill	27,245	39,033	5,028	1,229	72,535
Campbell Hill	736	---	---	---	736
Murphysboro	34,064	86,016	147,370	124,343	391,794
Rock Island No. 1	111,286	65,230	85,904	6,539	268,959
Assumption-Litchfield	27,794	265,473	1,010,768	---	1,304,035
Willis	6,892	---	---	---	6,892
Makanda	1,962	---	---	---	1,962
Coal beds of unknown correlation lower than No. 6	21,186	---	6,375	---	27,561
Total	19,563,095	41,124,535	60,279,271	16,354,211	137,321,110

recovery for strippable coal and 50 percent recovery for non-strippable coal, totaled 18,778,593,000 tons as of January 1, 1951. In preparing the estimate, which is presented by counties and by beds, data were compiled from published reports of the U. S. Geological Survey and the Indiana Geological Survey, and from records made available by other State and Federal agencies, coal companies, and oil companies.

The reserves were classified in three thickness categories as follows:

More than 42 inches
28 to 42 inches
14 to 28 inches

The estimated reserves are all under less than 1,000 feet of overburden. The coal beds under 90 feet of overburden or less were considered strippable providing the ratio of overburden thickness to the coal bed thickness was no more than 20 to 1. Where the information was adequate and where the ratio of overburden to bed thickness was small enough to classify the coal as strippable, the reserves were classified into one of three overburden categories, as follows:

0 to 40 feet
0 to 60 feet
0 to 90 feet

The assumed areal extent of each coal bed was determined according to standard U. S. Geological Survey methods. The classification of coal beds according to relative abundance and reliability of information on which the calculations were based, was also made according to U. S. Geological Survey standards. The calculations were based on an assumed weight of 1,800 tons per acre-foot.

The table below shows the estimated original coal reserves of Indiana, classified according to abundance of information, thickness of bed, and amount of overburden.

Kansas

Bituminous coal.—The estimated remaining reserves of bituminous coal in Kansas as of January 1, 1950, totaled 20,774,230,000 tons, which include 1,244,900,000 tons of proved reserves and 19,529,330,000 tons of potential reserves. This estimate is a revision by Schoewe (1951a and personal communication) of an earlier appraisal by Abernathy, Jewett, and Schoewe (1947). The new figures differ from previously published figures in part because of recent studies by Schoewe, which show that 15,000,000 tons of coal in Linn County, Kansas, previously classified as potential should be reclassified as proved, and in part because of a revision in the assumed weight of the coal in the ground. In the 1947 estimate the coal was assumed to weigh 1,500 tons per acre-foot, whereas in the 1951 estimate it was assumed to weigh 1,800 tons per acre-foot. The data used in estimating the reserves were obtained from field investigations, State and Federal publications, mining companies, and private individuals.

In estimating the reserves the minimum thickness considered minable by underground methods at various depths is shown in the following table:

Maximum depth to coal (In feet)	Minimum thickness of coal (In inches)
100	16
150	18
200	22
600	32
1,200	36

A minimum thickness of 10 inches was assumed in estimating the rest of the bituminous coal reserves, including strippable coal. Strippable coal was defined as coal lying a maximum of 60 feet below the surface, or coal having an overburden of not more than 35 cubic yards per ton. The reserves were classified according to the relative abundance of information into two categories, termed proved and potential. Proved reserves were defined as reserves lying within a reasonable distance from a known occurrence of coal, based on the

Estimated original coal reserves of Indiana
(In thousands of short tons)

Overburden	Thickness of bed	Measured reserves	Indicated reserves	Inferred reserves	Total
Strippable, 90 ft or less	14 to 28 in.	71,472	111,815	41,033	224,320
	28 to 42 in.	308,134	305,690	111,648	725,472
	42 in.+	1,571,675	672,664	330,039	2,574,378
	Total	1,951,281	1,090,169	482,720	3,524,170
Nonstrippable, more than 90 ft	14 to 28 in.	264,003	767,369	1,084,860	2,116,232
	28 to 42 in.	429,949	1,599,542	4,877,426	6,906,917
	42 in.+	3,709,641	5,200,388	15,835,731	24,745,760
	Total	4,403,593	7,567,299	21,798,017	33,768,909
Total---------------------------------		6,354,874	8,657,468	22,280,737	37,293,079

experience of the coal industry, and on geological observations of the continuity of coal beds in Kansas. In general, the category of proved reserves is believed to include only beds that can be mined with profit under existing conditions. The limits of potential reserves were determined by projection from areas of proved reserves.

In computing proved reserves, a measured thickness of the coal bed was considered to prove the presence of coal of the same thickness in an area of 1 square mile. Two or more known occurrences of the same coal bed in a distance of 4 miles or less along the general line of strike were assumed to prove the bed to be continuous between these points. In calculating potential reserves, a measured thickness of coal indicated the presence of coal at the same thickness under 400 square miles. The maximum overburden used in outlining areas of proved reserves was 1,200 feet, and the maximum overburden for potential reserves was 3,000 feet. The areas of both classes of bituminous coal reserves were greatly reduced in many places because of additional information as to the location of poor coal, thin coal, or the absence of coal.

Lignite. —The lignite beds of Kansas for which there is known, reliable information are in general 30 inches or less in thickness. The minimum thickness accepted by the U. S. Geological Survey in estimating lignite reserves is 30 inches. Although the beds are thin, the reserves were appraised by the Kansas Survey (Schoewe, 1952) because the lignite has been mined in the past and is of local interest. The estimated original reserves of lignite total 198,000,000 tons, which include 55,000,000 tons of marginal reserves and 143,000,000 tons of alleged reserves.

These two classes were applied, rather than the proved and potential categories of bituminous coal, because the lignite is extremely variable in thickness and pertinent information was scarce. Marginal lignite reserves constitute known beds 30 inches or less in thickness. Alleged reserves, which are not associated with any mining activity, are comprised of reported beds, the presence of which is suggested by broad geologic field relationships; they are generally appraised as being more than 3 feet thick. In estimating the marginal reserves, the lignite was assumed to extend for a radius of half a mile from isolated points of measured thickness. The minimum average thickness considered was 12 inches. The maximum overburden employed was 1,000 feet. The lignite was assumed to weigh 1,750 tons per acre-foot.

This estimate of lignite reserves is not included in tables 1 and 2 because the standards used, particularly regarding the thickness of beds are not in accord with those employed elsewhere.

Maryland

The remaining coal reserves in Maryland as of January 1, 1950, are here estimated to total approximately 1.2 billion tons. This estimate is based in part on two reports by Toenges and others (1949, 1952) describing the results of recent investigations by the U. S. Bureau of Mines; the Maryland Department of Geology, Mines, and Water Resources; and the U. S. Geological Survey in three of the five coal fields in Maryland.

The first report pertains to the Georges Creek basin and the northern part of the Upper Potomac basin, and the second to the Castleman basin. In the areas covered by the two reports the estimated remaining reserves as of the period January 1, 1947-'50, total 858,998,000 tons. The total estimated remaining reserves of the State are derived by extrapolation of this figure on the basis of the proportionate distribution of reserves as calculated by Campbell in 1928. According to the earlier appraisal by Campbell, the proportionate distribution of reserves in the several coal basins in Maryland is as follows: Georges Creek basin, 50 percent; Upper Potomac basin, 20 percent; Castleman basin, 15 percent; Upper Youghiogheny basin, 5 percent; and Lower Youghiogheny basin, 10 percent. On this basis the total reserves in the Georges Creek, Upper Potomac, and Castleman basins constitute 85 percent of the total original coal reserves in the State. Approximately 16 percent of the reserves in these basins is believed to be outside the areas considered in the 1949 and 1952 estimates; therefore, the coal in the areas reappraised includes 69 percent of the total remaining coal reserves in Maryland. If Campbell's estimate of the distribution of reserves in Maryland is correct, and it can be assumed that 858,998,000 tons is 69 percent of the total remaining reserves, then the remaining reserves as of the period January 1, 1947-'50, total 1.2 billion tons. Based as it is upon a broad extrapolation of data from several sources, this figure is subject to modification as more information becomes available about Maryland coal reserves. It is, however, of the proper order of magnitude for comparison with other states where reappraisals of reserves have been completed in recent years.

Production of coal in Maryland to January 1, 1950 totaled 260,000,000 tons. Assuming a 50 percent loss in mining, the amount of coal produced and lost in mining in the State during that period totaled 520,000,000 tons. Adding this figure to that of 1,200,000,000 tons for remaining reserves as of January 1, 1950, provides an estimate of 1,720,000,000 tons for the original coal reserves of Maryland.

The coal-bearing rocks in Maryland include about 440 square miles and occur in three parallel structural troughs that extend northeastward across Garrett and Allegany Counties in the western part of the State. Within these three troughs five separate coal fields, or coal basins, are recognized. The easternmost trough is divided by the Potomac and Savage Rivers into the Georges Creek basin to the north and the Upper Potomac basin to the south. The central trough is divided into the Castleman basin to the north and the Upper Youghiogheny basin to the south. The westernmost trough is known as the Lower Youghiogheny basin.

The following paragraphs summarize briefly the recent appraisals of reserves remaining in the Georges Creek basin and the northern part of the Upper Potomac basin, and in the Castleman basin.

In 1949, Toenges and others estimated the remaining reserves in the Georges Creek basin and the northern half of the Upper Potomac basin, as of January 1, 1947, to total 626,729,000 tons. The estimate includes reserves in 10 beds, 18 inches thick or more lying below the Pittsburgh bed. The Pittsburgh bed and the overlying Sewickley bed have been mined extensively in the past and are now nearly depleted. Because the known thick coal beds omitted from the estimate are nearly mined out, the published figure represents essentially the total remaining reserves in the area covered by the report. The reserves are classified according to the relative abundance and reliability of information into measured, indicated, and inferred reserves, and according to thickness into four categories. The coal is of low volatile bituminous rank and is strongly coking.

In 1952, Toenges and others estimated the remaining reserves in the central part of the Castleman basin as of January 1, 1950, to total 232, 269, 000 tons. The estimate includes reserves in six beds, 14 inches thick or more. The reserves are classified according to the relative abundance and reliability of information into measured, indicated, and inferred reserves; and according to thickness into three categories. The coal is of low to medium-volatile bituminous rank and in general is strongly coking.

The estimates for the part of the Maryland coal fields contained in the reports discussed above are conservative, as may be concluded from observation of the separate bed maps accompanying the reports. These maps show the areal extent of the coal reserves estimated, the location of a comparatively large number of drill holes, and the thickness of the coal at many of the drill-hole locations. Another factor responsible for the conservative nature of the estimate is the minimum thickness of 18 inches used in the Georges Creek and Upper Potomac basin report, for in the Castleman basin report and in most other reserve estimates of bituminous coal, the minimum thickness of coal is 14 inches. The selected provisional figure of 1. 2 billion tons for the remaining reserves in Maryland as of January 1, 1950, thus appears to be reasonable and conservative.

Michigan

As estimated by Cohee and others (1950) the original coal reserves of Michigan totaled 296, 900, 000 tons. This figure includes remaining reserves as of January 1, 1950, totaling 219, 900, 000 tons plus an estimate for coal mined and lost in mining to January 1, 1950, totaling 77,000,000 tons. The reserves remaining on January 1, 1950, include 124, 870, 000 tons of measured reserves, 28, 980, 000 tons of indicated reserves, and 66, 050, 000 tons of inferred reserves. The estimate of 77, 000, 000 tons for coal mined and lost in mining to January 1, 1950, includes the recorded production of 46, 239, 607 tons, plus an allowance for coal lost in mining estimated to be equal to about 40 percent of the coal originally in the ground. To prepare the estimate, which is classified to show the distribution of total reserves by counties and by townships, data were assembled from published and unpublished reports in the files of the Michigan Geological Survey Division, and more than 2, 500 logs of coal test wells and several hundred sets of drill cuttings from exploratory wells for oil and gas were examined.

As coal in Michigan occurs sporadically in isolated beds that vary greatly in thickness and generally pinch out in relatively short distances, satisfactory estimates of extent and average thickness were possible only for relatively small areas. In preparing the estimate of Michigan coal reserves, therefore, only those areas having adequate test-hole information were considered, and no estimate was attempted for a large part of the Michigan coal basin where coal should be present but where specific information was lacking. The part of the coal basin for which the necessary information was available was confined to the Saginaw Valley, south and southeast of Saginaw Bay, and included 33 townships in Bay, Tuscola, Midland, Saginaw, Huron, Shiawassee, and Genesee Counties.

The measured coal reserves in Michigan were divided into the following categories according to the thickness of the coal beds:

More than 42 inches
28 to 42 inches
14 to 28 inches

The measured reserves were also divided into the following categories according to the thickness of overburden:

50 to 100 feet
100 to 200 feet
200 to 300 feet
300 to 400 feet

No attempt was made to break down the indicated and inferred reserves into thickness and depth categories because of the small amount of information available on these reserves. The indicated and inferred reserves are contained in beds 14 inches or more thick, however, and are less than 400 feet below the surface.

In classifying the reserves according to the relative abundance and reliability of the information on which the estimate was based, the usual U. S. Geological Survey standards were modified slightly to accord with the geologic nature of the coal beds in Michigan. Measured reserves were defined as reserves blocked out by closely spaced drilling, and the outer limit of a block of measured reserves was drawn within a few hundred feet of the outermost points of positive information. This conservative assumption was necessary to define measured reserves in Michigan because of the known lack of continuity of the beds. Indicated reserves were defined as reserves for which tonnage estimates were based primarily on thickness measurements in isolated drill holes. It was assumed that the thickness of coal observed in the drill holes was representative of the area covered by a circle having a radius of one-eighth mile with the drill hole as its center. Inferred reserves were defined as reserves for which tonnage estimates were based on the isolated drill holes that were also used in computing indicated reserves. The general rule was to limit inferred reserves to the area lying outside the one-eighth mile circle containing indicated reserves, and inside a circle with a radius of one-fourth mile. In some areas, however, where drill holes were more than half a mile but less than 1 mile apart, and where the evidence indicated that the coal was fairly persistent; some reserves were inferred to be present between the holes. In calculating the reserve figures, the coal in Michigan was assumed to weigh 1, 800 tons per acre-foot.

The tabulation on page 26 shows the estimated remaining coal reserves of Michigan as of January 1, 1950, classified according to thickness of bed, thickness of overburden, and abundance of reliable information.

Missouri

The original coal reserves of Missouri as estimated by Hinds (1913) totaled 79, 362, 016, 000 tons, all of bituminous rank. In Hinds' report the reserves are classified by counties, and, for certain counties, additional tables are presented to show reserves by coal beds or by townships.

The estimate includes all coal beds 14 inches or more in thickness based on an assumed weight of 1, 800 tons

Estimated remaining coal reserves of Michigan, January 1, 1950
(In thousands of short tons)

Overburden	Thickness of bed	Measured reserves	Indicated reserves	Inferred reserves	Total
		Bituminous coal			
50 to 100 feet	(14 to 28 in.	1,180	---	---	---
	(28 to 42 in.	[1] 2,630	---	---	---
	(42 in.+	---	---	---	---
	Total	[1] 3,810	---	---	---
100 to 200 feet	(14 to 28 in.	23,800	---	---	---
	(28 to 42 in.	64,100	---	---	---
	(42 in.+	10,160	---	---	---
	Total	98,060	---	---	---
200 to 300 feet	(14 to 28 in.	3,920	---	---	---
	(28 to 42 in.	[2] 14,430	---	---	---
	(42 in.+	4,650	---	---	---
	Total	[2] 23,000	---	---	---
Total		124,870	[3] 28,980	[3] 66,050	219,900

[1] Includes 30 thousand tons with overburden ranging from 22 to 26 feet.
[2] Includes 3,010 thousand tons with overburden ranging from 300 to 366 feet.
[3] Estimate not classified by thickness of bed or amount of overburden.

per acre-foot for the coal. No attempt was made to classify reserves according to thickness of beds or overburden.

Hinds further estimated that the recoverable coal reserves of Missouri, assuming ideal market and labor conditions, will not exceed 60 percent of the original reserves, or 47,702,108,400 tons.

Montana

The original coal reserves of Montana totaled 222,046,940,000 tons, as estimated by Combo and others (1949). This estimate includes 2,362,610,000 tons of bituminous coal, 132,151,060,000 tons of subbituminous coal, and 87,533,270,000 tons of lignite. The distribution of the coal reserves of various ranks in Montana is also shown on a map by Combo and others (1950).

Published and unpublished detailed geologic reports in the files of the U. S. Geological Survey, publications of the Montana State Bureau of Mines and Geology, and similar sources were analyzed for data necessary for the calculation of the Montana reserve figures, which are classified by rank, counties, thickness of beds, and relative abundance and reliability of the available information. Approximately 10 percent of the total area of coal-bearing rocks in Montana was not included in the estimate because no information was available on the thickness and extent of the beds. The areas omitted are concentrated, in general, in the northeastern, lignite-bearing part of the State, where the coal-bearing rocks are concealed by glacial drift. The estimated reserves of lignite should be increased in the future as more detailed work is carried on in these areas.

The minimum thickness of coal considered in the estimate was 14 inches for bituminous coal, and 2½ feet for subbituminous coal and lignite. For the purpose of classifying the reserves, separate estimates were prepared for coal in the following thickness ranges:

Rank	Thickness categories
Bituminous coal----------------	More than 36 inches 24 to 36 inches 14 to 24 inches
Subbituminous coal and lignite----------------------	More than 10 feet 5 to 10 feet 2½ to 5 feet

The estimate includes reserves to a maximum depth of 2,000 feet below the surface. No attempt was made to estimate reserves in intermediate overburden categories, but it is believed that approximately 75 percent of the total is less than 1,000 feet below the surface.

The assumed areal extent of each coal bed was determined according to the standard U. S. Geological Survey methods. Coal in the narrow weathered zone at the outcrop was included in the assumed areas of coal occurrence, as was coal under roads, railroads, and the like. All known areas of burned coal were excluded.

Two classes of coal, based on the quantity of reliable information available for making reserve estimates, were established: (1) Measured and indicated reserves, (2) inferred reserves. Measured and indicated reserves include coal for which positive information about thickness and extent was available from surveys of the outcrop, mine workings, and drill records. The extent of such coal underground was limited everywhere, however, by a line drawn 2 miles from the outcrop, so that all coal classed as measured and indicated was less than 2 miles from the outcrop and more than 50 percent was less than 1 mile from the outcrop. Inferred reserves include, in general, coal lying more than 2 miles from the outcrop.

Based on 20 specific gravity determinations of coal from various parts of Montana, a specific gravity of 1.3, or a weight of 1,770 tons per acre-foot, was selected as being representative of lignite and subbituminous coal.

A specific gravity of 1.32, or a weight of 1,800 tons per acre-foot, was selected as being representative of all the bituminous coal except that in the Red Lodge field, Carbon County, which was assigned a specific gravity of 1.39, or a weight of 1,890 tons per acre-foot.

The accompanying table shows the estimated original coal reserves of Montana classified according to rank, thickness of bed, and relative abundance of reliable information.

Estimated original coal reserves of Montana
(In thousands of short tons)

Overburden	Thickness of bed	Measured and indicated reserves	Inferred reserves	Unclassified reserves	Total
		Bituminous coal			
0 to 2,000 feet	(14 to 24 in.	278,780	167,080	---	445,860
	(24 to 36 in.	347,690	143,740	---	491,430
	(36 in.+	1,036,330	388,990	---	1,425,320
	Total	1,662,800	699,810	---	2,362,610
		Subbituminous coal			
0 to 2,000 feet	(2½ to 5 ft	5,392,110	2,326,150	---	7,718,260
	(5 to 10 ft	15,485,620	9,245,940	---	24,731,560
	(10 ft +	26,370,190	15,974,920	---	42,345,110
	(Unclassified	---	---	57,356,130	57,356,130
	Total	47,247,920	27,547,010	57,356,130	132,151,060
		Lignite			
0 to 2,000 feet	(2½ to 5 ft	4,876,170	10,177,750	---	15,053,920
	(5 to 10 ft	6,613,070	13,135,880	---	19,748,950
	(10 ft +	2,566,030	435,000	---	3,001,030
	(Unclassified	---	---	49,729,370	49,729,370
	Total	14,055,270	23,748,630	49,729,370	87,533,270
Total, all ranks		62,965,990	51,995,450	107,085,500	222,046,940

New Mexico

The original coal reserves of New Mexico totaled 61,754,600,000 tons, as estimated by Read and others (1950). This figure includes 50,801,200,000 tons of subbituminous coal, 10,947,700,000 tons of bituminous coal, and 5,700,000 tons of anthracite. The estimate, which is classified to show reserves by counties and coal fields, and other categories as outlined below, was based on published and unpublished geologic and mining data concerning the coal fields. Drilling data were used where available, but exploratory drilling for coal has been carried on only in a few areas in the State.

The minimum thickness of coal considered in preparing the New Mexico estimate was 2½ feet for subbituminous coal and 14 inches for bituminous coal and anthracite. Reserve figures for the different ranks of coal were classified by thickness of bed as follows:

Rank	Thickness categories
Subbituminous coal	2½ to 5 feet 5 to 10 feet More than 10 feet
Bituminous coal and anthracite	14 to 28 inches 28 to 42 inches More than 42 inches

In areas where information about the thickness of coal beds was reasonably adequate because of drilling and mining development, isopach lines drawn on the coal beds were used to determine variations in thickness, and to establish boundaries between coal in the several thickness categories. In many districts, however, where the data were restricted to outcrop measurements, it was possible to determine only approximate thicknesses at critical points by interpolation.

Coal lying more than 3,000 feet below the surface was not included in the estimate. For coal less than 3,000 feet in depth the following categories of reserves were established according to thickness of overburden:

0 to 1,000 feet
1,000 to 2,000 feet
2,000 to 3,000 feet

The coal reserves of New Mexico were further classified according to the relative abundance and reliability of the information on which calculations were based. The categories of measured, indicated, and inferred reserves were established according to the U. S. Geological Survey standards already described. One further category was added, however, to provide for reserves which, because of the geologic nature of the coal beds and the topography and structure of the larger coal-bearing areas, would not fit into any of the three categories generally used. In New Mexico the coal beds commonly occur in zones as a series of lenticular deposits interbedded with other sedimentary rocks. Although single coal beds in New Mexico are limited in extent, the coal-bearing zones are very persistent and may be regional in occurrence. In consequence, the usual analysis of reserves by beds would not indicate the total reserves of the interior parts of the San Juan Basin or the Raton Mesa field. The coal zones were therefore subjected to further examination as zones instead of individual beds and the additional reserves thus derived were included in a fourth category termed "inferred by zone."

Estimated original coal reserves of New Mexico
(In thousands of short tons)

Overburden	Thickness of bed	Measured reserves	Indicated reserves	Inferred reserves	Reserves inferred by zones	Total
		Bituminous coal				
0 to 1,000 feet	(14 in.+	---	---	---	2,377,900	2,377,900
	(14 to 28 in.	72,800	359,100	334,300	---	766,200
	(28 to 42 in.	151,900	334,200	27,100	---	513,200
	(42 in.+	429,500	611,600	360,100	---	1,401,200
	Total	654,200	1,304,900	721,500	2,377,900	5,058,500
1,000 to 2,000 feet	(14 in.+	---	---	---	1,763,600	1,763,600
	(14 to 28 in.	400	7,100	694,300	---	701,800
	(28 to 42 in.	---	39,400	355,400	---	394,800
	(42 in.+	---	69,400	715,300	---	784,700
	Total	400	115,900	1,765,000	1,763,600	3,644,900
2,000 to 3,000 feet	(14 in.+	---	---	---	1,838,900	1,838,900
	(14 to 28 in.	---	2,600	25,300	---	27,900
	(28 to 42 in.	---	600	---	---	600
	(42 in.+	---	---	376,900	---	376,900
	Total	---	3,200	402,200	1,838,900	2,244,300
Total ----------------------		654,600	1,424,000	2,888,700	5,980,400	10,947,700
		Subbituminous coal				
0 to 1,000 feet	(2½ ft +	---	---	---	16,363,500	16,363,500
	(2½ to 5 ft	446,800	1,021,300	1,227,000	---	2,695,100
	(5 to 10 ft	228,100	348,400	997,600	---	1,574,100
	(10 ft +	151,600	160,900	---	---	312,500
	Total	826,500	1,530,600	2,224,600	16,363,500	20,945,200
1,000 to 2,000 feet	(2½ ft +	---	---	---	13,154,700	13,154,700
	(2½ to 5 ft	---	60,900	165,300	---	226,200
	(5 to 10 ft	---	39,100	743,800	---	782,900
	(10 ft +	---	121,300	537,800	---	659,100
	Total	---	221,300	1,446,900	13,154,700	14,822,900
2,000 to 3,000 feet	(2½ ft +	---	---	---	13,288,000	13,288,000
	(2½ to 5 ft	---	3,600	502,000	---	505,600
	(5 to 10 ft	---	12,100	448,600	---	460,700
	(10 ft +	---	---	778,800	---	778,800
	Total	---	15,700	1,729,400	13,288,000	15,033,100
Total ----------------------		826,500	1,767,600	5,400,900	42,806,200	50,801,200
		Anthracite				
0 to 1,000 feet	(14 in.+	---	---	---	---	---
	(14 to 28 in.	900	2,500	---	---	3,400
	(28 to 42 in.	1,400	300	---	---	1,700
	(42 in.+	500	100	---	---	600
	Total	2,800	2,900	---	---	5,700
Total ----------------------		2,800	2,900	---	---	5,700
Total, all ranks -----------------		1,483,900	3,194,500	8,289,600	48,786,600	61,754,600

The methods used for coal-zone calculations were similar to those used for coal beds, and the same minimum thicknesses for coal of different ranks and the same ranges in overburden thickness were established.

In calculating the reserves of New Mexico, the bituminous coal was assumed to weigh 1,800 tons per acre-foot; the subbituminous coal was assumed to weigh 1,770 tons per acre-foot; and the anthracite was assumed to weigh 2,000 tons per acre-foot.

The estimated original reserves of New Mexico, classified according to rank of coal, thickness of bed, amount of overburden, and abundance of reliable information, are listed in the tabulation on page 28.

North Carolina

All coal of commercial quality in North Carolina is contained in the Deep River field in Chatham, Lee, and Moore Counties. The original reserves of this field, as estimated by Reinemund (in preparation) totaled 111,958,000 tons. This figure is a revision, based on additional data from mining and drilling, of an earlier estimate also prepared by Reinemund (1949). The reserve estimate includes only coal in the main bench of the Cumnock coal bed and in the Gulf coal bed; it does not include coal in the lower benches of the Cumnock bed, which, in general, are too high in ash, too thin, and too far below the main bed for profitable mining. In addition to bituminous coal, the estimate includes small amounts of semianthracite and anthracite where the coal has been altered locally by igneous intrusions.

The reserves were divided into three classes according to the thickness of the coal, and separate estimates were prepared for reserves in beds 14 to 28 inches thick, beds 28 to 36 inches thick, and beds more than 36 inches thick.

The reserves were also classified on the basis of overburden, and separate estimates were made for coal less than 2,000 feet in depth and for coal lying between 2,000 and 3,000 feet in depth. No coal more than 3,000 feet below the surface was included in the estimate.

A further classification of the reserve figures was made according to the relative abundance of reliable information regarding the continuity and thickness of the coal beds. Reserves were classed as measured where the tonnages were computed from thicknesses shown in closely spaced drill holes, mine workings, and outcrops; as indicated where the tonnages were computed partly from specific measurements and partly from projections of visible data; and as inferred where computations were based entirely on geologic evidence without benefit of actual measurements.

In calculating the reserves of the Deep River field, a specific gravity of 1.32, or a weight of 1,800 tons per acre-foot, was used for all coal except that metamorphosed by contact with the intrusive igneous rocks. A specific gravity of 1.47, or a weight of 2,000 tons per acre-foot, was assumed for this metamorphosed coal.

The accompanying table (see below) shows the estimated original reserves of coal in the Deep River field, North Carolina, classified according to thickness of bed, amount of overburden, and relative abundance of reliable information.

North Dakota

The original lignite reserves of North Dakota as estimated by Brant (1953) totaled 350,909,820,000 tons, of which 9,521,400,000 tons is classed as measured; 50,120,390,000 tons as indicated; and 291,268,030,000 tons as inferred. Approximately 70 percent of the total reserves is less than 500 feet below the surface; 28 percent is 500-1,000 feet below the surface; and 2 percent is 1,000-1,200 feet below the surface.

Data used in preparing the estimate were obtained from North Dakota Geological Survey reports, mining companies, private individuals, and U. S. Geological Survey reports. The information available was limited almost entirely to outcrops of the beds,

Estimated original coal reserves in the Deep River field, North Carolina
(In thousands of short tons)

Overburden	Thickness of bed	Measured reserves	Indicated reserves	Inferred reserves	Total
		Bituminous coal[1]			
0 to 2,000 feet	(14 to 28 in.	7,705	24,992	22,373	55,070
	(28 to 36 in.	9,037	3,863	---	12,900
	(36 in.+	20,934	6,786	---	27,720
	Total	37,676	35,641	22,373	95,690
2,000 to 3,000 feet	(14 to 28 in.	---	2,055	---	2,055
	(28 to 36 in.	805	4,923	---	5,728
	(36 in.+	1,183	7,302	---	8,485
	Total	1,988	14,280	---	16,268
Total ----------------------------		39,664	49,921	22,373	111,958

[1] Includes small amounts of anthracite and semianthracite.

but was supplemented by a few drill logs. In many areas that were not mapped information was available only for the thickest or best known bed. Of the entire area considered to be underlain by lignite beds more than 2.5 feet thick, about 1.7 percent was omitted because no data were available. A substantial increase in the estimate for North Dakota should be possible when additional mapping and exploration have been carried out.

The North Dakota reserves were estimated according to the standard procedures of the U. S. Geological Survey as previously defined, and the results are tabulated in the Brant report by individual beds and townships, in categories according to thickness and relative abundance of reliable information available for making the estimate. A summary of this information is presented in the accompanying table (see below).

Ohio

According to combined estimates of Clark (1917) and Flint (1951), the original coal reserves of Ohio totaled 86,583,559,032 tons, all of bituminous rank. In 1917, Clark estimated the original reserves of Ohio to be 87,638,000,000 tons, of which 2,141,000,000 tons was estimated to be in Perry County. On the basis of new geologic work in 1951, Flint recalculated the reserves of Perry County and estimated the reserves to be only 1,086,559,032 tons. This new figure has been added to Clark's estimate for the remainder of the State to give the present total reserve estimate.

Clark based his estimate, which includes a table showing reserves by counties and by coal beds, upon data assembled for the most part from reports of the Geological Survey of Ohio. All coal in beds 14 inches or more thick to a depth of 3,000 feet below the surface was included in the estimate. Average thicknesses for each bed by counties were obtained.

The areal extent of the coal underground was determined by various methods depending upon the amount of information available to Clark on each coal bed. Higher beds, whose outcrops encircle upland areas, were assumed to underlie the area enclosed by the outcrop. Except where positive evidence indicated the absence of coal, each of the lower beds was assumed to extend below drainage toward the center of the coal basin at right angles to the strike for a distance equal to the distance that the bed was known to extend above drainage. Where the coal bed was believed to be persistent along its outcrop and reasonably constant in thickness, it was assumed to have the same average thickness below drainage as observed above drainage.

Several of the coal beds in Ohio were not shown on the maps available to Clark. The probable area of these beds had to be determined from maps showing the outcrop of the base of the coal measures, the outcrops of the more important coal beds, and the locations of coal sections; from the records of deep borings; and from references in the texts of the State reports. In the calculation of the reserves a weight of 1,800 tons per acre-foot was assumed for the coal.

In the more recent work in Perry County, Flint also used 14 inches as the minimum thickness of coal included in his estimate. Of the seven coal beds that Clark recognized in Perry County, however, four beds were excluded by Flint, because detailed mapping showed that in this county these beds generally are less than a foot thick or are completely missing. In calculating the reserves, Flint also assumed the coal to have a weight of 1,800 tons per acre-foot.

According to an estimate by Ray (1929, p. 330), approximately one-sixth of the total original reserves of coal in Ohio, or 14,399,296,000 tons, can be classified as reserves of thick, reasonably accessible coal. For his estimate Ray included only coal 2.7 feet or more thick in 10 specified beds, and he used an assumed specific gravity of 1.1, or a weight of 1,500 tons per acre-foot, for the coal. This weight is very low for bituminous coal in the ground, however, and a more accurate, though conservative, figure can be obtained by recalculation of Ray's estimate using a specific gravity of 1.32, or a weight of 1,800 tons per acre-foot. The estimated original reserves of thick coal in Ohio would thereby be increased 20 percent, to a total of 17,279,155,800 tons.

A detailed report on reserves in the Meigs Creek (No. 9) coal bed in Ohio by Smith and others (1952) was published early in 1953 by the Ohio Division of Geological Survey. According to this report, the original reserves in the Meigs Creek bed in Ohio totaled 4,020,762,000 tons, as compared to the earlier Clark estimate of 4,071,000,000 tons. The new detailed estimate, which presents the reserve data in a number of carefully defined categories for each county, is so nearly the same as the earlier, generalized estimate that no change in the over-all reserves of Ohio

Estimated original reserves of lignite in North Dakota[1]
(In thousands of short tons)

Thickness of bed	Measured reserves	Indicated reserves	Inferred reserves	Total
2½ to 5 feet	3,094,560	20,094,980	224,180,360	247,369,900
5 to 10 feet	3,963,720	18,627,180	36,937,700	59,528,600
10 feet +	2,463,120	11,398,230	30,149,970	44,011,320
Total	9,521,400	50,120,390	291,268,030	350,909,820

[1] All beds are less than 1,200 ft. below the surface.

is required. Nevertheless, the new estimate represents an important step toward full and complete knowledge of reserves in Ohio.

Pennsylvania

Bituminous coal. —The original bituminous coal reserves of Pennsylvania, as estimated by Reese and Sisler (1928), totaled 75,093,459,000 tons. This figure was determined by plotting on county base maps all the information about the area and thickness of the coal beds in the State that could be obtained from the reports of the U. S. Geological Survey and the Pennsylvania Topographic and Geologic Survey, and from drill records, mine maps, and personal interviews with mine operators and others familiar with the coal fields of Pennsylvania.

All coal beds having a minimum thickness of 18 inches were included in the Reese and Sisler estimate. An assumed specific gravity of 1.24, or a weight of 1,688 tons per acre-foot, was used in calculating the coal reserves of all counties in Pennsylvania except Clarion and Jefferson Counties. A specific gravity of 1.34, or a weight of 1,820 tons per acre-foot, was used in computing the coal reserves of these two counties. The specific gravity of 1.34 not only represents the average weight of the coal in two counties in Pennsylvania as determined by a large number of tests, but it also closely approximates the specific gravity of samples of typical bituminous coal in the ground. The assumed specific gravity of 1.24 used in calculating the coal reserves of most of the counties is low for typical bituminous coal, and therefore, yields a conservative figure for the coal reserves of Pennsylvania. Had a specific gravity of 1.34 been used in the calculations for all counties, the estimated bituminous coal reserves of Pennsylvania would have been increased by 6 percent to a total of 80,545,165,000 tons.

Several additional estimates of the coal reserves of small areas in Pennsylvania have been calculated and can be used as a partial check on the Reese and Sisler estimate for the entire State. These estimates are discussed in the following paragraphs:

The coal reserves of the adjoining Punxsutawney and Curwensville quadrangles, were estimated by G. H. Ashley (1926 and 1940). As Reese and Sisler reported reserves by counties and Ashley reported by quadrangles, Ashley's estimate for the two quadrangles cannot be compared directly with the estimate by Reese and Sisler. It is possible, however, to compare the two estimates of coal reserves for those townships which lie entirely within the Punxsutawney and Curwensville quadrangles. For the 14 townships thus situated, Reese and Sisler estimated that the original coal reserves totaled 2,347,600,000 tons, whereas Ashley estimated that the original coal reserves totaled 2,765,375,000 tons. Ashley's estimate, therefore, represents an increase of nearly 18 percent over the estimate of Reese and Sisler.

In calculating the reserves of the Curwensville quadrangle, Ashley included only coal having an average net thickness of at least 18 inches. In calculating the reserves of the Punxsutawney quadrangle, he included only coal having an average net thickness of at least 1 foot. Ashley defined the net thickness of the coal bed as "the thickness left after rejecting any minor benches separated from the main bench by a parting of greater thickness than the coal bench. In the case of a parting thinner than the coal bench, only the difference in thickness between the minor bench and the parting was added to the thickness of the major bench." For both quadrangles, Ashley assumed the coal to weigh 1,800 tons per acre-foot.

The coal reserves of the Smicksburg quadrangle were estimated by M. N. Shaffner (1946), but again a comparison with the Reese and Sisler estimate can be made only for the townships lying completely within the quadrangle. For six townships, therefore, Shaffner estimated that the original coal reserves totaled 525,771,000 tons, and Reese and Sisler estimated that the original reserves totaled 931,300,000 tons. Shaffner's estimate is only 56 percent of that made by Reese and Sisler.

Much of the difference between the two estimates is probably accounted for, however, by the fact that Shaffner determined the thickness of the coal beds used in his calculations by the modulus of irregularity. As already discussed, this formula results in a figure for the thickness of the coal that is less than the average thickness, and an estimate based on the use of the formula tends to be extremely conservative. This is the only known published use of the modulus of irregularity in recent calculations of coal reserves.

Shaffner assumed a specific gravity of 1.35, or a weight of 1,840 tons per acre-foot, for the coal in the Smicksburg quadrangle.

F. T. Moyer estimated that the original coal reserves of Fayette County, Pa., totaled 7,570,000,000 tons (Hickok and Moyer, 1940). For the same area Reese and Sisler estimated that the original coal reserves totaled 5,230,000,000 tons. Moyer's estimate represents an increase of 45 percent over the estimate of Reese and Sisler.

The townships in Fayette County were divided by Moyer into areas in which the coal showed the same characteristics and for which an average section could be determined. The area underlain by coal was obtained by planimeter measurements. Minable thicknesses of the average sections were used in all calculations. The minable thickness of a coal bed, as defined by Moyer, is the thickness of the coal remaining after subtracting partings, bone, and bony coal from the total thickness of the bed. Thin benches separated by a thick parting from the principal bench of a coal bed were also excluded in considering minable thickness. No coal having an average minable thickness of less than 26 inches was included in the estimate. Moyer assumed a specific gravity of 1.37, or a weight of 1,860 tons per acre-foot, for the coal in Fayette County.

The remaining measured and indicated reserves in six counties in the bituminous coal field of Pennsylvania have been estimated recently by Dowd and others (1950-52), as part of a program of the U. S. Bureau of Mines to investigate known minable reserves of coking coal. The reserves as estimated by Dowd and his associates are considerably less than those estimated in 1922 by Reese and Sisler. The apparent decrease in estimated reserves is due, for the most part, to the fact that the Dowd estimate includes only measured and indicated reserves in a relatively small area, whereas Reese and Sisler include all classes of reserves in a relatively larger area. Dowd considered all beds 14 inches or more thick, and used a specific gravity of 1. 32, or 1, 800 tons per acre-foot.

The accompanying table (see below) compares the two estimates for six counties according to acreage and tonnage.

In the strictest sense none of the reserve estimates just discussed can be compared with the Reese and Sisler estimate because of the different standards applied, particularly for minimum thickness of coal beds and weight of coal. For practical purposes, however, the several recent estimates serve to show the conservativeness of the older Reese and Sisler estimate.

Ashley (1944) recognized the conservative nature of the Reese and Sisler estimate and, on the basis of the other estimates just described, increased the Reese and Sisler figures of original coal reserves 10 percent for every county in Pennsylvania except Fayette County, for which he used the new estimate by Moyer.

As previously mentioned, the low estimate by Reese and Sisler is partly the result of the use of a lower-than-average specific gravity for the coal in Pennsylvania. Recalculation of the estimate using a somewhat higher specific gravity for the coal, however, still results in a smaller figure for the coal reserves of Pennsylvania than is indicated by other estimates that include all classes of reserves. Considering the conservative nature of the Reese and Sisler estimate, and the fact that no new complete estimate for the coal reserves of Pennsylvania is available, the continued use of their estimate without revision in the present tables seems justified at this time.

Anthracite. —The original reserves of anthracite in Pennsylvania totaled 22, 805, 000, 000 short tons, according to the most recent estimate, which was made by Ashley (1945). This estimate was based directly upon a previous one by Ashmead (1926), with the exception of the reserve figures for two counties, Dauphin and Lebanon, which Ashley decreased on the basis of later mining reports.

Ashmead based his reserve estimate on careful measurements of coal bed areas as shown on mine maps, but he listed no standards for the thickness or weight of the coal included. Presumably, therefore, in computing the anthracite reserves of Pennsylvania, Ashmead, and subsequently Ashley, used the same limits of thickness and the same figures for specific gravity that were adopted by Smith (1893) who made the first careful estimate of the anthracite reserves, see also Lesley and others (1895).

The minimum thickness of coal included in Smith's estimate was 2. 5 feet for the Northern anthracite field and 2 feet for the other fields.

In calculating anthracite reserves, Smith used different values, as determined by numerous tests, for the specific gravity of the coal in different parts of the anthracite fields. The coal in the Eastern Middle field, Western Middle field, and part of the Southern field was assigned a specific gravity of 1. 61, or a weight of 2, 190 tons per acre-foot. The remainder of the coal in the Southern field was assigned a specific gravity of 1. 5, or a weight of 2, 040 tons per acre-foot, and the coal in the Northern field, was assigned a specific gravity of 1. 55, or a weight of 2, 110 tons per acre-foot. Smith estimated that the original reserves of anthracite in Pennsylvania totaled 21, 848, 800, 000 short tons.

Recent detailed mapping by the U. S. Geological Survey in parts of the Western Middle anthracite field has revealed a number of faulted and sheared areas that are not shown on earlier maps. If such structures prove to be numerous throughout the anthracite region, future estimates of anthracite reserves may be somewhat reduced (Rothrock, 1950, p. 195). Smith's older estimate of 21, 848, 800, 000 short tons for original reserves may therefore prove to be more accurate than the more recent Ashley estimate of 22, 805, 000, 000 tons, which has been accepted for use in this report.

Comparison of coal reserve estimates of Reese and Sisler, and Dowd and others for individual counties in Pennsylvania

County	Reese and Sisler 1922[1]		Dowd and others 1950-52[2]	
	Acres (thousands)	Tons (millions)	Acres (thousands)	Tons (millions)
Armstrong	669	3,643	425	1,550
Cambria	1,030	4,916	725	2,406
Fayette	638	4,330	314	943
Indiana	1,142	6,040	754	2,544
Jefferson	742	3,056	165	710
Westmoreland	905	5,163	290	922
Total	5,126	27,148	2,673	9,075

[1] All classes of remaining reserves, 1922, beds 18 inches or more thick, assuming a weight of 1,688 tons per acre-foot in all counties except Jefferson County, for which the assumed weight is 1,820 tons per acre-foot.

[2] Measured and indicated remaining reserves, 1948-50, beds 14 inches or more thick, assuming a weight of 1,800 tons per acre-foot.

South Dakota

The original coal reserves of South Dakota, as estimated by D. M. Brown (1952), totaled 2,032,910,000 tons of lignite and 10,900 tons of bituminous coal. The estimate is based on published and unpublished reports of the U. S. Geological Survey and the South Dakota Geological Survey, and on information provided by operating companies and private individuals. The estimated lignite reserves are tabulated in the Brown report by counties and townships and by a number of reserve categories, but the small quantity of bituminous coal is described only in the text.

In estimating the reserves, the assumed areal extent of each coal bed was determined according to the standard U. S. Geological Survey procedures. The minimum thickness of coal considered was 14 inches for bituminous coal and 2½ feet for lignite. The calculation of the lignite reserves was based on three thickness categories, as follows:

More than 10 feet
5 to 10 feet
2½ to 5 feet

The lignite reserves were further divided into the measured, indicated, and inferred categories, according to the relative abundance and reliability of information. All reserves were grouped into one overburden category, less than 1,000 feet. The lignite was assumed to have a weight of 1,750 tons per acre-foot.

The accompanying table (see below) shows the estimated original reserves of lignite of South Dakota classified by thickness of bed and relative abundance of reliable information.

Virginia

As estimated by Brown and others (1952), the original coal reserves of Virginia totaled 12,051,270,000 tons, of which 932,000,000 tons had been mined and lost in mining to January 1, 1951, and 11,119,270,000 tons remained in the ground. Of the total amount of coal included in the estimate, 97 percent is concentrated in the southwest Virginia field, where the coal is of bituminous rank, and 3 percent is in the Valley fields, where the coal is semianthracite. No estimates were prepared for the coals of Triassic age in the Richmond and Farmville basins, because the information available was insufficient for the purpose.

The tabulation listed on page 34 shows the distribution of the total remaining reserves of bituminous coal and the original reserves of semianthracite in various categories classified according to rank, overburden, thickness of beds, and relative abundance and reliability of information. Noteworthy is the fact that most of the reserves included in the estimate are less than 1,000 feet below the surface.

The appraisal of the coal reserves of Virginia was prepared by the U. S. Geological Survey in cooperation with the Virginia Geological Survey. Information was obtained from mining companies, private individuals, and publications of the two cooperating organizations. In preparing the appraisal, the reserves were classified into three categories of thickness as follows:

More than 42 inches
28 to 42 inches
14 to 28 inches

The reserves were further classified according to the relative abundance and reliability of information into measured, indicated, and inferred reserves, according to the standard U. S. Geological Survey methods. In making calculations the bituminous coal was assumed to weigh 1,800 tons per acre-foot, and the semianthracite to weigh 2,000 tons per acre-foot.

West Virginia

The original coal reserves of West Virginia totaled 116,618,446,894 tons, according to an estimate by Headlee and Nolting (1940). This figure represents the sum of the original coal reserves in each of 44 coal-bearing counties as estimated in numerous county reports published by the West Virginia Geological Survey. The Headlee-Nolting summary report includes tables showing the distribution of reserves by minable coal beds as well as by counties.

The estimate includes reserves in a few beds averaging 1 foot in thickness, but the amount of such coal is small. Price and others (1938) state that approximately 75,500,000,000 tons of coal in West Virginia is contained in beds that average 3 feet or more in thickness. The remainder of the original reserves, or approximately 41,000,000,000 tons, is contained in the thinner beds.

In computing the reserves of West Virginia, the coal was assumed to have a specific gravity of 1.28,

Estimated original reserves of lignite of South Dakota
(In thousands of short tons)

Thickness of bed	Measured reserves	Indicated reserves	Inferred reserves	Total
2½ to 5 feet	104,420	992,480	177,290	1,274,190
5 to 10 feet	33,680	673,490	60	707,230
10 feet +	---	51,490	---	51,490
Total	138,100	1,717,460	177,350	2,032,910

Estimated remaining coal reserves of Virginia, January 1, 1951
(In thousands of short tons)

Overburden	Thickness of bed	Measured reserves	Indicated reserves	Inferred reserves	Total
Remaining reserves of bituminous coal, January 1, 1951					
0 to 1,000 feet	(14 to 28 in.	51,390	1,693,930	2,963,850	4,709,170
	(28 to 42 in.	270,040	2,572,080	874,000	3,716,120
	(42 in.+	463,960	1,311,130	100,670	1,875,760
	Total	785,390	5,577,140	3,938,520	10,301,050
0 to 2,000 feet	(14 to 28 in.	---	630	331,180	331,810
	(28 to 42 in.	---	4,830	72,020	76,850
	(42 in.+	---	33,640	32,300	65,940
	Total	---	39,100	435,500	474,600
Total		785,390	5,616,240	4,374,020	10,775,650
Original reserves of semianthracite					
0 to 1,000 feet	(14 to 28 in.	---	30,940	23,880	54,820
	(28 to 42 in.	---	10,640	18,410	29,050
	(42 in.+	---	126,850	144,900	271,750
Total		---	168,430	187,190	355,620
Mined and lost in mining, January 1, 1951					12,000
Total remaining reserves of semianthracite, January 1, 1951					343,620
Total remaining reserves, all ranks, January 1, 1951,					11,119,270

or a weight of 1,742 tons per acre-foot. A specific gravity of 1.28 is rather low, however, for typical bituminous coal in the ground. By assuming a specific gravity of 1.32, or a weight of 1,800 tons per acre-foot, which is more generally accepted as the average of typical bituminous coal in the ground, the West Virginia estimate would be increased 3 percent.

The remaining reserves in Raleigh County as of January 1, 1949, were estimated by Dowd and others (1952) to total 2,532,384,000 tons. In McDowell County the remaining reserves as of January 1, 1951, were estimated by Wallace and others (1952) to total 2,216,691,000 tons. These estimates, prepared as part of a program of the Bureau of Mines to investigate minable reserves of coking coal, include measured and indicated reserves in beds 14 inches thick or more. The coal in each county was assumed to weigh 1,800 tons per acre-foot. The Bureau of Mines figures for Raleigh and McDowell Counties are not comparable with the West Virginia Survey figures because the Bureau of Mines figures are for remaining measured and indicated reserves only, whereas the West Virginia Survey figures are for original measured, indicated, and inferred reserves.

Wyoming

The original coal reserves of Wyoming, as estimated by Berryhill and others (1950), totaled 121,553,850,000 tons, of which 13,234,950,000 tons is bituminous coal and 108,318,900,000 tons is subbituminous coal. According to the few available analyses, a large tonnage of coal on the eastern side of the Powder River Basin is close to the dividing line between subbituminous coal and lignite, but it is included in this estimate with reserves of subbituminous coal. The areal distribution of coal in Wyoming is shown on a map by Berryhill and others (1951), which is complementary to the reserve report.

The Wyoming estimate, which shows the coal reserves classified by counties and by townships, was based on published and unpublished reports of the U. S. Geological Survey; on publications of the Geological Survey of Wyoming; and on records made available to the U. S. Geological Survey by mining companies, oil companies, and private individuals. Approximately 53 percent of the total area of coal-bearing rocks in Wyoming was not included in the estimate because little or no information on the coal beds in these areas was available. The estimate of reserves in Wyoming should therefore be substantially increased as mapping and exploration continue.

The minimum thickness of coal included in the Wyoming reserve estimate was 14 inches for bituminous coal and 2½ feet for subbituminous coal. The reserves of different ranks of coal were classified according to the following thickness ranges:

Rank	Thickness categories
Bituminous coal	14 to 28 inches 28 to 42 inches More than 42 inches
Subbituminous coal	2½ to 5 feet 5 to 10 feet More than 10 feet

The assumed areal extent of each coal bed was determined according to the standard U. S. Geological Survey procedures. Coal in the narrow weathered zone at the outcrop was included in the assumed area of coal occurrence, as was coal under roads and railroads. All known areas of burned coal were excluded.

The Wyoming coal reserves were further classified in the following ranges according to thickness of overburden:

0 to 1,000 feet
1,000 to 2,000 feet
2,000 to 3,000 feet

The reserves were also divided, according to the relative abundance of reliable information on which the estimates were based, into three additional categories—measured, indicated, and inferred—established according to the standard procedures of the U. S. Geological Survey.

In calculating the reserve estimate, the bituminous coal in Wyoming was assumed to have a weight of 1,800 tons per acre-foot, and the subbituminous coal was assumed to have a weight of 1,770 ton per acre-foot.

The accompanying table (see below) shows the estimated original coal reserves of Wyoming classified according to rank of coal, thickness of bed, thickness of overburden, and relative abundance of reliable information.

Estimated original coal reserves of Wyoming
(In thousands of short tons)

Overburden	Thickness of bed	Measured reserves	Indicated reserves	Inferred reserves	Total
		Bituminous coal			
0 to 1,000 feet	(14 to 28 in.	24,400	446,070	57,050	527,520
	(28 to 42 in.	149,610	680,760	82,900	913,270
	(42 in.+	1,512,910	2,180,750	593,460	4,287,120
	Total	1,686,920	3,307,580	733,410	5,727,910
1,000 to 2,000 feet	(14 to 28 in.	4,860	143,590	276,060	424,510
	(28 to 42 in.	21,840	332,310	425,770	779,920
	(42 in.+	318,840	1,507,040	967,600	2,793,480
	Total	345,540	1,982,940	1,669,430	3,997,910
2,000 to 3,000 feet	(14 to 28 in.	---	58,700	294,480	353,180
	(28 to 42 in.	---	98,350	448,410	546,760
	(42 in.+	30,140	1,043,580	1,535,470	2,609,190
	Total	30,140	1,200,630	2,278,360	3,509,130
Total------------------------------		2,062,600	6,491,150	4,681,200	13,234,950
		Subbituminous coal			
0 to 1,000 feet	(2½ to 5 ft	7,890	6,503,920	7,358,730	13,870,540
	(5 to 10 ft	70,960	9,151,400	15,428,480	24,650,840
	(10 ft +	1,473,670	15,561,830	35,148,700	52,184,200
	Total	1,552,520	31,217,150	57,935,910	90,705,580
1,000 to 2,000 feet	(2½ to 5 ft	---	737,660	2,871,010	3,608,670
	(5 to 10 ft	5,070	673,090	9,499,040	10,177,200
	(10 ft +	1,780	363,600	498,300	863,680
	Total	6,850	1,774,350	12,868,350	14,649,550
2,000 to 3,000 feet	(2½ to 5 ft	---	281,540	810,180	1,091,720
	(5 to 10 ft	---	266,210	1,215,630	1,481,840
	(10 ft +	---	171,830	218,380	390,210
	Total	---	719,580	2,244,190	2,963,770
Total------------------------------		1,559,370	33,711,080	73,048,450	108,318,900
Total, both ranks------------------------------		3,621,970	40,202,230	77,729,650	121,553,850

Other states

In this report of progress on the U. S. Geological Survey's program to reappraise the coal reserves of the United States, it has not been possible to include new appraisals for all states. Nor has it been considered desirable to make arbitrary and undocumented changes in the older estimates. For states not previously discussed, therefore, the estimates prepared by Campbell in the years prior to 1928 have been included in tables 1 and 2 for the sake of completeness, but they are shown in lower case letters to indicate their origin.

In these older estimates of original reserves, the following minimum thicknesses were used for the different ranks of coal:

Rank	Minimum thickness
Bituminous coal and anthracite	14 inches
Subbituminous coal	2 feet
Lignite	3 feet

The estimates were based on an assumed specific gravity of 1.3, or a weight of 1,770 tons per acre-foot, for coal of all ranks, and all coal to a depth of 3,000 feet below the surface was included in a single category.

As the presently active program of reappraising the coal reserves of the U. S. continues, new detailed estimates for other states will become available, thus increasing the accuracy and completeness of knowledge of the national coal resources.

Alaska

Coal is known to occur in substantial quantities at numerous places in Alaska. Very little detailed mapping or exploration has been carried on in the coal-bearing areas, however, and only a generalized estimate of the total coal reserves in the Territory can be made at the present time. According to an estimate prepared in 1944 by Clyde Wahrhaftig of the Geological Survey, the total original coal reserves of Alaska were inferred to be 107,394,000,000 tons, (Buch, and others 1947, p. 235), of which 23,800,000,000 tons is bituminous coal; 82,594,000,000 tons, subbituminous coal and lignite; and 1,000,000,000 tons, anthracite.

The coal reserves of Alaska cannot be classified by thickness of bed or overburden because of the scarcity of detailed information. Access to transportation facilities is the chief factor affecting coal-mining development in Alaska, and the reserve figures presented in the tabulation shown on page 37 and are therefore classified by region and by accessibility to present railroads.

By January 1, 1953, the total recorded production of coal in Alaska totaled 7,138,000 tons, most of which came from the Matanuska Valley and Nenana fields on the Alaska Railroad. High costs of mining and shipping limit Alaskan coal at present to use within the Territory.

POSSIBLE ADDITIONAL RESERVES NOT INCLUDED IN ESTIMATES

In states for which modern, classified estimates have been prepared, large areas of coal-bearing rocks have been omitted from consideration for want of specific information about the thickness and continuity of the coal beds. In Wyoming, for example, 53.5 percent of the known area of coal-bearing rocks was omitted, and in Montana, 9.3 percent was omitted. When full and complete information is available about such areas the estimated coal reserves will be increased substantially.

Because most mining and prospecting in the United States is done along surface outcrops, very little information is available about the occurrence of coal at depth, or at a distance of more than a few miles from the outcrops; and no information is available about reserves in the centers of the large coal basins. Therefore, most of the estimated reserves, particularly in the states for which modern, classified estimates are available, are confined to a narrow zone a few miles wide parallel to the outcrops of the individual coal beds. This is well illustrated by the fact that 87 percent of the reserves classified in figure 5B is less than 1,000 feet below the surface. When exploration is pushed to greater distances from the outcrops, and to greater depths, reserves should be increased correspondingly.

Many known coal-bearing areas, particularly those remote from present means of transportation or centers of use, have been mapped or examined only in reconnaissance. Reserve estimates for such areas tend to be small because of the paucity of information, and because only the thicker and better beds are examined during the course of reconnaissance work. The extension of detailed mapping in such areas should, therefore, yield data that would permit an increase in reserve estimates.

In many other areas, information about the thickness and nature of rocks between coal beds is so scanty that it is impossible to establish correlations between coal beds in different parts of an area. Where correlations cannot be established, estimated reserves are restricted to areas near the known outcrops. Where correlations can be established, reserves can be inferred to exist at greater distances between the outcrops, and the total estimated reserves tend to be larger.

It is thus apparent that the newer estimates of reserves, based as they are on conservative assumptions, are minimum estimates, and will be increased in the future as additional information is acquired through geologic mapping and physical exploration.

NEED FOR ADDITIONAL WORK

The results of the current study of coal reserves in various states show clearly the need for additional mapping and exploration. Although the recent estimates are an improvement over previous ones, primarily because they are presented in carefully defined categories, they point to many obvious deficiencies in the state of knowledge about the distribution, extent, and correlation of coal beds as outlined in paragraphs above.

Estimated original coal reserves of Alaska
(In thousands of short tons)

Region	Accessible by present means of transportation	Within 40 miles of present means of transportation but not immediately available	Remote from present means of transportation	Total
		Bituminous coal		
Arctic Ocean drainage --	---	---	22,000,000	22,000,000
Yukon and Kuskokwim drainage basins[1] ------	---	(2)	---	---
Pacific Ocean drainage and Alaska Peninsula[3] ------------	450,000	1,350,000	---	1,800,000
Total -----------------	450,000	1,350,000	22,000,000	23,800,000
		Subbituminous coal and lignite		
Arctic Ocean drainage --	---	---	60,000,000	60,000,000
Yukon and Kuskokwim drainage basins[1] ------	---	400,000	---	400,000
Pacific Ocean drainage and Alaska Peninsula[3] -------------	2,400,000	19,600,000	186,000	22,186,000
Total -----------------	2,400,000	20,000,000	60,186,000	82,586,000
		Lignite		
Southeastern Alaska ----	8,000	---	---	8,000
		Anthracite		
Pacific Ocean drainage and Alaska Peninsula[3] ------------	---	1,000,000	---	1,000,000
Total, all ranks -----	2,858,000	22,350,000	82,186,000	107,394,000

[1] Excludes areas south of the Tanana River tributary to the Alaska Railroad and the Richardson Highway.
[2] Present, but quantity unknown.
[3] Includes areas excluded in Yukon and Kuskokwim drainage basins.

Full knowledge about the coal resources of the United States is thus dependent on a continuing, active program of detailed geologic mapping and exploratory drilling in the coal field areas, accompanied by periodic inventories of reserves.

The cooperation between Government and Industry in the accumulation, preservation, and analysis of coal reserve data, which has been so effective in the preparation of recent reserve appraisals, should be strengthened and improved at every opportunity.

UNITED STATES COAL COMMISSION COMMITTEE REPORT, 1922

The recoverable coal reserves of the United States as of January 1, 1922, were estimated to be 1,634,130 million tons, by a committee established by the United States Coal Commission. This committee, the Engineers' Advisory Valuation Committee, was requested to estimate the market value of coal mines and of the coal in the ground. The Coal Commission did not accept the estimate of the valuation committee for use in their reports although permission was given for separate publication by the committee (Am. Inst. Min. Met. Eng., 1924). The estimate of recoverable reserves prepared by the committee, now largely of historical value, was based on the estimate of original reserves prepared by Campbell and on estimates of several state surveys. These estimates were reduced to allow for future mining losses and to exclude "thin and unavailable coal." No specific information as to the criteria used in reducing the basic original reserve figures is contained in the committee report. It is interesting to note, however, that if a 50 percent recovery is assumed, the recoverable reserves of the United States as of January 1, 1919, based on the estimate of remaining reserves by Campbell, totaled 1,768 billion tons, whereas the recoverable reserves as of January 1, 1922, suggested by the valuation committee totaled 1,634 billion tons.

A few writers have implied that the valuation committee's estimate differed significantly from the Campbell estimate as they fail to emphasize the fact that the Campbell estimate was for original coal reserves in the ground, whereas the valuation committee's estimate was for recoverable reserves as of January 1, 1922. The two estimates are in quite close accord when they are adjusted to the same basis of comparison.

U. S. ARMY CORPS OF ENGINEERS, 1952

A survey of the United States to determine general areas suitable for the location of synthetic liquid fuel plants was completed in 1952 under the auspices of the Corps of Engineers, Department of the Army (1952). The estimated recoverable reserves of coal in the United States as of January 1, 1949, considered during the course of the survey totaled about 170 billion tons, of which a maximum of 126 billion tons was deemed to be suitable for immediate large scale use in the manufacture of synthetic liquid fuels. The Corps of Engineers estimate of 170 billion tons for recoverable reserves is about 18 percent of the Geological Survey estimate of almost 950 billion tons presented in tables 1 and 2 of this report. The difference between the two estimates is explained by the different purposes for which they were intended, and the different assumptions on which they are based. The major objective of the Corps of Engineers survey was to outline large blocks of coal that would be immediately available for large-scale mining to supply hypothetical synthetic liquid fuel plants. The maximum depth of coal considered in the Corps of Engineers estimate, for example, is 1,500 feet, whereas in the Geological Survey estimate the reserves of coal are computed in three categories; 0 to 1,000 feet; 1,000 to 2,000 feet; and 2,000 to 3,000 feet. The minimum thickness of coal considered for underground mining in the Corps of Engineers estimate is 24 inches for bituminous coal, and 48 inches for lignite; whereas, the Geological Survey estimate includes in its several categories of thickness, bituminous coal in beds as thin as 14 inches and lignite in beds as thin as 30 inches.

The Corps of Engineers figure is thus a conservative statement of coal that is known to be immediately available for use under present mining conditions. It is roughly comparable with the U. S. Geological Survey estimate for measured and indicated reserves in beds 28 inches or more thick, and less than 1,000 feet below the surface. (See fig. 6.)

The larger figure of the U. S. Geological Survey includes in separate categories reserves of both present economic interest and possible future usefulness, and thus provides a more comprehensive statement of information available about the total coal reserves of the United States.

PEAT RESERVES

Peat, the first stage in the metamorphism of plants to coal, is the partly carbonized remains of roots, trunks of trees, twigs, seeds, shrubs, grasses, and mosses that have been covered or saturated with water so that decomposition is arrested. It contains a large proportion of the carbon of the original vegetable matter, and the plant structures of which it is composed are generally visible without the aid of a microscope. In general, peat accumulates on poorly-drained land in regions of cool climate or high humidity, where evaporation is slow, and peat-forming plants may flourish.

Peat is an important fuel in Europe, but only small quantities have been produced as commercial fuel in the United States because of the abundance and superiority of coal. The United States contains large deposits of peat, however, and it is produced commercially for a number of purposes other than as fuel. Air-dried peat is a convenient source of concentrated organic matter, and it contains about 2 percent nitrogen. Its principal uses in the United States, therefore, are for soil improvement and as an ingredient in commercial fertilizers. According to Corgan and Chiriaco (1952), 194,416 short tons of peat were produced in this country in 1951. Of the total, 73 percent was used for soil improvement, 19 percent for mixed commercial fertilizers, and 8 percent for other purposes, which included litter for barns and poultry yards, use in nurseries and greenhouses, and packing material for plants, fruits, vegetables, eggs, and other fragile articles.

The United States contained original known peat reserves totaling 13,827,000,000 short tons, calculated on an air-dried basis, as estimated in a detailed report on peat by Soper and Osbon (1922, p. 92-93). Of this total only about 2,000,000 tons was mined between 1922 and 1951. The peat reserves occur primarily in local deposits distributed throughout two general regions. The northern peat region, which contains approximately 80 percent of the total reserves, includes Minnesota, Wisconsin, Michigan, eastern South Dakota, the northern parts of Iowa, Illinois, Indiana, Ohio, and Pennsylvania, and New York, New Jersey, and the New England States. The Atlantic coastal region, which contains approximately 19 percent of the total reserves, includes the southern part of Delaware, the eastern parts of Maryland, Virginia, North Carolina, South Carolina, and Georgia, and all of Florida. Small deposits of peat also occur in a narrow belt of land adjoining the Gulf Coast; in the valleys of the Sacramento and San Joaquin Rivers and in Siskiyou, Los Angeles, Orange, and San Bernardino Counties, California; and in the basins of lakes and rivers in Oregon and Washington.

The accompanying table by Soper and Osbon shows the known original reserves of peat in the United States, calculated on an air-dried basis, by regions and states. In addition to this general table, the report by Soper and Osbon includes tables of reserves classified by counties for the states having important peat reserves, as well as detailed descriptions of individual peat deposits.

Known original reserves of peat in the United States, estimated on an air-dried basis, by regions and states

(In thousands of short tons)

Region and state	Reserves	Region and state	Reserves
Northern region:		Atlantic coastal region:	
Minnesota	6,835,000	Virginia and	
Wisconsin	2,500,000	No. Carolina	700,000
Michigan	1,000,000	Florida	2,000,000
Iowa	22,000	Other states[1]	2,000
Illinois	10,000	Total	2,702,000
Indiana	13,000		
Ohio	50,000	Other regions:	
Pennsylvania	1,000	Gulf Coast[2]	2,000
New York	480,000	California	72,000
New Jersey	15,000	Oregon and	
Maine	100,000	Washington	1,000
New Hampshire	1,000	Total	75,000
Vermont	8,000		
Massachusetts	12,000		
Connecticut	2,000	Total,	
Rhode Island	1,000	all	
Total	11,050,000	regions	13,827,000

[1]Includes Delaware, Maryland, South Carolina, and Georgia.
[2]Exclusive of Florida.

WORLD COAL RESERVES

Estimates of the remaining coal reserves of the world by continents and principal coal-producing countries are shown in table 4. The figures included in the table were taken from Statistical Year-books Nos. 4 and 5 of the World Power Conference (F. Brown, 1948 and 1950) except for estimates of the United States, Alaska, Colombia, and Brazil, which were prepared by the U.S. Geological Survey.

Most of the figures in the table are for remaining reserves as of different dates in the period between 1913 and 1953; others are for original reserves. This minor discrepancy does not affect the relative standing of any continent or country to a significant degree. All figures in the table are in metric tons, the standard unit for measuring coal in most countries. One metric ton is equivalent to 2,205 pounds, or 1.1 short tons.

With remaining reserves of 1,723,416 million metric tons of coal, as currently estimated, the United States appears to have 34.4 percent of the total remaining world reserves of 5,008,566 million tons. By comparison, the entire North American continent appears to have 38.2 percent of the total, and Asia, including European Russia, appears to have 46.0 percent.

Table 4 gives only a very generalized comparison of the reserves in the principal coal-producing countries of the world. Because of the different methods of calculating coal reserves, the different standards of thickness and depth adopted, and the different dates for which estimates were made for individual countries, the figures shown in the table are comparable only to the extent that they show the general order of magnitude of the reserves in each country. In particular, the revisions in recent years of methods of calculating coal reserves by some countries, and continued adherence to older methods by others, mean that certain figures in the table are conservative and represent only immediately accessible proved coal in thick beds, whereas other figures are much more comprehensive and include total reserves in thick and thin beds without regard to quality, minability, or accessibility of the coal.

Canada provides an example of the effect of changes in methods of calculating coal reserves. Figures published in 1913 gave Canada remaining reserves of 1,216,770 million metric tons as of that year (Twelfth International Geological Congress, 1913). In 1946 the remaining reserves in Canada were re-estimated at less than 10 percent of that amount, or only 89,645 million metric tons (MacKay, 1947). The earlier estimate was made on general assumptions of continuity of coal beds which were based on few observations, and included statistical allowance for all possible coal to a minimum thickness of 1 foot and to a maximum depth of 4,000 feet. The more recent estimate includes only known developed or explored coal beds, which, for reasons of thickness, quality, and extraction costs, were considered economically minable in 1946. Reserves for most other countries shown in table 4 relate to all coal in the ground, irrespective of quality, minability, or accessibility, and many of these figures will no doubt be reduced in the future as more detailed information becomes available and more restricted methods of calculating reserves are adopted.

RELATION OF COAL IN THE UNITED STATES TO OTHER FORMS OF ENERGY

The industrial machine of the United States annually consumes prodigious quantities of energy. The mineral fuels and water power produced in 1952, for example, contained heat energy equivalent to 8 horsepower per person per day, for the entire year. Furthermore, the production and use of energy is increasing annually at a very rapid rate. As shown in figure 8, the over-all use of energy in the United States has quadrupled in the last 50 years, and nearly doubled in the last 25 years. And the curve is still headed sharply upward. This upward surge in the use of energy is impelled partly by our rapidly growing population, which has doubled in the last 50 years, and partly by our increased reliance on machines and manufactured products. Considering the potential future increase both in population and in use of energy, no one can forecast with assurance the time when the ascending curve will level off. With consumption of energy in progress on such an enormous and ever increasing scale, it is interesting and instructive to review the position of coal in the total energy use pattern.

During 1952, a year second only to 1951 in the use of fuel in the United States, coal supplied only 34 percent of the total energy produced from all sources, while petroleum and natural gas together supplied a total of 61.9 percent. The remaining 4.1 percent was supplied by water power (U. S. Bureau of Mines, 1953). As shown in figure 9, the percentage of total energy supplied by coal has decreased steadily from about 90 percent in 1900 to the present record low of 34 percent. The percentage decrease in use of coal through the years has been accompanied by a corresponding percentage increase in the use of petroleum and natural gas, which have had greater consumer appeal because of their convenience, and which have filled a number of new uses not competitive with coal. Included in the percentage figures for petroleum and natural gas, for example, are gasoline and diesel oils used in automobiles and trucks, heavy oils used in road construction and maintenance, natural gas consumed in the manufacture of carbon black, and lubricants.

The trend toward increased use of petroleum and natural gas is not expected to continue indefinitely. As the Nation's energy requirements increase, the reserves of petroleum and natural gas cannot be expected to increase proportionately and coal, or some other equally abundant and economical source of energy, must carry an increasing part of the load.

Table 4.—Estimated remaining coal reserves of the world by regions and principal coal-producing countries[1]
(In millions of metric tons)

Region and country	Anthracite; bituminous and subbituminous coal	Lignite and brown coal	Total	Percent of regional total	Percent of world total
Asia:					
U. S. S. R.[2]	998,000	202,000	1,200,000	52.2	24.0
China	1,011,000	600	1,011,600	44.0	20.2
India	62,143	2,833	64,976	2.8	1.3
Japan	16,218	473	16,691	.7	.3
Others[3]	7,214	349	7,563	.3	.2
Total	2,094,575	206,255	2,300,830	100.0	46.0
North America:					
United States[4]	1,303,066	420,350	1,723,416	90.2	34.4
Alaska[5]	[6] 22,498	[6] 74,915	97,413	5.1	2.0
Canada[7]	65,053	24,592	89,645	4.7	1.8
Total	1,390,617	519,857	1,910,474	100.0	38.2
Europe:					
Germany	279,516	56,758	336,274	51.0	6.7
United Kingdom	172,200	(11)	172,200	26.1	3.4
Poland	80,000	18	80,018	12.1	1.6
Czechoslovakia	6,450	12,500	18,950	2.9	.4
France	11,224	125	11,349	1.5	.2
Portugal	[8] 6,036	[8] 4,200	10,236	1.7	.2
Others[9]	16,619	14,289	30,908	4.7	.6
Total	572,045	87,890	659,935	100.0	13.1
Africa:					
Union of South Africa	68,014	0	68,014	97.2	1.4
Others[10]	1,720	210	1,930	2.8	(11)
Total	69,734	210	69,944	100.0	1.4
Australasia:					
Australia	[6] 13,900	[6] 39,200	53,100	99.0	1.1
Others[12]	57	489	546	1.0	(11)
Total	13,957	39,689	53,646	100.0	1.1
South and Central America:					
Colombia[13]	10,000	0	10,000	72.8	.2
Chile	2,116	?	2,116	15.4	(11)
Others[14]	1,617	4	1,621	11.8	(11)
Total	13,733	4	13,737	100.0	.2
World total	4,154,661	853,905	5,008,566	---	100.0

[1] Brown, Frederick, Statistical year-book of the World Power Conference, No. 4, Central office, World Power Conference, London, 1948; No. 5, Central office, World Power Conference, London, 1950; with the exception of the United States, Alaska, Colombia, and Brazil.
[2] Total for European U.S.S.R. included with Asiatic U.S.S.R.
[3] Includes Korea, Federation of Malaya, Manchuria, and Turkey.
[4] Estimate of remaining reserves as shown in tables 1 and 2, converted to metric tons.
[5] Estimate of original reserves as shown on page 37, converted to remaining reserves in metric tons as of January 1, 1953.
[6] Subbituminous coal tabulated with lignite and brown coal.
[7] Includes only reserves of coal considered minable in 1946 estimate of the Canadian Geological Survey.
[8] Figures may not include proved reserves.
[9] Includes Austria, Belgium, Bulgaria, Denmark, Eire, Greece, Hungary, Italy, The Netherlands, Norway, Roumania, Sweden, and Yugoslavia.
[10] Includes Algeria, Belgian Congo, French Morocco, Madagascar, Nigeria, and Tanganyika.
[11] Negligible.
[12] Includes New Zealand and New Caledonia.
[13] Singewald, Q. D., Mineral resources of Colombia (other than petroleum): U. S. Geol. Survey Bull. 964-B, p. 94, 1950.
[14] Includes Peru, Honduras, and Brazil. Estimate of reserves in Brazil by MacKenzie Gordon, Geologist, U. S. Geological Survey, personal communication.

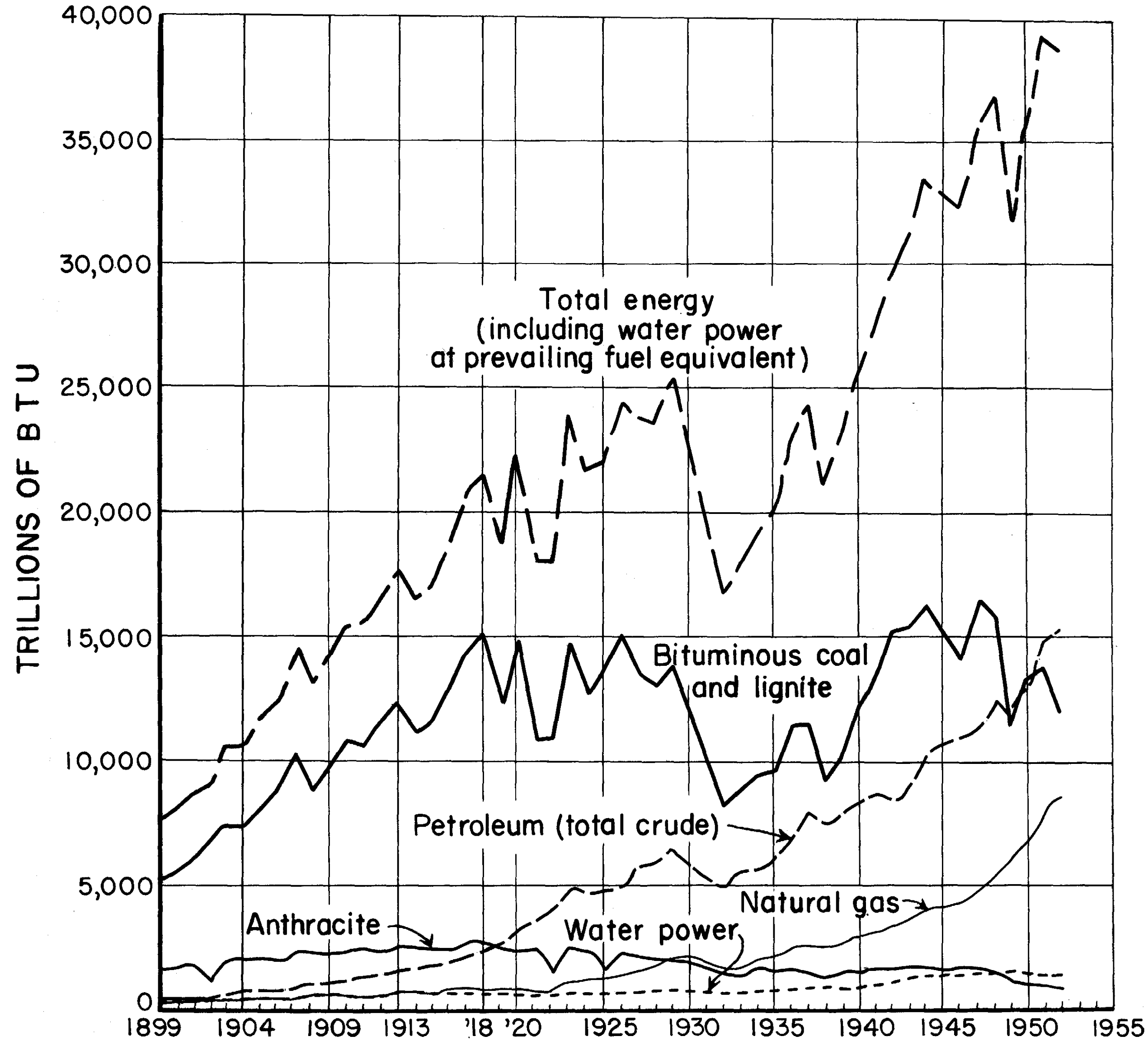


Figure 8. —Annual supply of energy from mineral fuels and water power in the United States, 1899-1952.

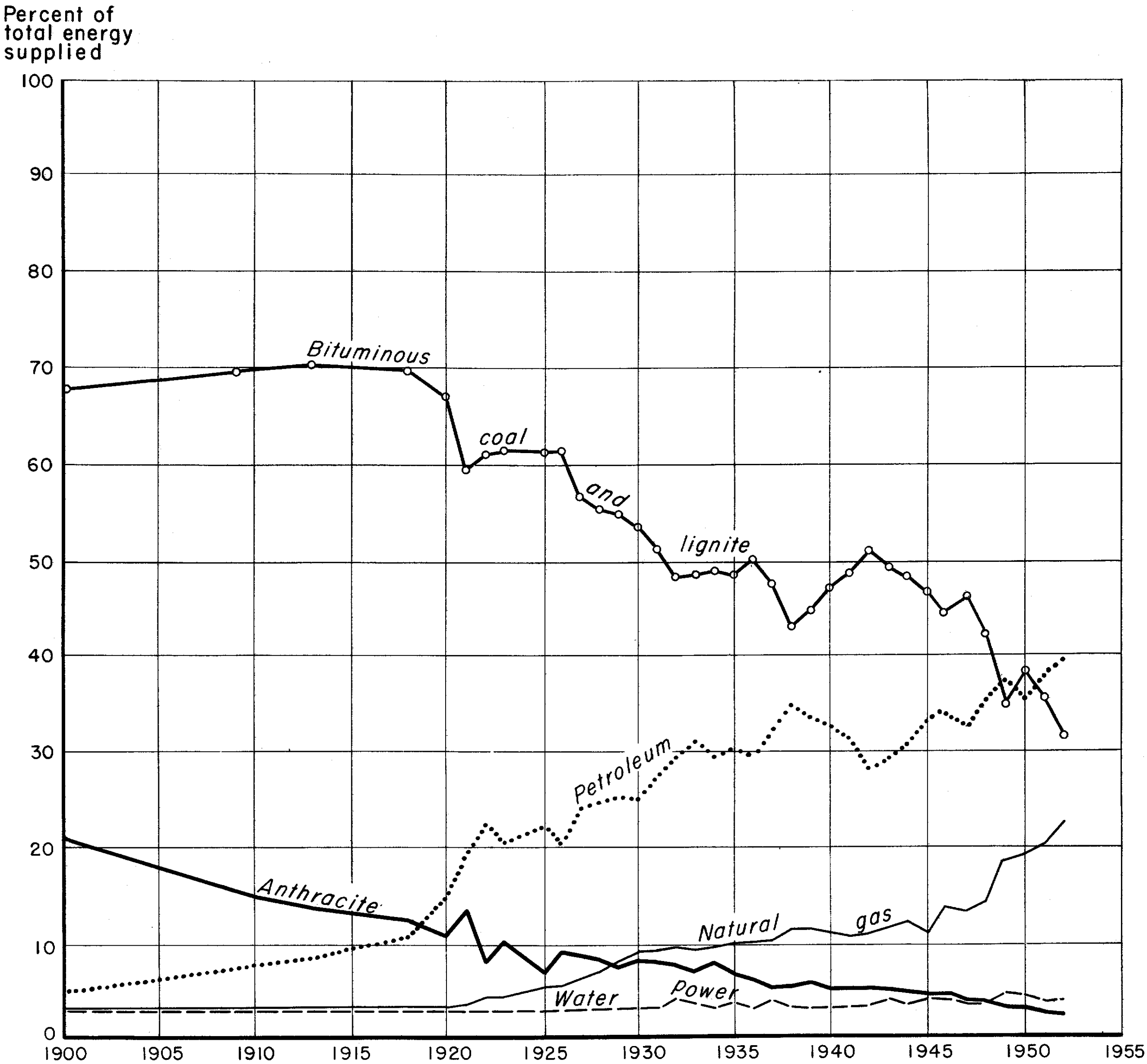


Figure 9. —Percentage of total energy supplied by mineral fuels and water power, 1900-1952.

The decrease in the percentage contribution of coal to the total consumption of mineral fuels in the United States has not been accompanied by a comparable decrease in the actual production of coal. On the contrary, an all-time record was established in 1947 when 688 million tons of coal was mined. (See figure 8.) The trend of high production of coal during World War II and the years immediately following is similar, however, to the trend that took place during and after World War I, when the previous record was set in 1918 with a production of 678 million tons. The President's Materials Policy Commission (1952, p. 24, 25) has stated that coal may be expected gradually to take over a larger share of the energy load after 1975, at which time an annual coal production of 800,000,000 tons would not be an unreasonable expectation.

Estimates of coal reserves cannot readily be compared with estimates of petroleum and natural gas reserves because differences in the mode of occurrence of these fuels necessitate different methods of calculating reserves. Coal occurs in stratified deposits in sedimentary rocks, and the individual beds maintain a fairly uniform thickness over relatively large areas. The total quantity of coal in the ground can thus be estimated with reasonable accuracy from geologic observations made at the outcrops of coal beds, in mines and prospect pits, and from evidence supplied by drilling operations. The total reserves of bituminous sandstone and oil shale can be estimated with similar accuracy because these substances also occur in stratified deposits, the thickness and lateral extent of which may be determined at many places by geologic and prospecting observations at the surface.

Petroleum and natural gas, on the other hand, are highly mobile substances. They move underground through minute openings in the rocks and accumulate only where traps, or barriers, prevent further migration. As a great variety of structural and stratigraphic relations create such traps, the total number existing in the widespread thick sequences of sedimentary rocks cannot be predicted accurately, nor can the ultimate amount of recoverable oil or gas contained in these traps be ascertained. As a result, only proved reserves, i. e., reserves in developed areas, can be estimated with any certainty for petroleum and natural gas. Consequently, the estimates tend to be conservative, and they must be changed frequently to accord with new discoveries, and new methods of recovery.

Despite the recognized difficulty of comparing reserve estimates for the several mineral fuels, it is possible to show the approximate relative magnitude of reserves by reducing all estimates to a common Btu basis, and by making certain adjustments to allow for differences in the methods of making calculations. Estimates of the reserves of various fuels are thus presented in table 5, which shows in quadrillions of Btu the estimated recoverable reserves of coal, petroleum, natural gas, bitumen, and oil from oil shale in the United States as of January 1, 1953. The table gives the reserves of these individual fuels according to two major points of view: Column 1, termed, "measured and indicated," includes only reserves believed to be recoverable by current production methods, and at costs equal to, or only slightly in excess of present costs. Column 2, termed, "total—all classes," includes total measured, indicated, and inferred reserves, or the total potential reserves available for present and future use without regard to cost of recovery. The figures in column 1 are thus markedly more conservative than the figures in column 2.

The figure of 5,117 quadrillion Btu used for coal in column 1 of table 5 is based on 25 percent of the total recoverable reserves of each rank as shown in table 1. This fraction is intended to represent measured and indicated reserves in beds 28 inches or more thick, and less than 2,000 feet below the surface. It was obtained from figure 6, which is based on a consideration of the distribution of reserves in ten states—Illinois, Indiana, Michigan, Montana, New Mexico, North Carolina, North Dakota, South Dakota, Virginia, and Wyoming—for which the reserves of coal have been classified according to the thickness of bed and overburden. As these ten states contain about 40 percent of the total reserves in the United States, and include coal deposits of diverse ages, ranks, and types, the average observed distribution of reserves in the selected restricted category in these states is believed to be reasonably typical of the United States as a whole.

The figures used for petroleum and natural gas in column 1 of table 5, are based on proved reserves as currently estimated by the American Petroleum Institute and the American Gas Association (Oil and Gas Journal, 1953). The figures for other fuels are based on similar conservative assumptions as explained in the footnotes to the table.

The figure of 20,469 quadrillion Btu used for coal in column 2 of table 5 is based on the total recoverable reserves shown in table 1. It includes measured, indicated, and inferred reserves in beds 14 inches or more thick, and beds to depths of 3,000 feet below the surface.

Several attempts have been made to prepare estimates for total (measured, indicated, and inferred) reserves of petroleum and natural gas. These estimates have been based on the assumption that the total volume of marine sedimentary rocks in the United States within range of exploration by drilling will yield petroleum and natural gas in amounts proportional to the yields obtained from the volume of rock thoroughly explored thus far. Although no special accuracy is claimed for the figures resulting from this method of analysis, the figures provide some basis for comparison. Weeks (1948, p. 1094) estimated the potentially recoverable reserves of petroleum in the United States, excluding the Continental Shelf, to be 110 billion barrels; and Pratt (Fanning, 1950, p. 151) using

Table 5.—Total estimated recoverable mineral-fuel reserves of the United States, Jan. 1, 1953.[1]

Type of mineral fuel	Recoverable reserves January 1, 1953 (In quadrillions of Btu)		Percent of total fuel reserves	Average annual production 1940-49 (In quadrillions of Btu)
	Measured and indicated (column 1)	Total all classes (column 2)	(column 3)	(column 4)
Coal	[2] 5,117	[3] 20,469	84	16
Petroleum	[4] 198	[5] 413?	2	11
Natural gas	[6] 200	[7] 487	2	5
Bitumen from bituminous sandstone	[8] 4	[8] 8	(9)	(9)
Oil from oil shale	[10] 150	[11] 3,000	12	(9)
Total	5,669	24,377	100	32

[1] Reserves and production figures converted to Btu according to the following heat values: anthracite, 12,700 Btu per pound; bituminous coal, 13,000 Btu per pound; subbituminous coal, 9,500 Btu per pound; lignite, 6,700 Btu per pound; petroleum, bitumen from bituminous sandstone, and oil from oil shale, 6,000,000 Btu per barrel; and natural gas, 1,000 Btu per cubic foot.

[2] Twenty-five percent of reserves as shown in table 1, determined by consideration of ten states for which reserves have been classified by thickness of bed and overburden. The estimate is intended to show reserves of measured and indicated coal in beds at least 28 inches thick and under no more than 2,000 feet of overburden.

[3] From tables 1 and 2.

[4] Proved reserves. Estimate by the American Petroleum Institute, as reported in the Oil and Gas Journal, v. 51, no. 45, p. 78-79, March 16, 1953. Figure includes Btu equivalent of 5 billion barrels of natural-gas liquids.

[5] Recoverable reserves of petroleum remaining after subtracting petroleum production to January 1, 1953, from original petroleum reserves of 115 billion barrels, of which 100 billion barrels represent reserves of the United States exclusive of Continental Shelf, as estimated by W. E. Pratt in *Our oil resources*, second edition, edited by L. M. Fanning, McGraw-Hill Book Company, New York, 1950; and 15 billion barrels represent reserves in the Continental Shelf, as published in a statement prepared by the U. S. Geological Survey at the request of the Committee on Interior and Insular Affairs, U. S. Senate, on *Fuel reserves of the United States:* Committee Print, 82 Cong., 1st sess., p. 32, 1951.

[6] Proved reserves. Estimate by the American Gas Association, as reported in the Oil and Gas Journal, v. 51, no. 45, p. 78-79, March 16, 1953.

[7] Recoverable reserves of natural gas as of Jan. 1, 1953, obtained by subtracting production of 23 trillion cubic feet in 1950, '51, and '52 from estimate of 510 trillion cubic feet as of Jan. 1, 1950, as presented by L. F. Terry in *The future supply of natural gas:* Gas Age, v. 106, no. 9, p. 59 and 98, October 26, 1950. Figure includes Continental Shelf.

[8] Fifty percent of estimated reserves of bitumen from bituminous sandstone in deposits near Vernal and Sunnyside, Utah; Casmalia, Santa Cruz, Edna, Sisquoc, Sulphur Mountain, and San Ardo, Calif.; and Uvalde, Tex. Estimate incomplete.

[9] Negligible.

[10] Sixty percent of reserves of oil in oil shale containing 30 gallons of oil per ton, as estimated by D. C. Duncan, U. S. Geological Survey. Personal communication.

[11] Fifty percent of reserves of oil in oil shale deposits having an average content of 15 gallons of oil per ton, as estimated by D. C. Duncan, U. S. Geological Survey. Personal communication.

essentially the same data, estimated the amount to be 100 billion barrels.

The U. S. Geological Survey (1951) estimated the potential petroleum reserves of the Continental Shelf along Texas, Louisiana, and California to total about 15 billion barrels, based on consideration of the quantity of petroleum already discovered in nearby coastal belts of comparable size.

On the basis of these three figures, the total potentially recoverable reserves of petroleum in the United States, including the nearer, more accessible parts of the Continental Shelf may be assumed for the purpose of this discussion to be about 115 billion barrels. This assumed figure is, of course, intended to represent the total, ultimately recoverable original reserves before production began; that is to say, past production, present proved reserves, and assumed future discoveries. To make it comparable with figures for total reserves of coal and other fuels as of January 1, 1953, it must be reduced to allow for production to January 1, 1953. The figure for petroleum reserves used in column 2 of table 5 was thus obtained by subtracting the total recorded production of petroleum to January 1, 1953, from the assumed figure of 115 billion barrels.

Using the same general methods as those used for arriving at the total oil reserves, Terry (1950) estimated the potential recoverable natural gas reserves of the United States, including the Continental Shelf, to total 510 trillion cubic feet, as of January 1, 1950. After subtracting production of 23 trillion cubic feet in 1950, 1951, and 1952, the estimated potential recoverable natural gas reserves of the United States, as of January 1, 1953, total 487 trillion cubic feet. Terry's estimate for natural gas reserves was used as the source of the figure shown in column 2 of table 5.

Considering the ever-present possibility of future additions to petroleum and natural gas reserves beyond those allowed for by a statistical analysis of currently available data, it is likely that these figures are too small rather than too large. However, they are the best figures available for comparison with estimates of total coal reserves.

The dominance of coal in the total fuel picture is clearly shown in both columns 1 and 2 of table 5. Reducing the figures in column 2 to percent as given in column 3, coal is seen to represent 84 percent of the total reserves of fuel in the United States, whereas, petroleum and natural gas together represent only 4 percent. In view of the relatively large reserves of coal, and the relatively small reserves of petroleum and natural gas, it is instructive to consider the rates at which these fuels are currently being produced and used. In column 4 of table 5 it will be noted that on a Btu basis the combined average annual production of petroleum and natural gas during the period 1940-49 equals the average annual production of coal. This average rate has been exceeded every year since 1945, and by 1952, petroleum and natural gas together supplied 61.9 percent of the total energy obtained from all sources. These rates are far out of proportion to the known or inferred total reserves of petroleum and natural gas, and point to the day when we shall be forced to place greater reliance on coal, or else develop and vastly expand other sources of energy.

LIFE EXPECTANCY OF UNITED STATES FUEL RESERVES

Because of the many imponderable factors to be taken into consideration, it is impossible to estimate the life expectancy of fuel reserves in the United States with any degree of accuracy. Even so basic a factor as the magnitude of the reserves is at best but an approximation, based on data currently available, and is therefore subject to change in the future. Other factors, such as the observed increase in population and use of energy, increase in efficiency in production and use of fuel, imports of fuel oil, and the possibility of developing new sources of energy, are highly variable and so closely related as to defy precise analysis. A few of these factors are discussed briefly in the following paragraphs as a means of emphasizing the uncertainty attending statements about the life expectancy of fuel reserves.

The estimates of reserves presented in this report and used as a basis for this discussion of life expectancy are based on information currently available. The information is admittedly incomplete, and with the experience of the past as a guide it seems safe to predict that the total reserves of all fuels, particularly reserves of petroleum and natural gas, ultimately will be found to be larger than the present figures suggest. Because of the conservative assumptions now being employed, the newer coal reserve estimates tend to be smaller than older estimates, and the total figure for the United States, based as it is on both old and new figures, is subject to further decrease in the immediate future. Once a minimum conservative figure is established for United States coal reserves, however, it is likely that subsequent exploration and development will increase the estimate, and that the total coal reserves ultimately will be found to be larger than the present figure. The life expectancy of all fuels is therefore subject to increase as additional knowledge is acquired about the magnitude of reserves.

In considering the life expectancy of fuel reserves it is necessary to make generous allowance for the probable future increase in use of fuel. The only yardstick for this purpose is the experience of the past 50 years, which shows an unprecedented fourfold increase, due in part to an increase in population, and in part to an increase in the per-capita use of energy. It is difficult to project such a steeply rising trend far enough into the future to be meaningful.

In the production of petroleum, recoverability has increased steadily throughout the years, and this is one of the reasons why proved reserves of petroleum tend to increase annually. Similarly, many methods have been devised to improve recoverability in coal mining. In this report the recoverable reserves of coal are assumed to be only 50 percent of the total reserves in the ground, which factor accords with the past average experience in a number of mining districts. The recoverability from a number of individual mines is much higher than 50 percent, however, and it is believed that the over-all recoverability in coal mining could be increased considerably, perhaps to 65 percent. Also, many thin coal beds, not now considered to be recoverable, or areas now considered to be mined out, may ultimately be included as recoverable reserves if underground gasification techniques, now in the experimental stage, can be improved (Fies, 1952). Any increase in the recoverability of fuels can be expressed directly as an increase in reserves.

Improvement in the use of fuels is illustrated by the marked economies introduced in the production of electricity at electric utility plants in the United States. In 1920, for example, an average of 3 pounds of coal was required to produce 1 kilowatt-hour of electricity, whereas, by 1951, only 1.14 pounds was required (U. S. Bureau of Mines, 1952). Possible future improvement in the use of fuels would permit a comparable increase in estimates of life expectancy of reserves.

The form in which the energy in coal is used is perhaps the largest indeterminable factor that enters into any consideration of the life expectancy of coal reserves. If the future uses of coal are considered for a long period, it is apparent that for many years to come, the uses will be the same as at present. Wrather and others (1950), however, have pointed out that the United States is committing itself to a liquid- and gaseous-fuel economy, and ultimately coal may become an important material for synthesis of these fuels in addition to filling the requirements for solid fuel. If such conversion of coal becomes general, the need for coal will be enormous for, on the basis of present technology, about 50 percent of the potential energy in coal is lost in the conversion to liquid fuel (Ayres and Scarlott, 1952, p. 113).

The large reserves of petroleum in the Near East, Venezuela, Mexico, and elsewhere are needed only in small quantities at the points of origin. Some of this petroleum is finding, and probably will continue to find, a market in the United States, which is by far the largest consumer of petroleum products in the world. In 1952 such imports of crude and residual oil and distillate represented a record of 5.2 percent of our total fuel needs (U. S. Bureau of Mines, 1953). Such foreign imports may greatly lengthen the life expectancy of domestic fuels.

As reserves of coal, petroleum, natural gas, and other fossil fuels approach exhaustion, we shall be forced to place increased reliance on other energy sources like atomic energy, solar energy, earth heat, and tides. Experiments and studies in the use of atomic energy to produce electricity are in progress on several fronts, and much thought has been devoted to the possibility of harnessing solar energy. Ayres and Scarlott (1952, p. 279-283) believe that solar energy deserves greater attention than it has yet received because it is the only constant energy source available for large scale development. The life expectancy of coal, petroleum, natural gas, and other fossil fuels will be lengthened to the extent that through progress in research these other energy sources can be utilized.

Appraisal of the life expectancy of any individual fuel is further complicated by the fact that most fuels can be used interchangeably, and at most installations the choice of fuel is determined largely by cost. The preferred position of petroleum and natural gas in the fuel economy, which is due to the present abundance, comparative economy, and convenience of these fuels will, therefore, continue as long as new petroleum and natural gas fields are discovered in the United States, and as long as imported petroleum is available in domestic markets. On the other hand, as petroleum and natural gas ultimately become less abundant, and hence more expensive than coal, many users of these fuels will convert to coal. Thus, long before petroleum and natural gas reserves in the United States are exhausted, increasing reliance will need to be placed on other energy sources, a trend in which coal probably will contribute substantially. This period of transition may be greatly lengthened by utilization of imported supplies of petroleum, and it will be obscured by fluctuations in the economic cycle and by irregularities in the rate of discovery of new petroleum and natural gas fields. Because the life expectancy of petroleum and natural gas reserves will be greatly extended as the relative use of coal and other energy sources is increased, and because of the possibility of future additions to reserves of petroleum, natural gas, and coal, an estimate of the life expectancy of any of these fuels is subject to serious question.

Although it is thus impossible to predict the life expectancy of coal and other mineral fuels, the ratios between reserves and recent annual production provide figures that are somewhat more meaningful for comparative purposes than the reserve figures alone. The presently estimated total recoverable reserves of coal in the United States, for example, are 1,279 times the average annual production during the period 1940-1949; a figure that is many times larger than the ratios obtained from presently estimated total recoverable reserves of petroleum and natural gas.

Similarly, measured and indicated coal reserves in beds 28 inches or more thick and less than 2,000 feet below the surface are 320 times the average annual production during the period, 1940 to 1949; whereas the proved reserves of petroleum are only 18 times the average annual production, and the proved reserves of natural gas are only 40 times the average annual production.

From consideration of the possible trends in the use of these fuels it is apparent that their probable life expectancy is quite different from the simple ratios of present production to reserves. Petroleum and natural gas certainly have a much longer life expectancy than the ratios indicate, and coal reserves, conversely, may have a shorter life expectancy.

In the long history of human affairs, coal, petroleum, and natural gas have been used in large quantities only in the last 50 years. However large the reserves of these fuels may seem at present, the quantities are quite meager when compared with the life expectancy and the predictable future needs of the human race. In analyzing the life expectancy of the United States fuel reserves, Ayres and Scarlott (1950, p. 162) conclude that the mineral fuels alone can supply our future needs for a short period of 75 to 250 years. In analyzing the life expectancy of world fuels reserves, Hubbert (1951) sees the present growth of population and use of energy from the mineral fuels as being unprecedented in the history of human affairs, and impossible of continuation beyond a few hundred years. Ultimately, he believes, population growth must level off, and other sources of energy must be made available if we are to continue the comfortable standard of living now enjoyed through use of the mineral fuels.

The predictions that the mineral fuels have a life expectancy of only a few hundred years are not intended to be precise, or discouraging in their outlook for the future. They are intended merely to show the approximate order of magnitude of the time during which an advanced technology must develop and harness new sources of energy. During the period of such development we have the comforting assurance that our substantial reserves of coal will meet all possible fuel needs.

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