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FUELS

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THE INDUSTRIAL COLLEGE OF THE ARMED FORCES

WASHINGTON, D. C.

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FUELS

19 January 1948

DR. ASHTON: Good morning, gentlemen. By this time in the course, you have come to realize, no doubt, that energy resources are among the most potential factors that any nation has in economic mobilization or economic warfare. Among these energy resources, of course fuels are probably the most significant. We are very fortunate this morning in having with us a man who has spent his entire life in the analysis and development of fuels.

You have all seen Dr. Fieldner's biography. I will not go into any details but will simply mention, for your remembrance, the fact that he is a man of wide experience as an engineer, an educator, and an administrator.

It is with a great deal of pleasure, therefore, that we introduce to you this morning and welcome again to the College Dr. Arno C. Fieldner, Chief of the Fuels and Explosives Division of the Bureau of Mines.

DR. FIELDNER: Mr. Chairman, Gentlemen: The subject of fuels is an extremely interesting one and one that is very important. The general public realizes this fact in the current shortage of fuels. A few years ago when some of us expressed concern about future supplies of some of our mineral fuels, especially the high-value liquid fuels such as gasoline, we were greeted with considerable skepticism by those who thought we would always have enough oil and gasoline for all possible needs. As a matter of fact, we thought we would have enough for our lifetime and perhaps for the next generation. We assumed that the tremendous demand of the late war would fall off after the war was over. We entered the war with a capacity for producing petroleum of about five million barrels a day. We were producing only four million barrels, but it was not difficult to expand our production to meet the needs. After the war it was thought that the demand would drop back to about four and a half million barrels a day. But the public thought otherwise. After the war, there were great increases in the number of trucks, buses, farm tractors, and airplanes, and those increases added up to a demand for gasoline that exceeded all expectations. There also was an unprecedented increase in demand for house-heating oil. But the means for expanding the oil industry were not available; for example, the large quantities of steel required for drilling more wells, for building more refineries, and for transportation by tankers, pipe lines, and transports. As a result, the demand for oil became greater than the quantity that could be supplied. It will take time for production to catch up with demand.

My subject today does not deal so much with our immediate fuel needs as it does with our total fuel reserves and the reserves of the United States in comparison with those of other countries of the world. Included are coal, lignite, oil shale, petroleum, and natural gas. These comprise our mineral fuels.

Conversion of Solid to Liquid or Gaseous Fuels

Each of these fuels has its preferred use, but there are chemical methods for transforming one form of fuel into another. If we were short of gas, for instance, we could make gas from coal and from oil. As a matter of fact, gases are so made in industry and have been for years by the carbonization of coal and the gasification of coke by the "water gas process". Water gas is enriched with oil (a process of carburetion) to bring the gas up to the desired heating value. We also can make solid fuel briquets from oil by certain cracking processes which produce a coke or carbon residuum. Petroleum coke can be used for fuel the same as coal coke. That has been done for many years in refinery towns like Whiting, Indiana. Such solid fuel from petroleum is a byproduct and ordinarily it is not economically desirable to make solid fuels from petroleum. On the other hand, it is practical and desirable to make liquid and gaseous fuels from coal, and they will be so made in the relatively near future to supplement declining supplies of petroleum.

Description of the Various Ranks of Coal

I will show you a chart illustrating the relative reserves of the different kinds of fuel. Before I do that, I shall describe the different kinds of coal because in this chart our reserves of coal are given under different varieties. These varieties are graded according to the rank of each kind of coal in the geological scale of development.

Brown Coal

Coal has its origin in buried and metamorphosed vegetable matter accumulated in past geological ages. Preliminary to the development of coal is the formation of a peat swamp. When peat is buried under sediments to a relatively shallow depth without being subjected to great geological pressure, it is transformed to brown coal. That is the first stage in coal formation. It is an unconsolidated material. Brown coal frequently is found in beds 30, 40 or 50 feet thick, buried under earth 30 to 60 or 80 feet in thickness. Such shallow beds are mined by open-cut methods. After the earth has been removed, the brown coal is scooped up by scraper conveyers. That is done on a large scale in central Germany. Brown coal is the lowest rank of coal. It is about 50 percent moisture as mined and, therefore, has a low heating value, less than half that of our good bituminous coal. Brown coal is mined by

underground methods when the overlying cover is too thick for economical strip mining.

Lignite

If a peat bog is buried deeper, if rocks form above it, and if it is subjected to pressure, then it is consolidated into a solid mass similar to bituminous coal. Such consolidated brown coal called lignite is the second rank of coal formation. Lignite is found in many parts of the world and occurs extensively in the United States and Canada. It is characterized by having about 30 to 40 percent moisture as mined, although it appears dry. Its heating value is about half that of Pennsylvania or West Virginia bituminous coal, that is, from 6,000 to 7,500 B.t.u.'s per pound. It does not store well nor can it be transported over long distances. The moisture evaporates when it is exposed to the weather, causing the lignite to break down and slack into small pieces. It must be stored in tight silos or other conditions which will prevent or retard the evaporation of the moisture.

Subbituminous Coal

The next stage of coal formation is called subbituminous coal. Subbituminous coal is between the lignitic and the bituminous ranks of coal. Like lignite, it contains considerable moisture but not so much as lignite. The usual range of moisture content is 18 to 28 percent moisture as mined. It appears dry. Subbituminous coal also weathers and slacks on exposure to the atmosphere. The moisture comes off less rapidly than it does from lignite. It can be shipped somewhat longer distances than lignite, and it can be stored if done with care to retard evaporation of moisture. It has a heating value of about two-thirds that of good bituminous coal, i.e., about 7,500 to 11,700 B.t.u.'s as mined. It does not coke when heated and neither lignite nor subbituminous coal can be used for making coke.

Bituminous Coal

The next higher stage in rank is bituminous coal. Bituminous coal comprises 60 percent of our coal reserves. It is our ordinary soft coal. It does not slack when exposed to the weather. The moisture content is lower than that of subbituminous coal and lignite, and ranges from two percent to about 15 percent as mined. The heating value is higher and in low-ash coals ranges from about 12,000 to 14,000 B.t.u.'s. Of course, bituminous coal with a high ash content has a proportionally lower heating value.

Most bituminous coals, when heated in a closed vessel, give off gas, light oils and tar, and leave behind a coherent cellular mass known as

coke. Coke is very important in our industrial and war economy because it is necessary for making pig iron in the blast furnace. Not all the coals that coke are suitable for making metallurgical coke. The coke from weakly coking coals is not strong enough to withstand the attrition that takes place while passing down the blast furnace and rubbing against the iron ore and limestone. Also, some coals contain too much ash or too much sulfur. High sulfur content is undesirable because the sulfur gets into the iron and lowers its quality. High ash content increases production costs because it results in a larger slag volume to be handled in the blast furnace. Therefore, in considering our reserves of coking coal, we are particularly concerned with those that are of good enough quality to use for the production of blast-furnace coke.

Bituminous coals are divided into high-, medium-, and low volatile coals. The high-volatile coals have about 30 to 40 percent volatile matter. (Volatile matter consists of the gaseous and liquid matter that is given off when the coal is heated in a closed vessel.) The medium-volatile coals contain from about 22 to 30 percent volatile matter; and the low-volatile bituminous coals contain from about 14 to 22 percent volatile matter.

The low-volatile bituminous coals are the most valuable coals that we have in this country. Because of their low percentage of volatile matter, they produce very little smoke and are called semismokeless. As a result, they are in demand for house-heating purposes and as industrial fuel in cities that have somewhat drastic smoke-abatement ordinances. Also, the low-volatile coals have very favorable coking properties. They are not used as coking coals by themselves, but when blends of 20 or 30 percent of low-volatile coals and 70 or 80 percent of high-volatile coals are used, a blast-furnace coke is obtained which is strong and resistant to abrasion. Most of the metallurgical coke made in the United States is produced from blends of 70 to 80 percent of high-volatile bituminous coal and 20 to 30 percent of low-volatile bituminous coal. There is a conflic of demand for the low-volatile bituminous coals arising from these uses. From the point of view of military security, it was necessary during the war to give priority to the use of low-volatile bituminous coals for making metallurgical coke. Coke was very important in maintaining the required production of steel.

The reserves of low-volatile bituminous coal are relatively small--only 2.2 percent of the total coal reserves. The principal reserves are found in the Pocahontas and New River fields of West Virginia and in central Pennsylvania. Small reserves occur in Arkansas and Oklahoma.

When low in ash, low-volatile bituminous coal has a very high heatin value--14,000 B.t.u.'s the highest heating value per pound of any of our coals.

Anthracitic Coal

After we pass the low-volatile coals, we come to the highest ranking group, from a geological point of view, the anthracitic coals. These are comprised of semianthracite, true anthracite, and meta-anthracite. For all practical purposes, this group may be referred to as anthracite, and principally Pennsylvania anthracite.

Anthracite has from two to eight percent volatile matter. It burns without smoke. It is hard and resistant to abrasion and makes an excellent domestic fuel, if the ash is not excessively high. Unfortunately, anthracite frequently is associated with more ash-forming material than is found in many bituminous coals.

Semianthracite is a transitional coal between low-volatile bituminous coal and anthracite. It may produce just a trace of smoke on ignition, and instead of burning with a blue flame, as does anthracite, it starts with a luminous flame. It contains about 8 to 14 percent volatile matter. Such coals are found in Virginia, Pennsylvania, and Arkansas.

Table 1 shows the classification of American coals by rank. 1/

The National Fuel Reserves

In discussing our reserves, I shall refer to four broad classes: the anthracitic coals, the bituminous coals, the subbituminous coals, and the lignitic coals.

Figure 1 is a graphical presentation of the national fuel reserves as of 1 January 1946. The various mineral fuels, solid, liquid and gaseous, were calculated to the equivalent tons of 13,000 B.t.u. coal. That is, knowing the heating values of oil, gas, and the various ranks of coal, calculations were made on the basis of their equivalents to 13,000 B.t.u. coal, which represents the average of our bituminous coals in heating value. Therefore, the areas on the graph are directly comparable. The graph is plotted so that each one of the small squares represents two billion tons of 13,000 B.t.u. coal.

Geologically Inferred and Recoverable Coal Reserves

Our total coal reserves in terms of actual tonnage have been estimated by the Federal Geological Survey (these are geologically inferred estimates and by no means proved reserves) at about 3.2 trillion tons. When that amount is calculated to an equivalent of 13,000 B.t.u. coal, it comes down

1/ Fieldner, A. C., Selvig, W. A., and Frederic, W. H., Classification Chart of Typical Coals of the United States: Bureau of Mines Rept. of Investigations 3296R, 1939, pp. 3-4.

Table 1.--Classification of coals by rank

Legend: F. C. = Fixed carbon. V.M. = Volatile matter B.t.u. = British thermal units.

Class	Group	Limits of fixed carbon on B.t.u., mineral-matter-free basis	Requisite physical properties
I. Anthracitic..	1. Meta-anthracite.....	Dry F. C., 98 percent or more (dry V. M., 2 percent or less	
	2. Anthracite.....	Dry F. C., 92 percent or more and less than 98 percent (dry V. M., 8 percent or less and more than 2 percent).	
	3. Semianthracite.....	Dry F. C., 86 percent or more and less than 92 percent (dry V. M., 14 percent or less and more than 8 percent)	Nonagglomerating1/
II. Bituminous2/	1. Low-volatile bituminous coal	Dry F. C., 78 percent or more and less than 86 percent (dry V. M., 22 percent or less and more than 14 percent).	
	2. Medium-volatile bituminous coal	Dry F.C., 69 percent or more and less than 78 percent (dry V.M., 31 percent or less and more than 22 percent).	
	3. High-volatile A bituminous coal	Dry F. C., less than 69 percent (dry V.M., more than 31 percent); and moist3/ B.t.u.,4/ 14,000 or more.	
	4. High-volatile B bituminous coal	Moist3/ B.t.u., 13,000 or more and less than4/ 14,000.	
	5. High-volatile C bituminous coal	Moist B.t.u., 11,000 or more and less than4/ 13,000.	Either agglomerating or nonweathering5/
III. Subbituminous	1. Subbituminous A coal.....	Moist B.t.u., 11,000 or more and less than4/ 13,000.	Both weathering and nonagglomerating
	2. Subbituminous B coal.....	Moist B.t.u., 9.500 or more and less than4/ 11,000.	
	3. Subbituminous C coal.....	Moist B.t.u., 8,300 or more and less than4/ 9,500.	
IV. Lignitic.....	1. Lignite.....	Moist B.t.u., less than 8,300.	Consolidated
	2. Brown coal.....	Moist B.t.u., less than 8,300.	Unconsolidated

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1/ If agglomerating, classify in low-volatile group of the bituminous class.

2/ Pending the report of the Subcommittee on Origin and Composition and Methods of Analysis, it is recognized that there may be noncaking varieties in each group of the bituminous class.

3/ Moist B.t.u. refers to coal containing its natural bed moisture but not including visible water on the surface of the coal.

4/ Coals having 69 percent or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of B.t.u.

5/ 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.

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to about 3.5 trillion tons. That total is subdivided as follows: The lignite, the lowest rank of coal, is equivalent to 484 billion tons of bituminous coal; the subbituminous coal calculates to about 600 billion tons; the high-volatile bituminous coal, which includes our coking coals, 1,405 billion tons; the low-volatile bituminous coals, which are very valuable in making metallurgical coke, 57 billion tons. This amount comprises only a very small slice compared to the large square of bituminous coal. It is our most valuable coal and unfortunately it will be exhausted within a hundred years. The original anthracite reserve is 30 percent exhausted; 15 billion tons remain.

Geologists have estimated that there is enough oil shale in the United States to produce 92 billion barrels of oil. That calculates over to 31 billion tons of 13,000 B.t.u. coal.

The petroleum reserves, as of 1 January 1946, were equivalent to 4.5 billion tons of coal and natural gas, 5.4 billion tons.

However, this Figure 1 is not a fair presentation of our fuel reserves because the natural gas and the petroleum reserves are expressed in terms of proved and recoverable oil and gas. These estimates are revised annually by the Committee on Petroleum Reserves of the American Petroleum Institute, and a similar committee of geologists under the sponsorship of the American Gas Association. The estimates are based on drilling and production data from the various companies and from governmental agencies. Much more oil and gas reserves will be discovered. No reliable estimates can be made of the potential amount of oil and gas in the earth if the earth has not been penetrated with wells and if production data and changes of pressure are not available to calculate the amount of oil or gas in a pool. On the other hand, geologists can plot outcrops of coal and any available drill cores and, from the general geology of a region, make calculations as to the number of tons of coal in that region. That was done for the U. S. Geological Survey by M. R. Campbell, who virtually devoted his life to the study of coal reserves. His first estimate was published in 1912 and his last estimate in 1926. The Survey has made some further revisions and I have used the table given by Dr. Wrather, the Director of the Survey, at the Synthetic Liquid Fuels Hearing in 1945. Some coal mining engineers think that they are too optimistic, and there are indications that they are on the high side. So we must not place too much confidence on these estimates of geologically inferred reserves. They refer to coal in the ground and not recoverable coal. The United States Coal Commission, under the chairmanship of John Hayes Hammond, in 1923 estimated that for the United States as a whole the average loss in mining coal was about one-third; only two-thirds of the reserves were recovered. Coal is left behind in pillars, and some of the beds are too thin to justify mining at present day costs. Current losses in modern mechanized mines may be more or less than in 1923. A nation-wide study of this subject should be made. The chart, in Figure 1, does not allow for the mining losses.

The graph, in Figure 2, shows recoverable coal assuming 50 percent recovery. Recovery was reduced from 65 percent to 50 percent as probably being more realistic and making some allowance for irrecoverable thin seams that may have been included in the geological estimate. Each of the small squares of Figure 2 represents one billion tons instead of two billion tons of reserve.

The graph in Figure 1 represents reserves as of 1 January 1946; Figure 2 represents reserves as of 1 January 1947. With respect to coal, the recoverable values of Figure 2 are one-half of the values given in Figure 1. The oil and gas reserves in both figures represent recoverable values.

The petroleum graph in Figure 2 represents proved reserves of 21 billion barrels of crude petroleum, the equivalent of 4.8 billion tons of coal.

Proved natural gas reserves increased from 155 trillion cu.ft. on 1 January 1946, to 160 trillion cu. ft. on 1 January 1947. In terms of 13,000 B.t.u. coal, the increase was from 5.2 to 6.2 billion tons.

On an energy basis, coal and lignite constitute 97.5 percent of the national mineral fuel reserves. (See Table 2.) However, we must keep in mind that this so-called recoverable reserve may be too large. It is based on a geologically inferred estimate made 20 to 30 years ago. The best way to determine reasonably correct reserves is to conduct a core-drilling program in regions where there are no mines. The greatest lack of data on thickness and area of coal beds is in the Western States. It is probable that our present coal reserve estimates will be revised downward as more exploratory data become available. The petroleum and natural gas estimates are based on proved and recoverable oil and gas. The petroleum and natural gas reserves will be increasing, whereas the estimated coal reserves will probably be decreased.

Ratio of Reserves to Approximate 1946 Production

The ratio of reserves to annual consumption is interesting because of its bearing on the life expectancy of the reserves. Column 7 of Table 2 gives such ratios for the various fuels on the basis of an assumed annual production approximating that of 1946. The presently proved reserves of crude petroleum and natural gas plus the estimated recoverable oil from oil shale would be sufficient to supply present rates of production of natural gas and petroleum for a period of 58 years. Assuming that from then on no more gas or oil is discovered (which is not true; more will be discovered) and that the annual consumption of oil and gas remain the same but that they will be produced synthetically from the estimated recoverable coal and lignite, then our coal reserves would last about 740 years. A year ago, I estimated that our coal reserves were ample

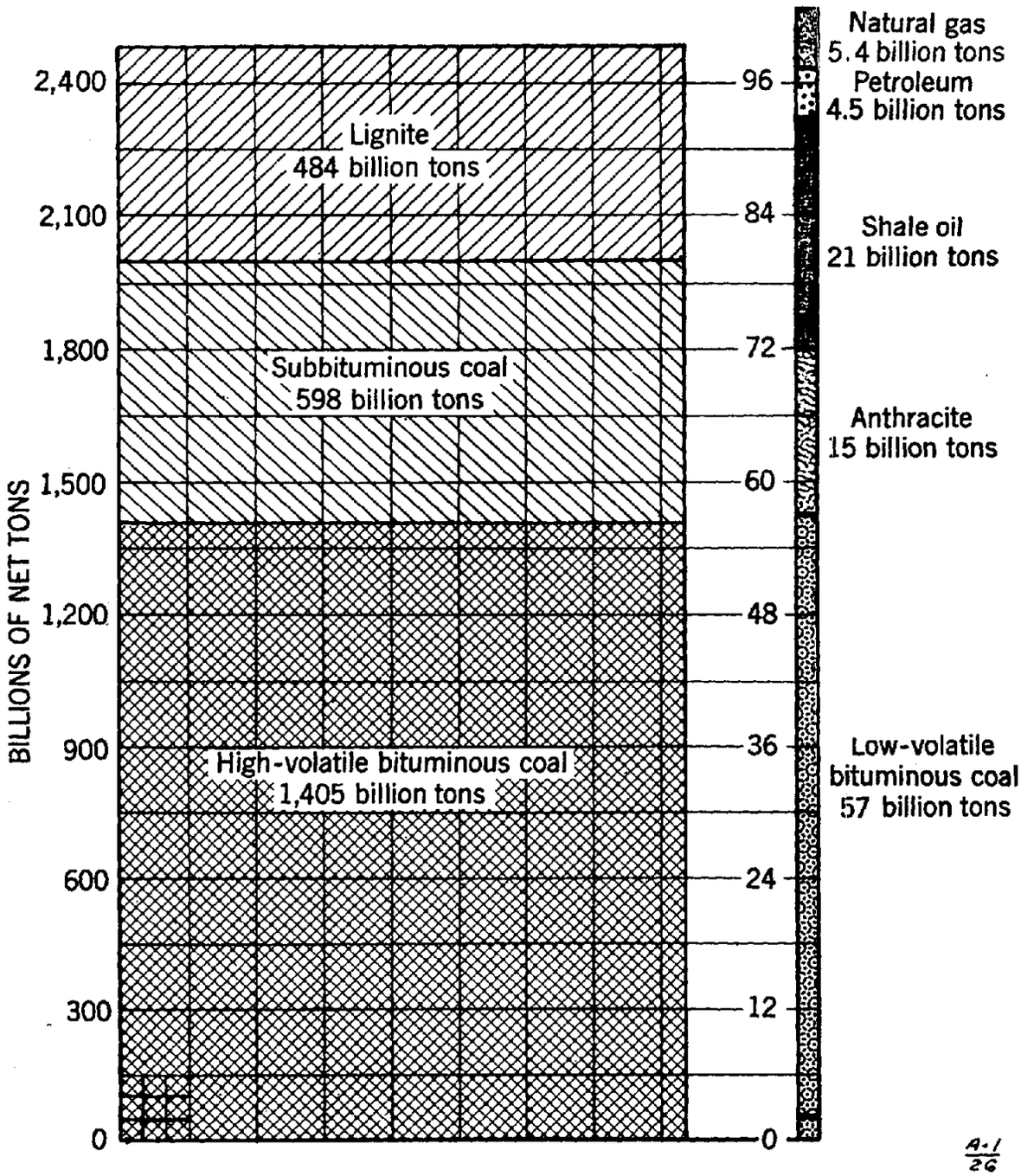

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Figure .—Estimated mineral fuel resources of the United States as of January 1, 1946, and expressed in equivalent tons of bituminous coal of 13,000 B.t.u. per lb. calorific value. Medium volatile bituminous coal is distributed between high and low volatile coal.
(1 small square = 2 billion tons.)

FIGURE 1.

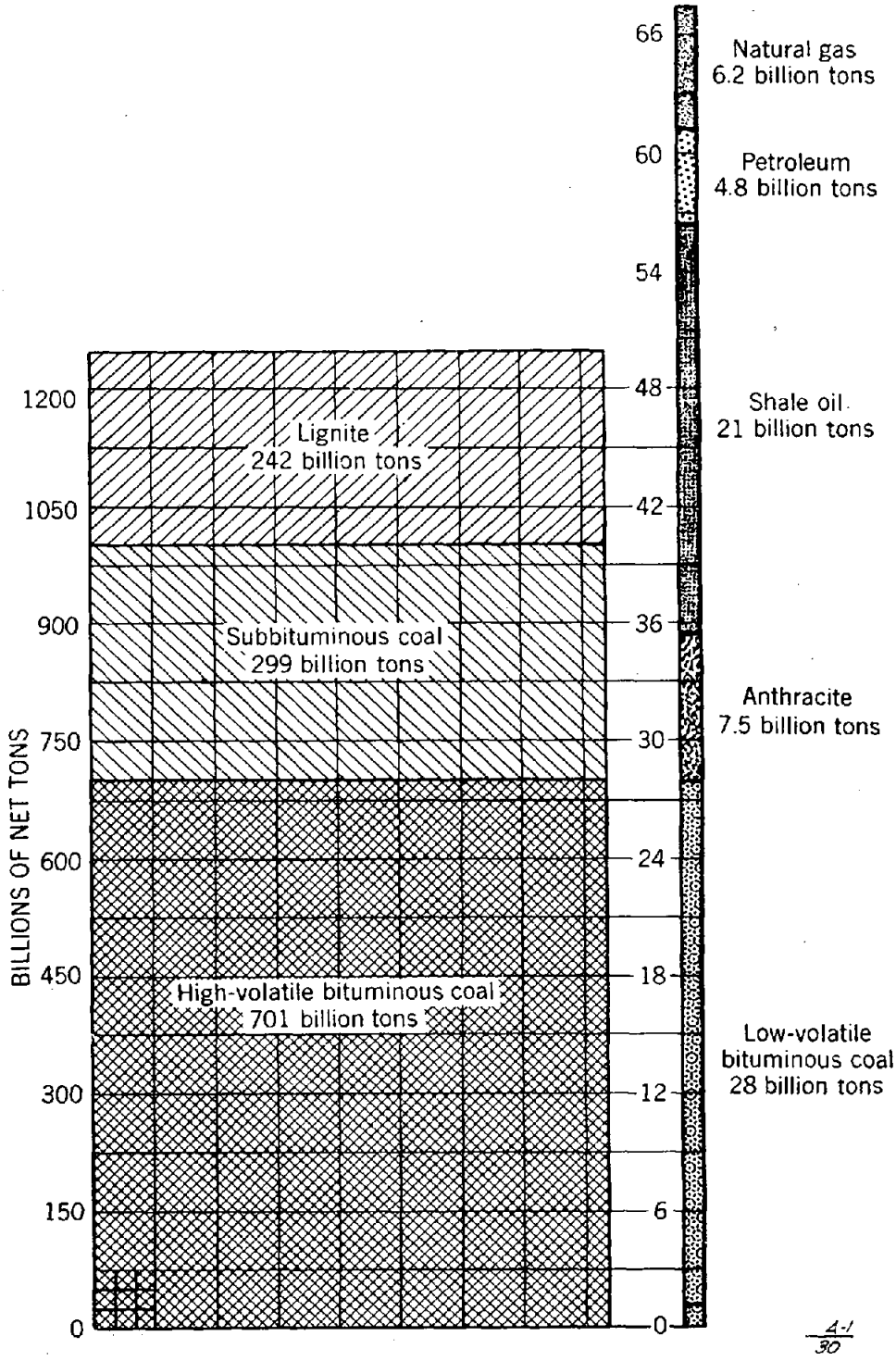

Figure .—Estimated recoverable mineral fuel reserves of the United States as of January 1, 1947.
All fuels expressed in equivalent tons of bituminous coal of 13,000 B.t.u. per lb. calorific value. Medium-volatile bituminous coal is distributed between high- and low-volatile coal. (1 small square equals 1 billion tons.)

FIGURE 2.

Table 2.--Estimated Recoverable Mineral-Fuel Reserves of the United States1/

Description	Reserve 1 Jan. 1947	Assumed Annual Production	Equivalent Billions of Net Tons, Bituminous Coal, 13,000 B.t.u. per lb. Calorific Value 2/			Reserve Divided by Annual Production
			Reserve 1 Jan. 1947	Percent of Total Fuel Reserves	Assumed Annual Production	
1	2	3	4	5	6	7
Anthracite, billions of net tons	7.5	0.060	7.3	0.6	0.059	124
Low-volatile bituminous coal., billions of net tons3/.....	26	0.115	28	2.1	0.124	226
High-volatile bituminous coal, billions of net tons3/.....	675	0.467	701	53.5	0.485	1445
Subbituminous coal, billions of net tons.....	409	0.014	299	22.8	0.010	--
Lignite, billions of net tons.....	470	0.004	242	18.5	0.002	--
TOTAL, all ranks of coal, billions of net tons.....	1587.5	0.660	1277	97.5	0.680	1878
Petroleum, billions of bbl.4/.....	20.9	1.73	4.82	0.4	0.399	12.1
Oil from oil shale, billions of bbl.	92	1.73	21.2	1.6	5/0.399	53.1
Natural gas trillions of cu. ft.4/	160	4.1	6.15	0.5	0.157	39.2
TOTAL, all fuels....	—	—	1309		1.236	6/1059

1/ Recoverable coal reserves are one-half of the coal reserves estimated by the U. S. Geological Survey and given by W. E. Wrather, Director, at Synthetic Liquid Fuels Hearing in 1943 and

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corrected for production to 1 Jan. 1947. Minimum thickness of beds included in the Geological Survey estimate is 14 inches for bituminous and anthracitic coals, 2 ft. for subbituminous coal and 3 ft. for lignite. Beds are included to a depth of 3,000 ft. below the surface.

2/ Heating values used in conversion; anthracite, 12,700 B.t.u. per lb.; low-volatile bituminous coal, 14,000 B.t.u. per lb.; high-volatile bituminous coal, 13,500 B.t.u. per lb.; subbituminous coal, 9,500 B.t.u. per lb.; lignite, 6,700 B.t.u. per lb.; crude petroleum, 6,000,000 B.t.u. per bbl.; natural gas, 1,000 B.t.u. per cu. ft.

3/ Includes some medium-volatile coal.

4/ Proved reserves only.

5/ Not included in the total.

6/ Assuming that one-half ton 13,000 B.t.u. coal is required to produce one bbl. oil and that one-fifteenth ton 13,000 B.t.u. coal is required to produce 1,000 cu. ft. of 1,000 B.t.u. gas, then to supply a current annual production of 1.73 billion bbl. crude petroleum and 4.1 trillion cu. ft. natural gas will require the conversion respectively of 865 and 273 million tons or a total of 1,138 millions tons of 13,000 B.t.u. bituminous coal.

This amount added to the 680 million tons of coal now produced per year would raise the total production of equivalent 13,000 B.t.u. coal required per year to produce all of the current consumption of gaseous, liquid and solid fuels from 680 to 1,818 million tons per year--nearly 3 times the present production.

$$\frac{4.82 + 21.2 + 6.15}{0.399 + 0.157} = 57.6$$

In round numbers, 58 years is the life of oil, oil shale, and natural gas reserves as sources of the assumed annual production of oil and gas, given in the table.

In these 58 years the total coal production at the assumed annual rate of 0.680 billion tons of equivalent 13,000 B.t.u. coal would be 58 x 0.680 = 39.44 billion tons, thus reducing the coal reserves to 1277 - 39 = 1238 billion tons.

1238 ÷ 1.818 = 681, the years life of coal reserves as exclusive source of coal, oil and gas after proved petroleum oil shale and natural gas reserves are exhausted.

681 x 58 = 739 years total life expectancy of all fuel reserves at 1946 rate of production of coal; oil and natural gas, the oil and gas to be made from coal, following exhaution of presently proved reserves.

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for 1,000 years and probably for 2,000 years. However, increasing doubt as to the percentage of minable coal that will be found to exist on further exploration has led me to reduce the former estimate. It also must be kept in mind that the consumption of oil, gas, and other fuels will increase. A rate of increase such as has taken place in the past 15 years could reduce the presently known national fuel to a few hundred years.

Increasing Cost Following Depletion of Richer Resources

From a practical point of view, the highly productive life of our coal reserves is considerably less than the calculated periods because the richer and more accessible coal deposits are depleted first, leaving the poor quality and thin beds for later development. A number of the finest coal beds of the Appalachian region are nearly exausted, such as the Blossburg and Moshannon of Pennsylvania, the Sharon in northern Ohio, the Brazil block of Indiana, and the Georges Creek Big Vein of Maryland.

The high-grade coking coals of the famous Pittsburg bed; the low-volatile semisnokeless coals of West Virginia; and the high-grade, low-ash and low-sulfur bituminous coals of the Appalachian region are from 15 to 40 percent exausted. Many of these remaining coals are becoming more costly, due to the necessity of operating on thinner and deeper seams and the need for washing plants for the removal of impurities present in the poorer quality coal.

Rice, Fieldner, and Tyron summarized this situation in a paper entitled "The Conservation of Coal Resources" from which the following is quoted:1/

> "The central problem in conservation of coal resources is not absolute exhaustion in the remote future but a relatively early increase in cost through depletion of the richer and more accessible deposits. The anthracite deposits of Pennsylvania are 29 percent exhausted, and the anthracite industry has already entered the stage of increasing costs. In the bituminous fields the life of certain of the finest seams of the Appalachians is limited to 30 to 100 years at 1929 production. Resort to thinner or less accessible beds, of which large reserves are available, will increase the difficulties of mining, and under really difficult conditions the labor required per ton may be doubled or quadrupled. Avoidable wastes in mining bituminous coal range from 5 percent to 30 percent of the seams now worked, the average being 19.4 percent. In an ordinary year the avoidable loss is 136,000,000 metric tons.

1/ Rice, George S.; Fieldner, A. C.; and Tryon, F. G.; Conservation of Coal Resources. Trans. Third World Power Conference, Washington, D. C., 1935, vol. VI, pp. 671-724.

"Prevention of these wastes is less a technical than an economic and institutional problem. In many cases recovery of pillars may add slightly to the cost of production, and under level agricultural lands damage may result from surface subsidence. A very small increase in total cost, however, would make possible a very large increase in recovery.

"While wastes in mining have shown little sign of abatement in recent years, great progress has been made in reducing wastes in consumption through the advance of fuel technology. Improvement in fuel utilization has enhanced the inherent value of the raw fuel."

Distribution of Coal Reserves

Table 3 gives the distribution of the recoverable coal reserves according to rank. On the basis of heating value, five-tenths of one percent of our coal reserves is anthracite. Low-volatile, bituminous coal comprises 2.5 percent; high-volatile, bituminous coal 55 percent; subbituminous coal 23 percent; and lignite 19 percent of the recoverable coal reserves. Subbituminous coal and lignite constitute 42 percent of the coal reserves. These ranks of coal are little used at present and only in the locality where they occur. They are logical raw materials for future supplies of synthetic liquid fuels because they cannot be transported long distances in open cars or stored without weathering and slacking.

Table 3 summarizes the distribution of the coal reserves according to rank and energy content.

Table 3.--Geologically Inferred Recoverable Reserves of Various Ranks of Coal Comprising the Total Coal Reserves of the United States as of 1 January 1947.

	Reserves in Equivalent Tons of 13,000 B.t.u. Coal	
	Billions of Net Tons	Percent of total Recoverable Reserves
Anthracitic Coal.....	7.3	0.5
Low-Volatile Bituminous Coal.....	28.0	2.5
High-Volatile Bituminous Coal.....	701.0	55
Subbituminous Coal.....	299.0	23
Lignite.....	242.0	19
Total.....	1277.3	100.0

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From the standpoint of regional distribution, the principal reserves are grouped in the Eastern Province (Figure 3) consisting of Pennsylvania, Ohio, Maryland, West Virginia, Virginia, eastern Kentucky, Tennessee, and Alabama; the Interior Province, consisting of Illinois, Indiana, western Kentucky (comprising the eastern region of this province), and Iowa, Missouri, eastern Kansas, Oklahoma, and Arkansas (comprising the Western region); and the northern Great Plains, Gulf, and Rocky Mountain Provinces, extending from North Dakota and Montana through Wyoming, Colorado, Utah, and New Mexico and including Texas. The recoverable reserves of these provinces are summarized in Table 4.

Table 4.-- Recoverable Coal Reserves of Various Ranks Distributed by Provinces

Provinces	Billions of Net Tons				
	Anthracitic Coal	Bituminous Coal	Subbituminous Coal	Lignite	Totals
Eastern.....	7.4	262.6			270.0
Interior.....	.1	254			254.1
Northern Great Plains, Rocky Mountain, and Gulf.....		180.1	384	469.7	1033.8
Totals.....	7.5	696.7	384	469.7	1557.9

Only one-third of the total tonnage of coal and lignite reserves occurs in the Eastern and Interior Provinces. Two-thirds is found in the Great Plains and Rocky Mountain Provinces. However, there is a great difference in rank between the eastern and western coals. Practically all of the Eastern and Interior Province coals, except the anthracitic coals, are coking bituminous coals; and the Appalachian region coals are strongly coking. This region supplies most of the coking coals used in the United States. It also contains almost all the reserves of low and medium-volatile bituminous coal that is of high value for metallurgical and domestic use. On the other hand, 80 percent of the Great Plains and Rocky Mountain Province coals are subbituminous coals and lignite. These coals do not cake on heating. As mined, lignite usually contains 28 to 45 percent and subbituminous coal 15 to 28 percent moisture. On exposure to air, the moisture is given off and the coal "slacks" into small pieces. It is not stable and cannot be stored for any length of time except under water, in carefully covered piles, or in closed bins where rapid loss of moisture cannot take place.

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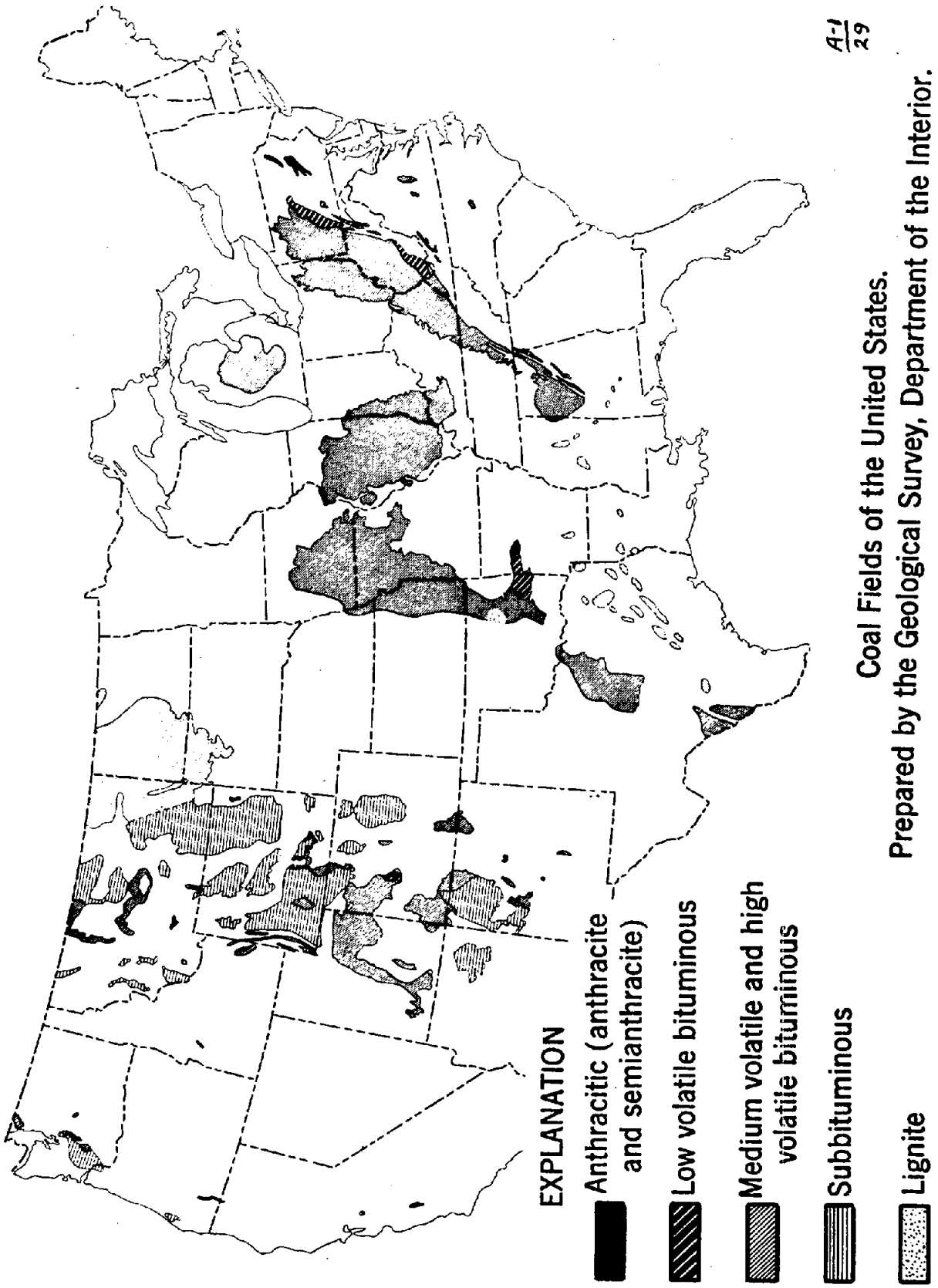
EXPLANATION
Anthracitic (anthracite and semianthracite)
Low volatile bituminous
Medium volatile and high volatile bituminous
Subbituminous
Lignite
Coal Fields of the United States.
Prepared by the Geological Survey, Department of the Interior.

FIGURE 3.

Lignite and subbituminous coals are used for industrial and domestic fuel in the Dakotas, Montana, Wyoming, Colorada, and western Nebraska. However, the total market is small because of the low density of population in these areas, and these low-rank fuels cannot be shipped very far on account of their low-heating value and their tendency to degrade in size with accompanying possibility of spontaneous ignition.

Most of the bituminous coal in the Western States is free-burning and noncoking. Relatively small deposits of coals suitable for the production of metallurgical coke occur in the Trinidad-Raton field of southern Colorado and northern New Mexico, the Sunnyside beds in the Castlegate field of Utah, and in Pierce and Kittitas Counties, Washington. Some of the coals are slightly coking but do not become plastic enough to form coke that is sufficiently strong for use in the iron blast furnace. In general, anthracite, and coking coals of metallurgical grade occur in the Eastern Province, coking coals of lower grade and lower bituminous rank in the Interior Province, and noncoking coals of lignitic, subbituminous, and bituminous rank in the Great Plains and Rocky Mountain Provinces.

Figure 4 shows the coal reserves by states. These are the geologically indicated reserves and are twice the recoverable reserves shown in Figure 2 and Table 2. The amount in each state, expressed in equivalent tons of 13,000-B.t.u. bituminous coal, is proportional to the height of the column erected in the state. The white space represents lignite, the vertical crosshatching subbituminous coal, the inclined crosshatching bituminous coal, and the solid black represents anthracite.

The Pennsylvania column is largely bituminous coal with a little anthracite. All of the West Virginia coals are bituminous, including low-, medium-, and high-volatile bituminous coal. West Virginia has the greatest reserves of the best grade and highest rank of bituminous coal of any state in the Union. Pennsylvania comes next in line. Illinois has the greatest tonnage of bituminous coal but it is inferior in grade and rank to the Appalachian coals. The coals of Illinois, Iowa, Missouri, Kansas, western Kentucky, and Indiana are inferior to the Appalachian coals for the production of metallurgical coke and are but little used for this purpose. The Ohio coals grade between the Illinois and West Virginia coals.

On the B.t.u. basis, Wyoming has the largest reserves. The Wyoming column is the tallest on the map. It represents 590 billion tons of subbituminous coal and 30 billion tons of bituminous coal; North Dakota is second with 600 billion tons of lignite; Colorado is third with 213 billion tons of bituminous coal and 104 billion tons of subbituminous coal; and Montana is fourth with 316 billion tons of lignite, 63 billion tons of subbituminous coal, and 3 billion tons of bituminous coal. These four states contain 51 percent of the Nation's energy reserves in the form of coal and lignite.

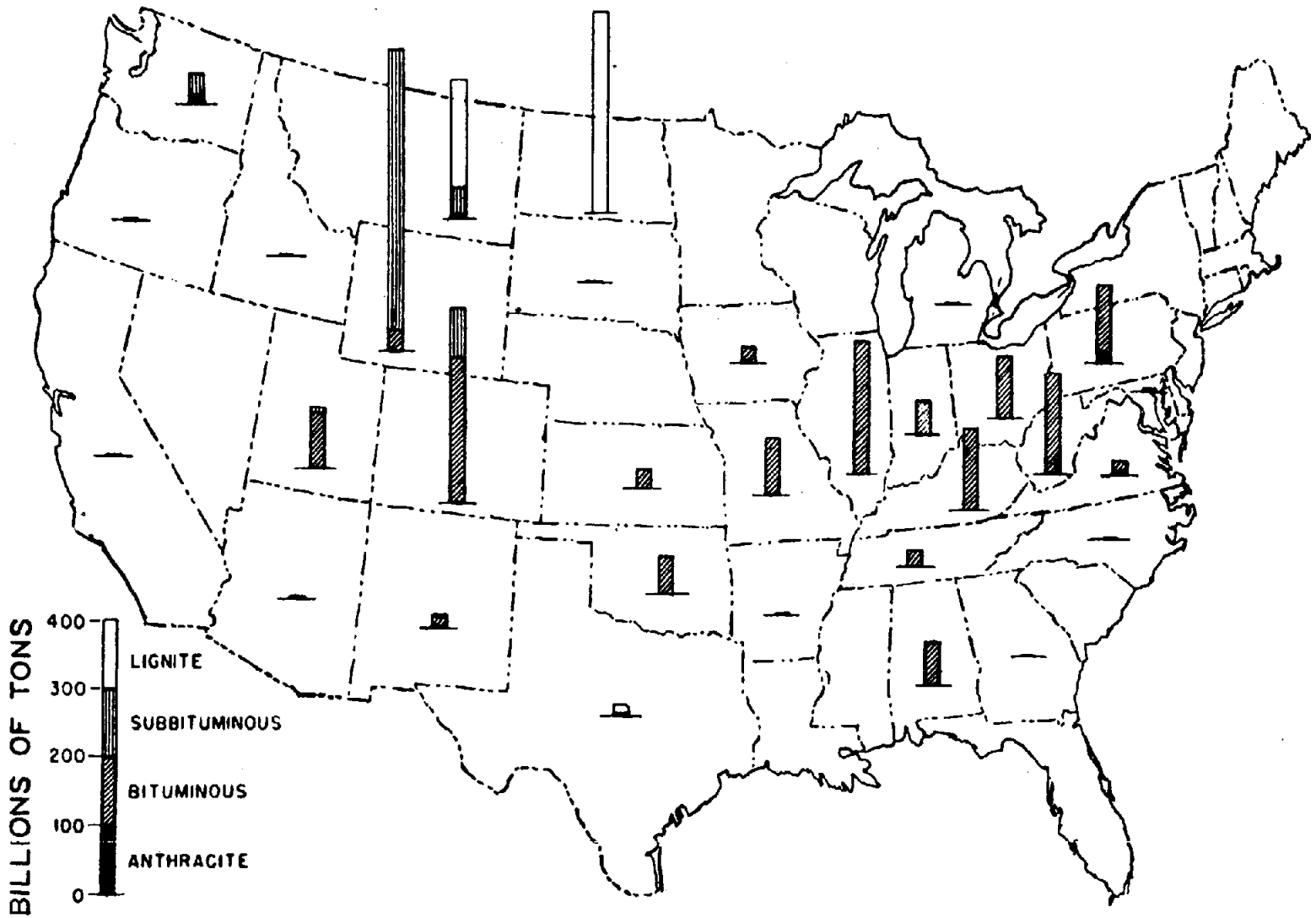

FIGURE 4.

Coal Reserves by States as of January 1, 1937

Anthracite, subbituminous, and lignite reduced to bituminous coal equivalent, according to "Energy Resources and National Policy" (*1*).

The large lignite reserves of the northern Great Plains region extends from South Dakota through North Dakota and eastern Montana into Saskatchewan, Canada. The best coking coal west of Oklahoma occurs in south central Colorado near Trinidad. This field extends into northern New Mexico near Raton. This coal field supplies the coke ovens of the Colorado Fuel and Iron Company at Pueblo, Colorado. A considerable reserve of low-rank but usable coking coal has been developed recently by the Bureau of Mines corodrilling program in western Colorado. This deposit will be important in supplying metallurgical coal for the new steel plants in Utah and California. These plants have difficulty in securing good coking coal. Their present supply is from the Sunnyside bed in Utah. This reserve is limited and the coking properties of the coal are poor. It makes coke, but it is the lowest rank coal that is used in this country for making coke. A good deal of work is being done on trying to improve the quality of the coke from the Utah coal.

Illinois has the fifth largest coal reserves. All of the coal is of bituminous rank and cokes to some degree. However, much of the coal is so high in ash and sulfur that it is not considered suitable for the production of metallurgical coke. With suitable washing, a fair portion of the Illinois and midcontinent region coals can be used for metallurgical purposes especially if blended with high-grade eastern coals from eastern Kentucky and West Virginia.

Numbers 6, 7, and 8 in the descending scale of coal reserves are West Virginia, Kentucky, and Pennsylvania. West Virginia has some of the finest coal in the country. It is low-, medium-, and high-volatile bituminous coal. All of it cokes and much of it is low in ash and sulfur. The heating value is high. Eastern Kentucky also has very high-quality metallurgical coking coal, and gas-making coal. Western Kentucky coals are of low rank and grade. They are high in ash and sulfur and are similar to Illinois, Iowa and Missouri coals. A large proportion of the best quality and cheaply mined coals of Pennsylvania have been seriously depleted. These are our principal states with reference to coal reserves. Production is highest in the eastern states and the Illinois region. The greatest production, including anthracite, comes from Pennsylvania at the present time. West Virginia is next and Illinois third.

The latest published revision of the Geological Survey's estimate of total coal reserves of the United States (not including Alaska) is given in Table 5. The total for all ranks of coal is 3085.4 billions of net tons, and this amount is equivalent to 2,474.2 billions of net tons of 13,000 B.t.u. coal. The total inferred coal reserves of Alaska are estimated by the Geological Survey at approximately 110 billion net tons of which 85 billion net tons consist of subbituminous coal and lignite. These are very approximate geologically inferred

Table 5--Geological Survey Estimate of Total Coal Reserves of United States, 1 January 1944, in Billions of Net Tons1/

Order of Reserves	State	Anthracite	Bituminous Coal	Subbituminous Coal	Lignite	Equivalent Bituminous Coal
	Alabama		66.5			69.0
	Idaho and Oregon		0.7	1.8		2.0
	Arkansas	0.2	1.3		0.1	1.6
3	Colorado	0.1	212.6	104.0		297.0
	Georgia		0.9			1.0
5	Illinois		197.2			204.5
	Indiana		51.8			53.8
	Iowa		28.7			30.0
	Kansas		29.6			30.9
7	Kentucky		121.0			125.6
	Maryland		7.7			8.0
	Michigan		1.9			2.0
	Missouri		83.6			86.8
4	Montana		2.6	62.9	315.5	211.0
	New Mexico		18.8	1.9		21.0
	North Carolina		0.1			0.1
2	North Dakota				600.0	309.0
	Ohio		91.7			95.2
	Oklahoma		54.7			56.8
8	Pennsylvania	14.9	65.0			82.4
	South Dakota				1.0	0.5
	Tennessee		25.2			26.2
	Texas		8.0		22.9	20.0
	Utah		87.9	5.2		91.2
	Virginia	0.5	20.5			21.8
	Washington		11.2	52.4		50.0
6	West Virginia		110.5			114.8
1	Wyoming		30.3	590.0		462.0
	Total	15.7	1330.0	818.2	939.5	2474.2

Total, all ranks of coal.....3,083.4 billion net ton

1/ Investigation of Natural Resources, Hearings before a Subcommittee of the Committee on Public Lands, U. S. Senate, 80th Congress, May 15, 16, and 20, 1947, pp. 232-4.

estimates based on inadequate data. About all of Alaska's coal production has been bituminous coal from the Matanuska Valley near the coast, and subbituminous coal from the Nenana fields on the Alaska Railroad about two-thirds of the distance from the coast to Fairbanks. Approximately 165,000 net tons of bituminous coal and 203,000 net tons of subbituminous coal were produced in Alaska in 1946.

No natural gas reserves have been discovered and petroleum has been developed at only one place in Alaska, the Katalla field near the Bering River coal field, where seeps first attracted attention in 1898. This field yielded about 150,000 barrels of oil before operations were discontinued in 1933. Geological indications are favorable for large oil reserves in northern Alaska, and exploratory work is in progress.

On an energy basis, the recoverable fuel reserves of the United States, excluding Alaska, consist of four-tenths of one percent crude petroleum, five-tenths of one percent natural gas, 1.6 percent oil from oil shale, and 97.5 percent coal and lignite.

World Fuel Reserves

Now let us look at our fuel reserves in comparison with the reserves of the rest of the world. The world reserves of coal, like ours, are based primarily on geological estimates. They are not proved reserves, nor measured reserves, nor minable reserves, but geologically inferred or indicated reserves. Our coal reserves are 44 percent, less than half, of the coal reserves of the world. Our proved oil reserve is 31 percent of the world's proved oil reserves. We produced 41 percent of the world production of coal in 1946 and 63 percent of the crude petroleum. Our percentage of world coal production was about the same as our percentage of the world reserves of coal; our oil reserves are about one-third of the world reserves, and we produced two-thirds of the world's production of petroleum. We are consuming our oil reserves much faster than the rest of the world, and our oil reserves have been much more intensively prospected. Prospecting for oil is just beginning in the Middle East and already their reserves are estimated to be much greater than ours. Their wells average some 2,000 barrels a day, wheras ours average about 11 barrels a day although those in Venezuela average about 250 barrels a day. They are just beginning to penetrate some lush reservoirs of oil in the Middle East.

Table 7 shows the world mineral fuel reserves as of 1 January 1947. Coal is expressed in metric tons. A metric ton is about ten percent more in weight than a short or net ton.

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Table 6.--Total Inferred Coal Reserves of Alaska Estimated by U. S. Geological Survey as of January 1, 1944, in Billions of Net Tons1/

Region	Accessible by present means of transportation		Within 40 miles of present means of transportation. Does not include preceding column.		Remote from present means of transportation	
	Bituminous coal	Subbituminous coal and lignite	Bituminous coal	Subbituminous coal and lignite	Bituminous coal	Subbituminous coal and lignite
1. Arctic Ocean drainage ..	—	—	—	—	22.0	60.0
2. Yukon and Kuskokwim drainage basins (exclusive of areas south of the Tanana River tributary to the Alaska Railroad and the Richardson Highway)	—	—	—	0.4	—	—
3. Pacific Ocean drainage and Alaska Peninsula (includes area excluded in 2).....	0.5	2.4	2.8 2/	22.0	—	.2
Totals	0.5	2.4	2.8	22.4	22.0	60.2

Total bituminous coal, 24.3; Subbituminous coal and lignite, 85.0; Anthracite, 1.

Total, all ranks of coal, 110.3 billion net tons.

1/ Investigation of Natural Resources, hearings before a subcommittee of the Committee on Public Lands, U. S. Senate, 80th Congress, May 15, 16, and 20, 1947, pp. 234-5.

2/ Includes one billion tons anthracite.

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6-2

North America has 3,707 billion metric tons of coal: The United states has 2,885 billion metric tons; Canada has 815 billion metric tons. South America has only three billion metric tons of which two billion are in Chile, and about one billion metric tons in Peru, with small amounts in other countries. There are additional minor coal reserves but no other figures are available.

North America has a proved reserve of 21.9 billion barrels of oil: The United States has 20.9 billion barrels; Mexico has nine-tenths of a billion barrels. South America has 8.3 billion barrels of oil, of which 7 billion barrels are in Venzuela, five tenths are in Colombia, and the rest scattered.

The coal reserves of Europe are estimated at 882 billion metric tons, of which Germany has 342 billion, Great Britain 174 billion, the USSR (in Europe) 80 billion, Poland 96 billion, Czechoslovakia 19 billion, Belgium 11 billion, and France 9 billion metric tons.

Europe has 8.2 billion barrels of crude oil, 7.6 billion of which are in USSR (including Asia). (We could not separate the figures for European Russia and Asiatic Russia because they do not give the figures separately for oil.) The rest is scattered.

In Asia the coal reserve is 1, 455 billion metric tons; 1,160 billion metric tons are in USSR (in Asia). The figure for USSR is based on Russia's own estimate. It was given by the Russians at the Third World Power Conference held in Washington in 1935 and was published in those proceedings. China (including Manchuria) has 250 billion metric tons. There is some question as to the figure for China. There are some larger figures that are doubtful. India, Burma, and Malaya have 20 billion metric tons, and Japan has 16 billion metric tons. The rest is scattered.

Asia has 28.5 billion barrels of crude oil, 27.3 billion of which are in the Middle East (Saudi Arabia, Iran, Iraq, and Kuwait), nine-tenths of a billion barrels are in the Netherlands East Indies and in the Far East.

There are 212 billion metric tons of coal in Africa, 206 billion metric tons of which are in the Union of South Africa. Africa has one-tenth of a billion barrels of crude oil.

Australasia (Australia and New Zealand and Tasmania) has 59 billion metric tons of coal, of which 58 billion metric tons are in Australia. No reserves of crude oil are estimated in Australasia.

That makes a world total of geologically inferred coal reserves of 6,318 billion metric tons. The world oil reserve total is 67 billion barrels.

Table 7.--World Fuels Reserves, 1 January 1947

Country	Probable Coal		Proved Crude Oil		Prov natu Ga
	billions of metric tons	percent of total	billions of barrels	percent of total	trill of cu
North America	3,707	59	21.9	33	
United States.....	1/2,885	44	20.9	31	16
Canada2/.....	3/815	13	—		
Mexico.....	—		.9		
South America	3		8.3	12	
Venezuela.....	—		7.0		
Columbia.....	—		.5		
Chile.....	2		—		
Europe	4/882	14	8.2	12	
Germany.....	342		—		
Great Britain.....	174		—		
U. S. S. R.	80		7.6		
Poland.....	96		—		
Czechoslovakia.....	19		—		
Belgium.....	11		—		
France.....	9		—		
Asia	1,455	23	28.5	43	
U. S. S. R. (in Asia).....	1,160		See Europe		
China, Manchuria...	250		—		
India, Burma, Malaya.....	20		—		
Japan.....	16		—		
East Indies, Far East.....	—		0.9		
Iran, Iraq, Arabia, Kuwait....	—		27.3		
Africa	212	3	0.1		
Union of S. Africa.	206		—		
Australasia	59	1	—		
Australia.....	58		—		
World total.....	6,318		67.0		

**(See next page for footnotes)

The United States has 44 percent of the coal reserves and 31 percent of the oil reserves. Asia has 23 percent of the coal reserves and 43 percent of the oil reserves. Europe has 14 percent of the coal reserves and 12 percent of the oil reserves (including Russia in Asia). South America has a negligible fraction of one percent of the coal reserves and 2 percent of the oil reserves.

World Fuels Production in 1946

Table 8 gives the 1946 production of mineral fuels. The United States production of coal in 1946 was 539 million metric tons. United States production of crude petroleum in 1946 was 1,733 million barrels. United States production of natural gas in 1946 was 4,904 billion cubic feet.

The world production of coal in 1946 was 1,312 million metric tons; of petroleum, 2,750 million barrels. World production figures for natural gas are not available.

The percentages of world production for the United States are as follows: 31 for coal, and 63 for petroleum. South America produced two-tenths of one percent of the coal and 17 percent of the petroleum. Europe, 49 percent of the coal and 8 percent of the petroleum. The coal production of Europe includes USSR production in Asia. The figure for Asia, without USSR in Asia, is 4.6 percent for coal and 9.6 percent for crude petroleum. Africa produced two percent of the coal and three-tenths of one percent of the petroleum. Australia and New Zealand produced 1.7 percent of the coal and no petroleum.

Utilization of Coal for the Production of Synthetic Liquid and Gaseous Fuels

It is evident from this review of the fuel reserves of the United States that ample supplies of coal are available for the production of the necessary requirements of gaseous and liquid fuels when the natural gas and petroleum reserves approach exhaustion and need to be supplemented from other sources. Satisfactory fuel gases have been manufactured from coal or from coke and petroleum for many years. Processes and equipment for this purpose have been all developed and the costs are known. In recent years, in Germany in particular, processes have been developed and put into commercial operation for the manufacture of liquid fuel from coal and from lignite. It is quite reasonable therefore to assume that plenty of gaseous and liquid fuels will be available in the future for as many years as coal may be available for conversion. The cost will be greater than the present cost of petroleum and

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Includes 854 billion tons lignite and 744 billion tons subbituminous coal. A recent Report of the Royal Commission on Coal of Canada, 1946, p. 11, places the minable coal reserves at 99 billion net tons of which 50 percent is recoverable.

Includes 573 billion tons lignite and subbituminous coal.

Includes 111 billion metric tons lignite and brown coal.

Table 8.--World Fuels Production in 1946

Country	Coal		Petroleum		Natural Gas
	millions of metric tons	percent of total	millions of barrels	percent of total	billi of cu.
North America	1/556	42.4	1,791	65.1	4,95
United States.....	539	41.1	1,733	63.0	4,90
Canada.....	16	1.2	8	.3	4
Mexico.....	1	.1	49	1.8	
South America	3	.2	466	17.0	—
Venezuela.....	—	—	389	14.1	—
Columbia.....	—	—	22	.8	—
Argentina	—	—	21	.8	—
Trinidad and Barbados.....	—	—	20	.7	—
Peru.....	—	—	13	.5	—
Chile.....	2	.1	—	—	—
Brazil	1	.1	—	—	—
Europe	2/645	49.1	219	8.0	—
Germany.....	114	8.7	5	.2	
Great Britain.....	179	13.6			—
U. S. S. R.	160	12.2	3/170	6.2	—
France.....	50	3.8	—	—	—
Poland.....	48	3.7	1	—	—
Czechoslovakia.....	34	2.6	—	—	—
Belgium.....	23	1.8	—	—	—
Asia	60	4.6	265	9.6	—
Japan.....	25	1.9	1	—	—
U. S. S. R.....	*	—	—	—	—
India, Burma, Malaya.....	30	2.3	3	.1	—
Iran, Iraq, Arabia.....	—	—	256	9.3	—
China, Manchuria....	*	—	1	—	—
East Indies	—	—	4	.1	—
Africa	26	2.0	9	.3	—
Egypt.....	—	—	9	.3	—
Union of S. Africa..	24	1.8	—	—	—
Australia and New Zealand	4/22	1.7	—	—	—
Australia.....	20	1.5	—	—	—
World totals.....	5/1,312	100.0	2,750	100.0	4,95

* See following page for footnotes.

natural gas, but future developments in the more efficient utilization of fuels should go far in offsetting the cost of conversion. This is the long-view picture. But how about the near view? What will be the effect of the declining rate of discovery of new petroleum fields?

Trend of Petroleum Reserves in the United States

Figure 5 shows that the trend of discovering additional reserves of petroleum in new fields has been downward since 1939. During the same period the annual production increased from 1.26 to 1.7 billion barrels. While the present proved reserves of 20.8 billion barrels are the largest ever established, they are only 12.5 percent greater than the reserves of 1 January 1940. This approximate figure has been maintained by the upward revision of reserves of previously discovered fields. Such revisions are made up of extensions of pools as more wells are drilled and increased recovery obtained in drilling and refining by the application of improved technological methods. In 1946, 400 million barrels were discovered in new fields and 1,700 million barrels were added to the proved reserves by the revision and extension of old fields. The total of 2,100 million barrels was 23 percent higher than the 1945 production of 1700 million barrels. The proved reserve is about 12 times the current rate of production. It is a serious question of whether this ratio of reserves to production can be maintained without greatly increased discovery and production costs. Higher production costs mean higher prices for gasoline and other petroleum products, which in turn will lead to a greater proportion of conversion of crude petroleum to the more valuable products, such as motor fuels and domestic heating oils, and it would lead to increasing importation of foreign petroleum from South America and the Persian Gulf region.

However, from the standpoint of national security, as well as sound business, it is not desirable to place too great a dependence upon foreign sources of petroleum. Recent wartime experience proved that overseas' supply of petroleum could be seriously interrupted, even from near-by sources such as South America and along our own coastal routes from Texas. Therefore, it seems essential that we develop our domestic sources of synthetic liquid fuels to the point where they could be utilized in time of emergency and where they would place a ceiling on the price that could be charged on foreign oil.

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* Data not yet available.

1/ Includes 5 million metric tons of subbituminous coal and lignite.

2/ Includes 97 to 122 million metric tons of lignite and brown coal.

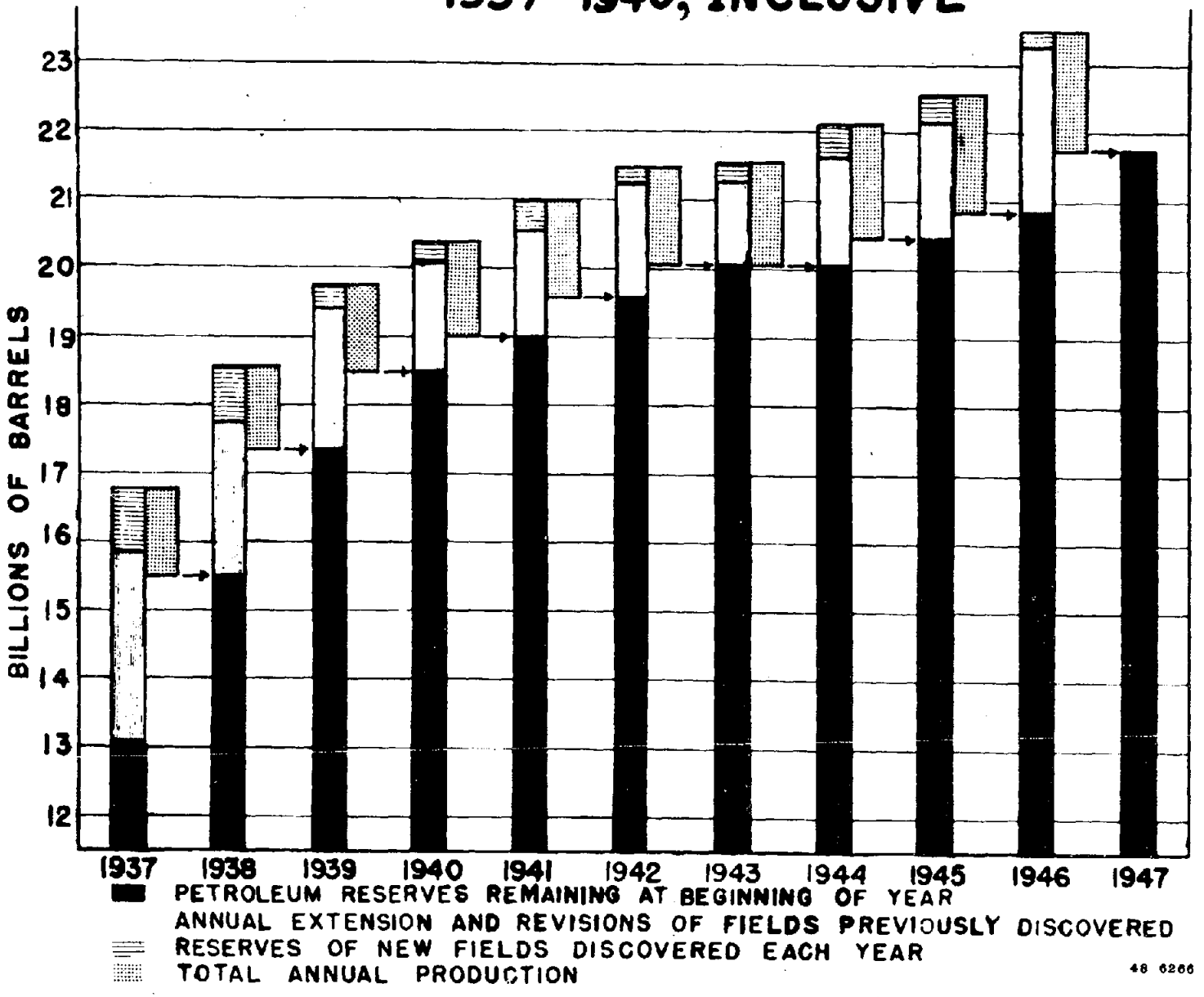
3/ Includes Asia.

4/ Includes 7 million metric tons of lignite and brown coal.

5/ Countries not reported may raise total to 1,380 million metric tons. Includes approximately 125 million metric tons of lignite and brown coal.

FIGURE 5.

HISTORY OF U.S. PETROLEUM RESERVES 1937-1946, INCLUSIVE



Sources of Synthetic Liquid Fuels

A broad survey of other sources of liquid fuels in the United States indicates that petroleum may be supplemented by: (1) Alcohols from the fermentation of vegetable matter; (2) conversion of natural gas by the gas-synthesis process; (3) distillation of oil shale; (4) liquefaction of coal or lignite by the high-pressure hydrogenation process, and (5) conversion of water gas from coal or lignite by the gas-synthesis process. Any or all of these supplementary sources may come into use as petroleum supplies decline to the point where these higher-cost synthetic products become commercially competitive with natural petroleum products.

Alcohol.--Alcohol has been used satisfactorily as a constituent in blended motor fuels in many foreign countries. Its present cost is greater than petroleum gasoline. The place which alcohol will take in the provision of future motor fuels will depend largely on its cost in comparison with gasoline from oil shale, lignite, and coal.

Conversion of Natural Gas.--Natural gas can be converted to carbon monoxide and hydrogen, which are the raw materials required for the production of liquid hydrocarbons by the gas-synthesis process. An improved process has been developed by American industry and a plant is being built by Carthage Hydrocol, Inc., at Brownsville, Texas. The plant capacity per day will be approximately 7,000 barrels of gasoline and Diesel oil and the over-all cost of the products will be competitive with the cost of petroleum products. The natural gas will be obtained from a near-by field at low cost.

A similar commercial plant is to be installed in the Hugoton gas field of southwestern Kansas. With natural gas costing not more than 5 cents per 1,000 cu. ft., engineers of American petroleum companies have estimated the cost of the gasoline produced at figures ranging from 5 to 9 cents per gallon. It is evident that low-cost natural gas in fields remote from markets will be the first source of synthetic fuels to come into commercial use in the United States.

Operation of the commercial plants in Kansas and Texas should give reliable technical and cost data for further development of more natural-gas plants, and also for the longer-range problem of utilizing coal or lignite in the gas-synthesis process.

While the proved reserves of natural gas are somewhat larger than the proved petroleum reserves, in terms of weight or heating value, they are very much smaller than the solid-fuel reserves, and much of the natural gas will find a more profitable outlet than its conversion to liquid fuel at the expense of losing one-half of its heating value.

Oil shale.--The oil-shale deposits are estimated at 92 billion barrels of recoverable oil. This amount is sufficient to supply our requirements at the 1945 rate of consumption of 1.7 billion barrels of oil for about 50 years, or about four times as long as our present proved petroleum reserves. The greater part of the shale reserve is in western Colorado, southwestern Wyoming, and eastern Utah. The assay value of these shales varies from 15 to 60 gallons of crude oil per ton of shale.

Present estimates of the over-all cost per barrel of producing crude shale oil in this country range from $2.00 to $2.50. Oil shale may prove to be an important supplementary source of liquid fuel in the United States. It is a material that has no commercial use at present. Its utilization for the production of liquid fuels would be a sound conservation measure.

Liquid Fuels from Coal.--Liquid fuels may be obtained from all ranks of coal, from lignite to anthracite, by one or more of the following processes: (1) The carbonization of bituminous coal; (2) the hydrogenation of high-volatile bituminous coal, subbituminous coal, lignite, and coal tar, and (3) liquid hydrocarbons by catalytic synthesis from water gas (carbon monoxide and hydrogen) by the Fischer-Tropsch process.

It seems that the gas-synthesis (Fischer-Tropsch) method is perhaps the most promising method for American use, although it does not give a high-octane gasoline for aviation use. The process is being improved and ultimately may be developed to produce aviation fuel. At present the hydrogenation method is best for high-octane aviation gasoline.

The gas-synthesis process can use as raw material any coal, coke, lignite, natural gas, or other carbonaceous material. The coal or other fuel is first converted with aid of steam to water gas, a mixture of carbon monoxide and hydrogen. This mixture of gases is in the proportion of two volumes or one volume of hydrogen to one volume of carbon monoxide and, after suitable purification, is then passed over a solid catalyst at relatively low pressures (1 to 10 atm.) and temperatures ranging from 300 to 400 F. Under these conditions the gases combine to form oils and waxes.

Hydrogenation-process oils are high in naphthenes and aromatic hydrocarbons. The gasoline has a high-octane value (up to 92 octane when treated with tetraethyl lead) and is suitable for aviation gasoline. Gas-synthesis-process oils are composed largely of paraffin hydrocarbons which have a low-octane value. It can be reformed to about 70 octane number and thus is suitable for motor gasoline. However, this process produces an excellent Diesel oil of high cetane number.

Most of the high-volatile bituminous coals, the subbituminous coals, and the lignites of the United States are suitable for the hydrogenation process. Anthracitic coals do not respond to hydrogenation, and progressively lower yields of liquid fuels are obtained, as the volatile matter of the coal decreases to medium-volatile and low-volatile rank. The ash of the coal should be as low as possible, and preferably under four percent. Fortunately, this requirement can be met with many coals because only one-half of the total coal used goes into the liquefiers. This consists of the low-ash portion of the coal, which is separated in a special washing process. The higher ash remainder is burned under the boilers for production of process steam and power used in the plant.

From a conservation point of view, it is fortunate that low- and medium-volatile bituminous coals are not suitable for hydrogenation. On the basis of energy content, these coals comprise only three percent of our total coal reserves. They are needed for the production of metallurgical coke for the steel industry and for supplying semismokeless domestic fuel. The large reserves of high-oxygen, poorly coking coals of Ohio, Indiana, Western Kentucky, and Illinois, and those high-volatile bituminous coals which are not excessively high in ash or sulfur west of the Mississippi River are available and potentially suitable for the production of liquid fuels by the hydrogenation process.

The subbituminous coals of Wyoming, Colorado, and Montana and the lignites of the Dakotas, Montana, and Texas are readily liquefied. From the point of view of wise utilization of mineral resources, these coals constitute appropriate raw materials for synthetic liquid fuels. These coals slack and break down into small pieces on exposure to air. Therefore they do not stand transportation to any great distance from the mines nor can they be stored safely for long periods without some precautions that will retard this weathering process. Conversion of these coals to liquids would solve the storage and transportation problems.

In the assay work thus far conducted in the Bureau of Mines laboratories, liquefaction proceeds most readily in coals of more recent geological age than carboniferous. Approximately six-tenths of a ton of high-grade bituminous coal is required for the production of one barrel of gasoline. Progressively larger amounts of coal are required as the rank of the coal decreases. For subbituminous coal, the requirement is 0 nine-tenths of a tons and for lignite 1.2 tons.

The gas-synthesis or Fischer-Tropsch process had a much wider application to more diverse raw materials than does the hydrogenation process. Almost any carbonaceous material can be reacted with steam to produce carbon monoxide and hydrogen, which in turn are reacted with each other in their conversion to liquid hydrocarbons. Raw materials that have been used for this purpose include anthracite, all ranks of bituminous coal, coke, lignite,

coal gas, natural gas, charcoal, wood, and other vegetable matter. The German plants used coke from bituminous coal in the Ruhr district and brown-coal briquete or brown-coal char in central Germany.

In the Appalachian region, the necessary synthesis gas can be produced from the lower grades of anthracite that do not find a ready market at the present time, and from high-volatile bituminous coals unsuitable for metallurgical coke.

The Interior Province on both sides of the Mississippi River, with its very large reserve of poorly coking coals and its large population, is in a favorable position for the development of a synthetic-liquid-fuel industry. However, the largest reserves of solid fuels that seem to have the most promise for future conversion to liquid fuels are the lignitic and subbituminous coals of the Dakotas, Texas, and western Great Plains States. North Dakota alone has a reserve of 600 billion tons of lignite, and Wyoming has 590 billion tons of subbituminous coal. Some of these coals occur in very thick (20- to 50-ft.) beds, and in one operation in Wyoming a total thickness of 80 feet is mined in an open strip pit. Strip mining under such conditions is inexpensive. It may be able to contribute enough saving in the cost of raw materials to compensate for the lower yields of liquids obtainable from these low-rank fuels. Transportation costs of the liquid product to centers of consumption is, of course, a handicap for plants in these fields. However, this problem will be no greater than it has been in the development of the great midcontinent petroleum industry.

Conclusion

In conclusion, the fuel reserves of the United States, solid, liquid, and gaseous, may be summarized as amounting to the energy equivalent of 2.5 trillion tons of bituminous coal having a heating value of 13,000 B.t.u. per pound. Coal and lignite comprise 97.5 percent of this energy reserve; 55 percent of this solid-fuel reserve consisting of high-volatile bituminous coal, 23 percent subbituminous coal, 19 percent lignite, 2.5 percent low-volatile bituminous coal, and 0.5 percent anthracite. The highest-rank and the highest-grade coals, amounting to about one-sixth of our total tonnage of coal and lignite, occur in the Eastern and Appalachian States, where industry and population are more concentrated. Another one-sixth occurs in the Central States on both sides of the Mississippi River. This coal is of lower rank, and much of it is of lower grade, but it is all of high-volatile bituminous rank, although less strongly coking than the eastern coals. Of the remaining two-thirds of our solid-fuel reserves, 80 percent consists of subbituminous coal and lignite in the Dakotas, Montana, Wyoming, Colorado, and Texas. All of these fuels can be converted by suitable processes to gaseous and liquid fuels. Some are operating commercial processes that have been used for many years in the gas- and coke-manufacturing industries. These are applicable to the coking coals of the Eastern and Central States.

No processes are operating commercially in this country for the production of fuel gases from the low-rank noncoking coals that predominate in the Western States. However, such processes have been developed and were in commercial operation before and during the war in Germany. It is probable that these methods can be modified for the gasification of American lignite and subbituminous coal, and it is possible also that new methods may result from American research now in progress in several organizations.

COLONEL HORNOR: I am sure Dr. Fieldner has covered the field thoroughly. Since it is getting rather late, we will have time for only two or three questions.

QUESTION: What is the approximate loss factor in converting coal into liquid fuels?

DR. FIELDNER: About six-tenths of a ton of bituminous coal is required to make a barrel of oil, and the loss in heating value in the conversion is about 50 percent. That is what I have used in my calculations. That is why it is such a drain on our coal reserve to make oil or gas from coal. Whether one makes oil or gas, about half of the B.t.u. value of the coal is lost in the process of conversion into the liquid or gaseous product.

QUESTION: I understand that the current demand for crude oil is roughly a million barrels a day in excess of the present United States supply. Assuming that figure is relatively correct, how much would it cost and how long would it take to produce the differential synthetically?

DR. FIELDNER: We have estimated that it would take ten years to design, build, and get into production plants having an aggregate capacity of two million barrels of synthetic oil a day. It requires many plants and much coal, also about 16 million tons of steel and a great deal of water. About 20 to 30 barrels of water, for cooling and reaction purposes, are required for each barrel of oil produced. The investment cost for these plants has been estimated as 9 billion dollars. The cost for a sufficient number of plants to make one million barrels a day would be half as much but the time to get them in full production would be almost the same as for two million barrels a day capacity because the developmental period would be about the same in both cases.

COLONEL HORNOR: Dr. Fieldner, I want to thank you for a very instructive and interesting lecture.

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