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UNITED STATES
DEPARTMENT OF THE INTERIOR
HAROLD L. ICKES, SECRETARY

BUREAU OF MINES
R. R. SAYERS, DIRECTOR

REPORT OF INVESTIGATIONS

TRENDS IN THE USE OF ENERGY IN THE WESTERN STATES WITH PARTICULAR REFERENCE TO COAL

BY

V. F. PARRY

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

TRENDS IN THE USE OF ENERGY IN THE WESTERN STATES[1]

With particular reference to coal

By V. F. Parry[2]

CONTENTS

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Report of Investigations 3680."

2/ Senior fuel technologist, Bureau of Mines Field Office, Golden, Colo.

ILLUSTRATIONS

TABLES

TABLES (Cont'd.)

ACKNOWLEDGMENTS

The author wishes to acknowledge the advice and criticism of A. C. Fieldner, chief, Coal Division, Bureau of Mines; the assistance of Durbin Van Law, consulting industrial engineer, Denver & Rio Grande Western Railroad, Denver, Colo., who furnished valuable information on trends of coal production in Utah by making available his unpublished report "Utah Coal Industry"; the aid of J. C. Beltz, associate research chemist, Bureau of Mines, Washington, D. C., who reviewed and checked the data; and of W. S. Landers, assistant chemical engineer, Bureau of Mines, Golden, Colo., who assisted in the preparation of many of the statistical data in this report.

INTRODUCTION AND SUMMARY

The amount of energy required to support a unit volume of industrial production appears to depend on the volume of industrial production, efficiency of utilization of fuel, the form of energy used, climate, and population served. Previous to the first World War, industries of the United States were learning how to use the vast resources of energy that were available. From 1895 to 1900 the total amount of energy produced was equivalent to 3.7 tons of 13,100 B.t.u. coal per capita, but from that period until 1920 the energy used increased steadily until it reached an average of 7.7 tons per capita. Since that time the amount used has fluctuated with business conditions and has averaged 6.9 tons per capita.

The 12 Western States, including North Dakota, contain two-thirds of all estimated coal and lignite reserves of the United States, but during the last 10 years production from this area has averaged less than 6 percent of the bituminous coal produced in the United States, and the proportional production has decreased steadily for 20 years. Figure 1 and table 1 give the location and estimated reserves of coal in the Western States. A superficial review of the western coal industry yields a pessimistic picture, but upon further examination the prospect appears to be bright for a moderate expansion of the industry to meet the demand for total energy to be consumed in the Western States.

The actual amount of energy produced in the West is more per capita than is produced in the United States as a whole. For 20 years the average production of energy in the 11 Western States, excluding the Dakotas, has been equal to 8.8 tons of coal per capita, or 27.5 percent more than the average of the United States.3/ Some of this energy is shipped to the East, but it is shown in this report that the Western States and the East use about the same relative amount per capita. In 1921, oil, natural gas, and hydro-power contributed 55 percent of all the energy produced in the West, but today these same forms of energy constitute 84 percent of all that is produced. The decline in use of coal was rapid from 1920 to 1924, but it has been less each year since then. From 1938 to 1941 the proportion of energy supplied by coal increased from 14.5 to 16.3 percent of the total produced. This increase may be due to subnormal industrial activity in 1938 and to abnormal industrial activity in 1941 or to other factors, such as the tendency for hydro-power to carry base loads. Nevertheless, it appears that the bottom has been reached and production of coal in the West should increase to meet a greater share of the demand for total energy. During the 1942 meeting of the American Association of Petroleum Geologists in Denver, Colo.,4/ there was some concern over the declining rate of discovery of new sources of petroleum, and the present war emergency places a new value on oil. These trends indicate that coal as a source of energy will become increasingly more important, especially to displace oil for uses that can be met just as efficiently by coal.

The object of this report is to analyze the trends of production of the different forms of energy and to determine the factors that affect the production and use of coal in a given area. The fuel statistics of the United States, the Rocky Mountain States, and the Pacific coast are analyzed to determine the relative position of the different forms of energy, and data are presented to show the trend in preparation of different sizes of coal and the

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3/ The "Western States" discussed in this paper exclude North Dakota because most of liginite mined in North Dakota is shipped eastward and competes with eastern coal.

4/ Research Committee, American Association of Petroleum Geologists, A symposium on Petroleum Discovery Methods; April 1, 1942, 164 pp.

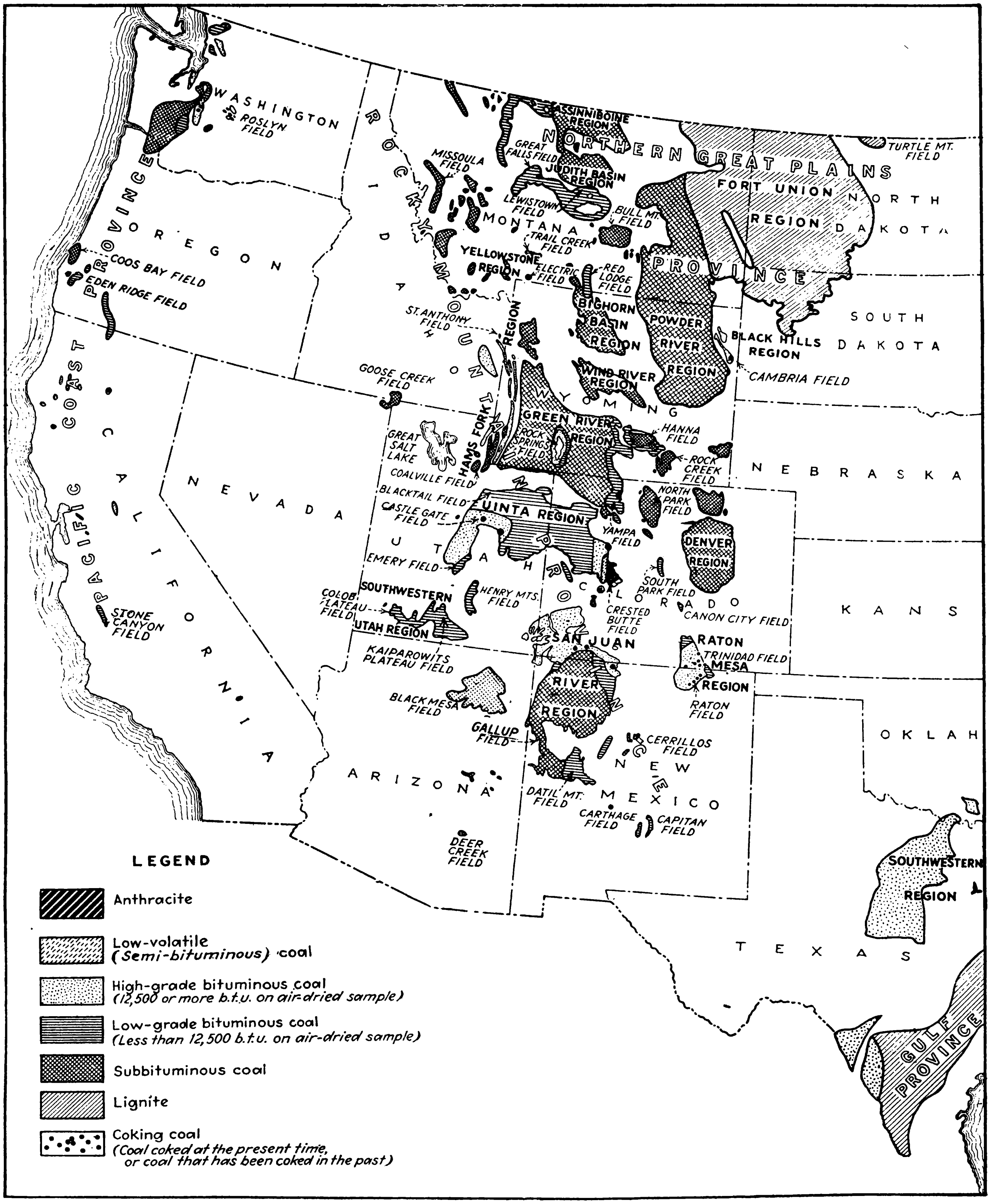

Figure I.- Coal fields of the Western States. (Prepared from 1917 base map, Federal Geological Survey.)

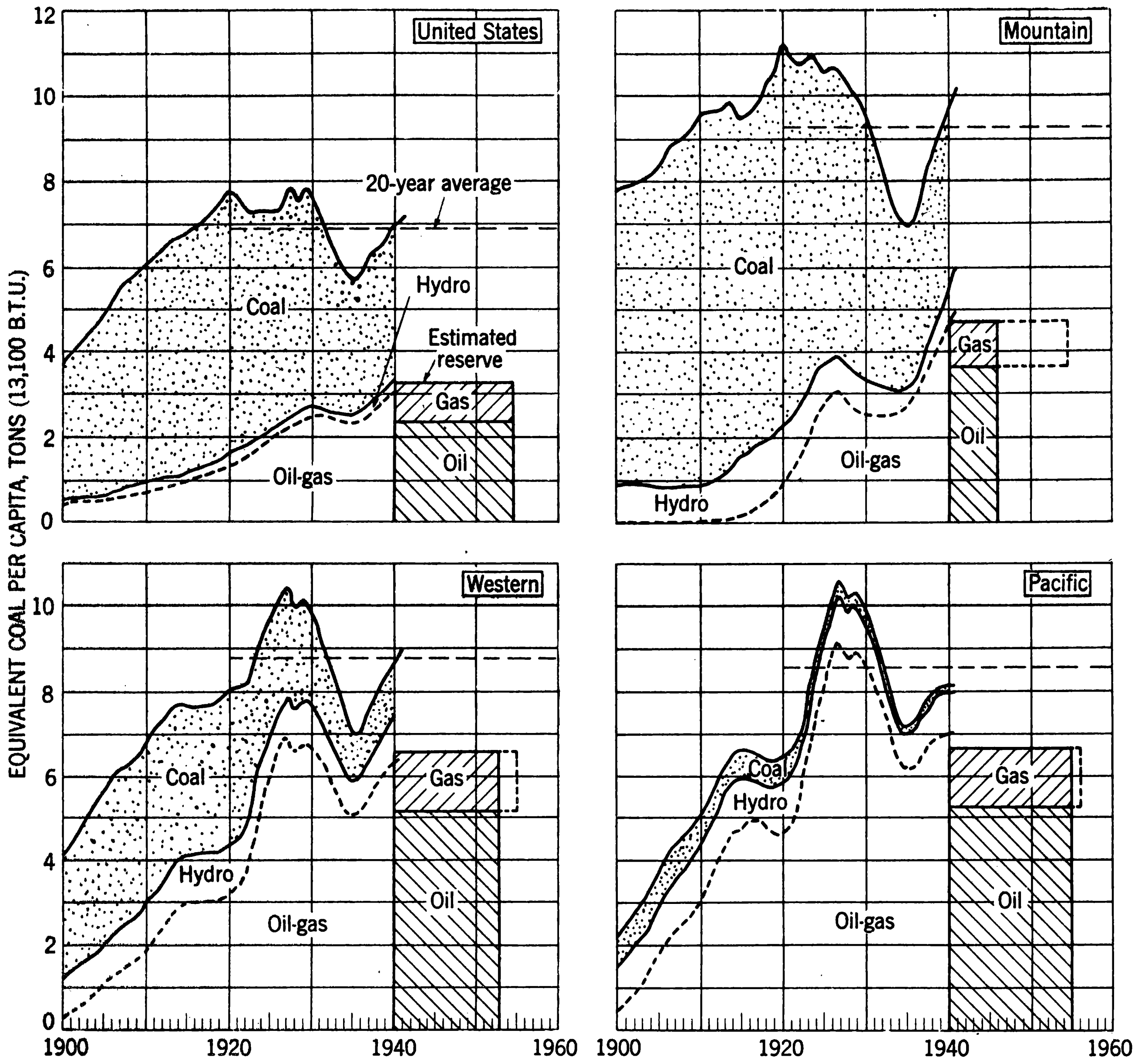

Figure 2.- Energy production per capita, 5-year averages ending year noted.

trends in prices. The major physical and chemical properties of solid fuel mined in the West are listed. A brief resume is given of present knowledge of hydrogenating western coal to make gasoline, and of carbonizing these coals for manufacture of metallurgical coke.

It is shown that the amount of total energy required for industrial purposes depends on population, amount of industrial activity, and rate of technologic improvement in the use of energy. The demand for domestic fuel is about 1.65 tons of 13,100 B.t.u. coal per capita. A formula is derived that correlates total energy demand, domestic fuel, population, improvement in technology, and the Federal Reserve Board Index of Industrial Production.

TABLE 1. - Reserves in 1935 and production of coal in the Western States, 1940 1/

	Anthracite	Reserves, billions of tons: Bituminous	Subbituminous	Lignite	Total	Production, 1940, 2/ thousands of tons
Arizona						
California						
Idaho		0.7	1.8		2.5	22
Oregon						
Nevada						
Colorado	0.09	212.6	104.0		316.7	6,516
Montana		2.6	62.9	315.5	381.0	2,974
New Mexico	(3/)	18.8	1.9		20.7	1,081
Utah		88.0	5.2		93.2	3,524
Washington	(3/)	11.2	52.4		63.6	1,688
Wyoming		30.3	590.0		620.3	5,748
North Dakota				600.0	600.0	4/ 2,256
Total	.09	364.2	818.2	915.5	2,098.0	23,809
United States	15.4	1,407.8	818.2	939.5	3,180.8	504,730

1/ Hendricks, T. A., Coal Reserves: Fuel Reserves of the United States, Pt. 2, Sec. I., pp. 281-286. Report of Energy Resources Committee: Energy Resources and National Policy, National Resources Committee, January 1939, Government Printing Office, Washington, D. C.
2/ Bureau of Mines, Minerals Yearbook, Review of 1940, p. 767.
3/ Less than 0.0001.
4/ Includes South Dakota.

RELATIVE POSITION OF COMPETING FUELS

The amount of each form of energy produced per capita in the United States, the Rocky Mountain area, and the Pacific Coast since 1900, is shown in figure 2.5/ Coal formerly has supplied a greater proportion of the per

5/ The sources of data, method of construction, and explanation of each chart are described in the appendix at the end of this paper.

capita energy in the Rocky Mountain area than in the United States, but at the present time, the proportion is about the same. Coal supplies only about 2 percent of the total energy produced in the Pacific Coast States. Although the average production of energy per capita in the United States has been equal to 6.9 tons of coal during 1920 to 1940, the average production in the Rocky Mountain States has been 9.2 tons, and on the Pacific coast production amounts to 8.6 tons. In other words, the Western States produce relatively more energy. Since energy is shipped to the West coast from the Mountain States and oil is shipped to the Rocky Mountains and the East from the Pacific coast, both areas comprising the 11 Western States have to be combined to show the trend of energy production in the West, and the data for this combined area are labeled "Western."

The per capita production of oil and gas in the Western States increased about 400 percent from 1900 to 1930, steadily displacing coal. Since 1930 the average production of oil and gas has been equivalent to 6.6 tons of coal per capita, or 60 percent more than during the first World War (1915 to 1920). Hydropower in terms of equivalent coal has actually decreased in relative amount when considered as a competitor of coal. Although it has so increased, the per capita increase, expressed as coal equivalent, using the prevailing fuel equivalent in central stations, decreased relative to increase in production of other fuels until 1923. Since that time there has been a slight relative increase as the large hydroprojects have come into operation. Figure 3 shows this trend. The average production of total energy in the 11 Western States has been 8.8 tons of 13,100 B.t.u. coal per capita, or 27.5 percent more than the average for the United States.

An estimate of the amount of energy that might be supplied in the future by coal, hydropower, and new discoveries of oil and gas can be made from the data in figures 2 and 3. The cross-hatched area marked "gas and oil" in figure 2 represents the present estimated, proved reserves of gas and oil in terms of tons of 13,100 B.t.u. coal per capita. The average production of total energy for the last 20 years has been equivalent to 6.9 tons of 13,100 B.t.u. coal per capita. Although the amount fluctuates each year with business conditions, it can be assumed that requirements over a long period will average about 7 tons per capita. If this rate is extended to 1970, the area under the projected line in figure 2 becomes a measure of total energy required. As the rate of discovery of oil is now less than the rate of production, a line representing new discoveries of oil and gas would extend downward from the top right-hand corner of the cross-hatched area at an angle depending upon success attained in making new discoveries. If it is assumed that the angle is 30° with the horizontal, and estimate can be made of the probable average production of the different forms of energy:

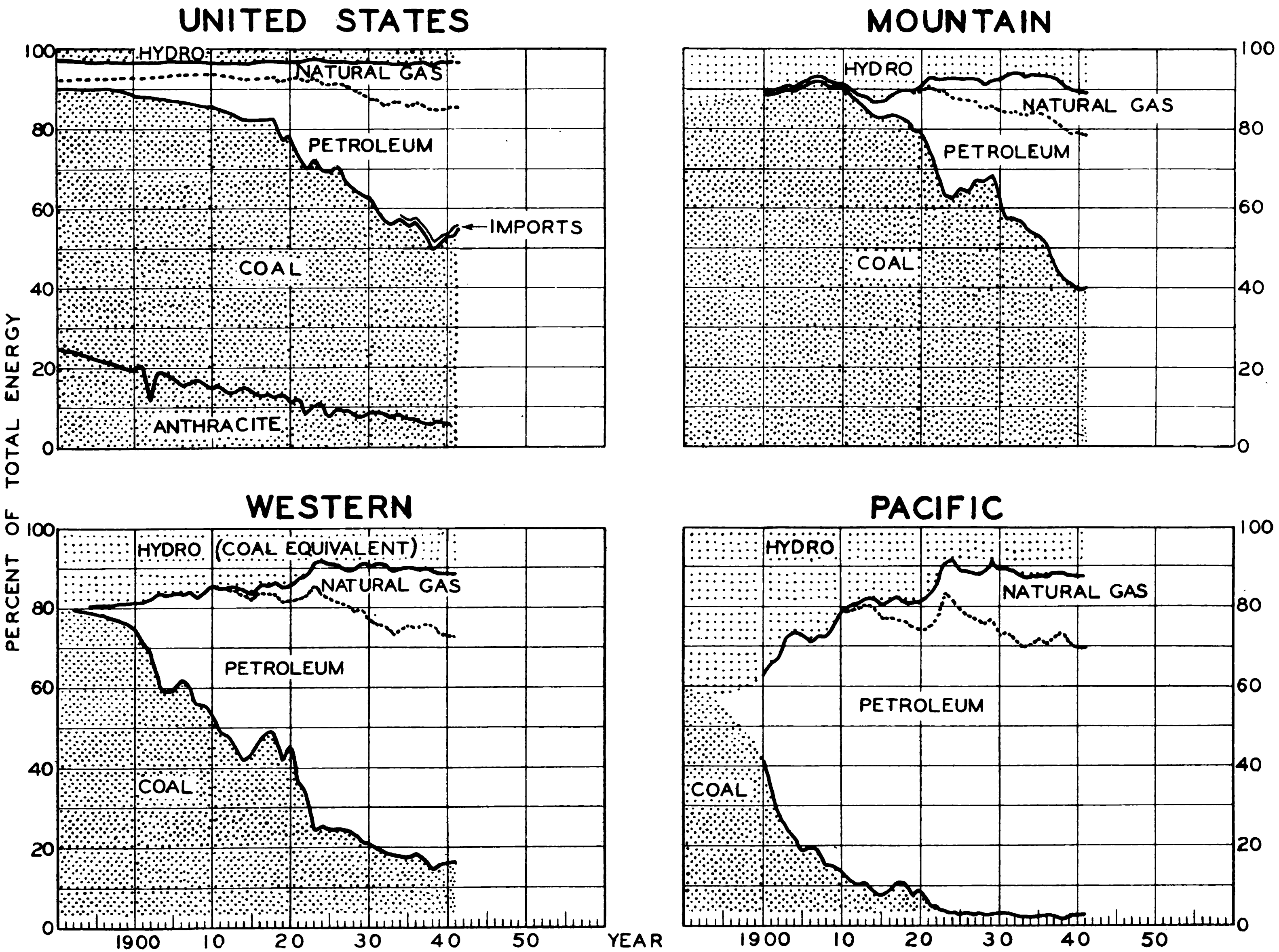

Figure 3.- B. t. u. equivalent of fuels produced, 1890-1941.

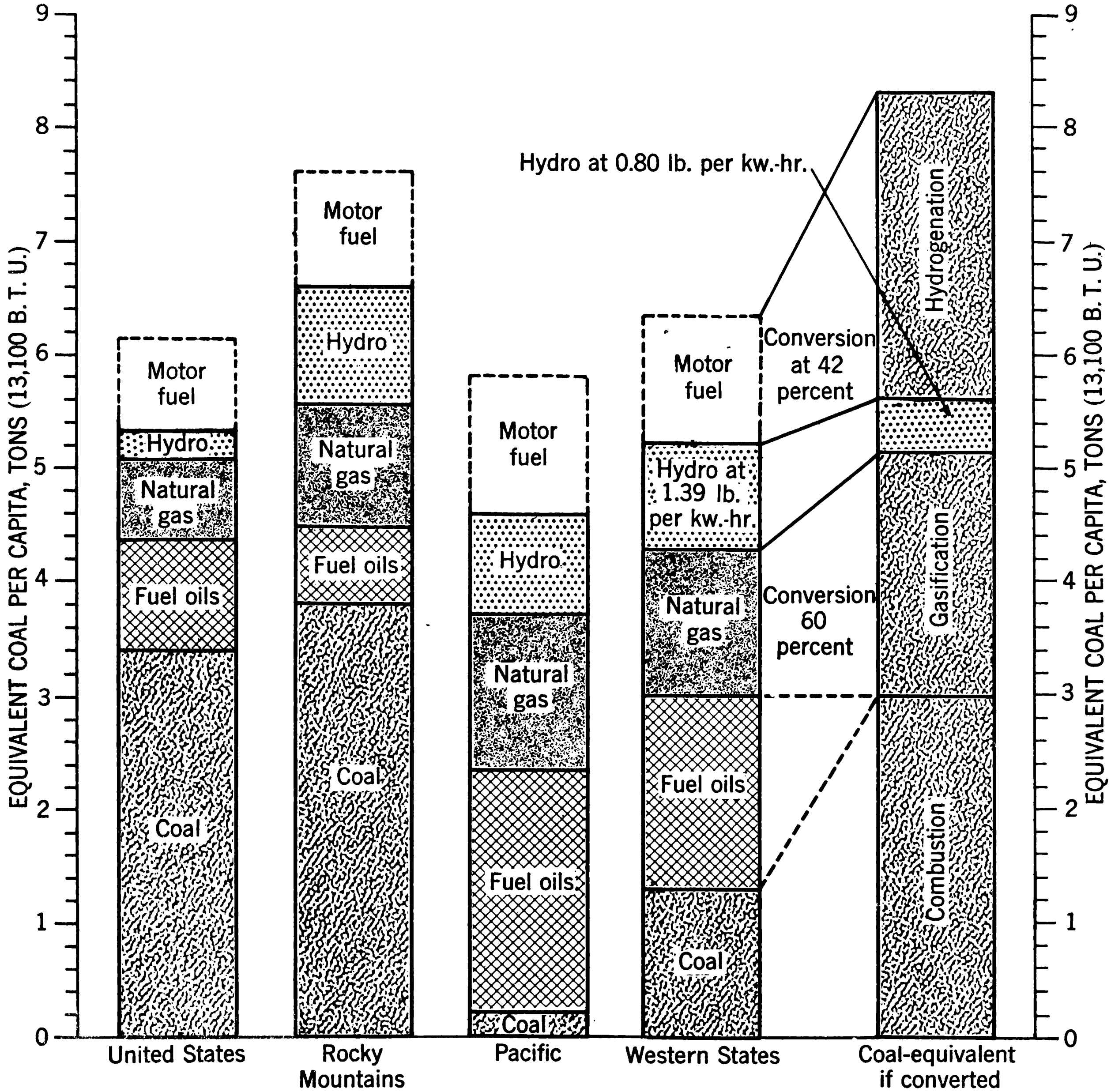

Figure 4.– Sales of competing fuels in 1939. Forms of energy used per capita expressed in terms of tons of 13,100 B. t. u. equivalent coal. The bar at right shows coal required to make different forms of energy used in 1939 in Western States, and it indicates improvement in average efficiency of production of electric power from coal.

		Tons of equivalent coal per capita
Total energy required, 1940 to 1970 (30 x 7.0)	=	210
Proved oil and gas reserves (3.2 x 14)	=	42.8
Estimated new oil and gas discoveries (2.4 x 16)	=	38.4
Water power equivalent (0.25 x 30)	=	7.5
Energy from coal by difference	=	121.3
Estimated average annual coal production 1940 to 1970, 121.3/30	=	4.03

These comparisons indicate probable expanded production of coal, especially in the Western States, where oil and gas now constitute such a large percentage of the total energy produced.

The relatively large quantities of gas and oil produced in the Western and Pacific Coast States is illustrated in figure 3, which shows the percentage distribution of the different kinds of energy produced. The Rocky Mountain area appears to be quite similar to the United States in regard to proportions of fuel produced, but the Pacific Coast States have almost no place for coal in the present energy picture. During the period of the first World War the proportion of energy supplied by coal increased in the United States. This was probably due to increased demand for metallurgical coke as well as increased rail traffic. The same trend appears in 1938-41, when coal increased from 50 to 55 percent of total energy. These trends are not as apparent in the diagram for the Western States, but the proportion has been increasing since 1938, reflecting increased industrial activity.

The amount of energy consumed per capita in the Western States, exclusive of motor fuel, is virtually equal to the consumption of energy per capita in the United States. Figure 4 shows the sales of competing fuels during 1939, a year in which the industrial activity index was about 100. The Rocky Mountain States appear to consume more, and the Pacific States consume less, proportionally. However, this difference is probably due to the greater relative production of railroad fuel, longer distances of travel in the Rocky Mountains, and a milder climate on the Pacific coast. The greater efficiency of utilization of oil and gas in small installations is a factor influencing the difference in consumption of energy.

The bar on the right-hand side of the figure indicates the coal that would be required if all energy used in the Western States, except hydropower, were derived from coal. This total requirement of energy may eventually be supplied by coal and hydropower when reserves of oil and gas are depleted. The comparison indicates that approximately 32 percent more energy than now used per capita would have to be produced to supply the energy required. If the Western States were forced to supply gasoline and gas from coal, and if coal displaced fuel oil directly, the production of coal per capita in the West would increase approximately 500 percent over present production. In other words, approximately 7.8 tons of 13,100 B.t.u. coal would be required per capita, compared with 1.3 tons produced in 1939. Production of gasoline from coal by conversion through hydrogenation or synthesis would consume large quantities of coal to supply the amount of motor fuel now used. A. C. Fieldner[6] estimates that a ton of average bituminous coal is required to make about 2 barrels of gasoline, or that the conversion efficiency is approximately 42 percent.

Correlation of Energy Production and Industrial Production

The total amount of energy now produced and consumed in the United States appears to follow the cycle of industrial activity. This is indicated in the graphs of figures 2 and 5. A further correlation of energy produced with the Federal Reserve Board Index of Industrial Production is shown in figures 5 and 6. A direct correlation is indicated by comparing the actual and calculated values. The formula can be used to estimate the demand for energy as business conditions change. It is shown by the equation in figure 6 that the amount of energy required per unit of industrial production decreases each year. In other words, the amount of gross heat needed to create goods and services has decreased an amount equivalent to 175 pounds of coal per year for each person served during the last 20 years. It is probable that this trend will continue until the maximum efficiency of a combustion and utilization is attained in all fuel-burning equipment. This decrease is a measure of improvement in efficiency of use of fuel, efficiency of manufacture of higher value fuels from coal, mass production, and other factors that make up our industrial economy; but changes in our industrial economy as a result of the war effort may alter this trend. The last two years of this figure give an estimate of the demand for total energy for this period, as production data are not yet available.

It should be noted in these graphs that the fuel having the highest form value displaces fuel of lower form value. This is a natural trend, because the higher-value fuels are easier to use, are uniform in quality, and con-

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6/ Fieldner, A. C., Davis, J. D., and Storch, H. H., Gasoline Substitutes from Coal: Reprinted from a hearing before a Subcommittee of the Committee on Interstate and Foreign Commerce, House of Representatives, 76th Cong., on H. Res. 290 and H. R. 7372, 1940, pp. 277-286.

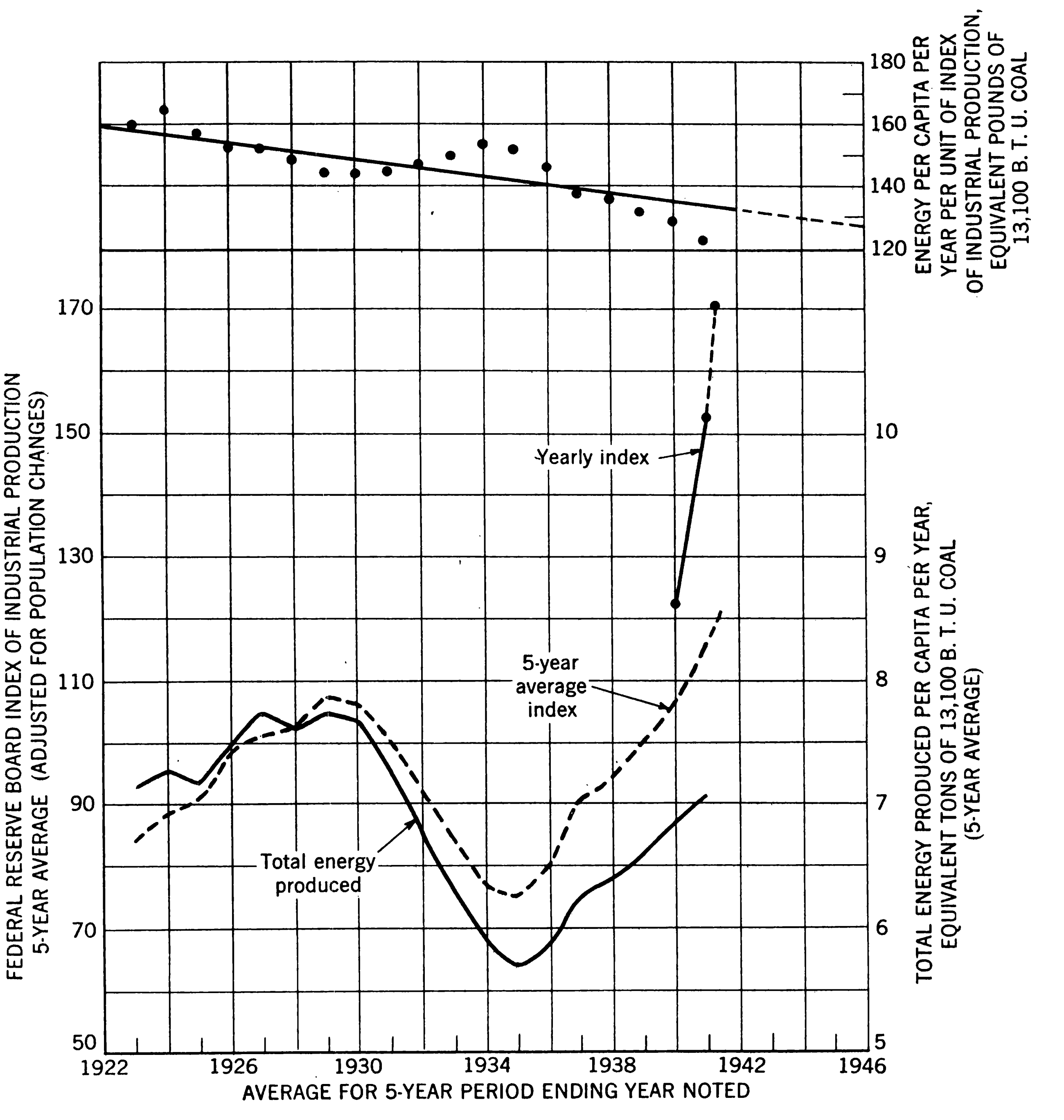


Figure 5.- Relation of total production of energy in United States to index of industrial production, 1919-41.

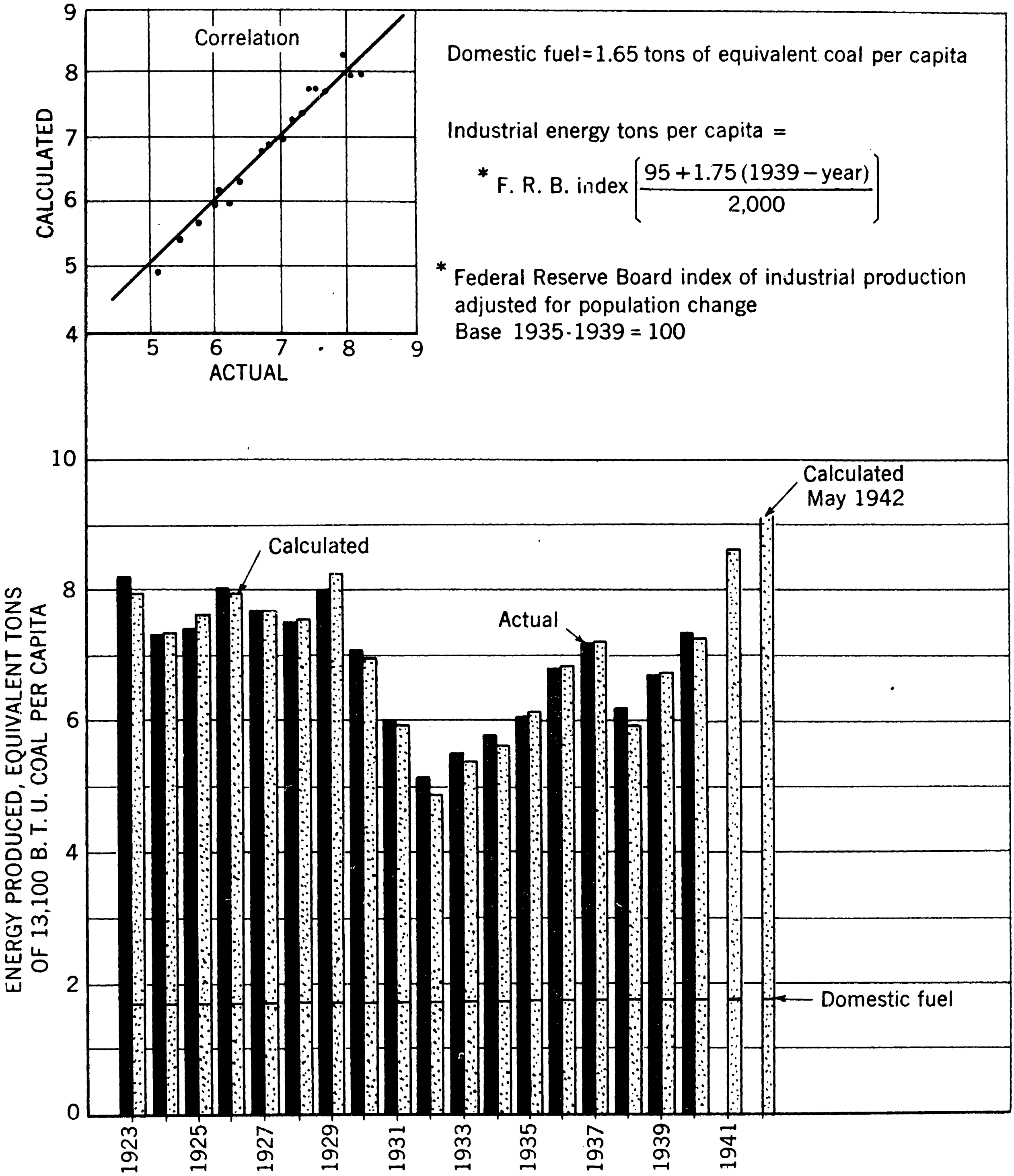


Figure 6.- Correlation of total annual production of energy in United States with Federal Reserve Board index of industrial production.

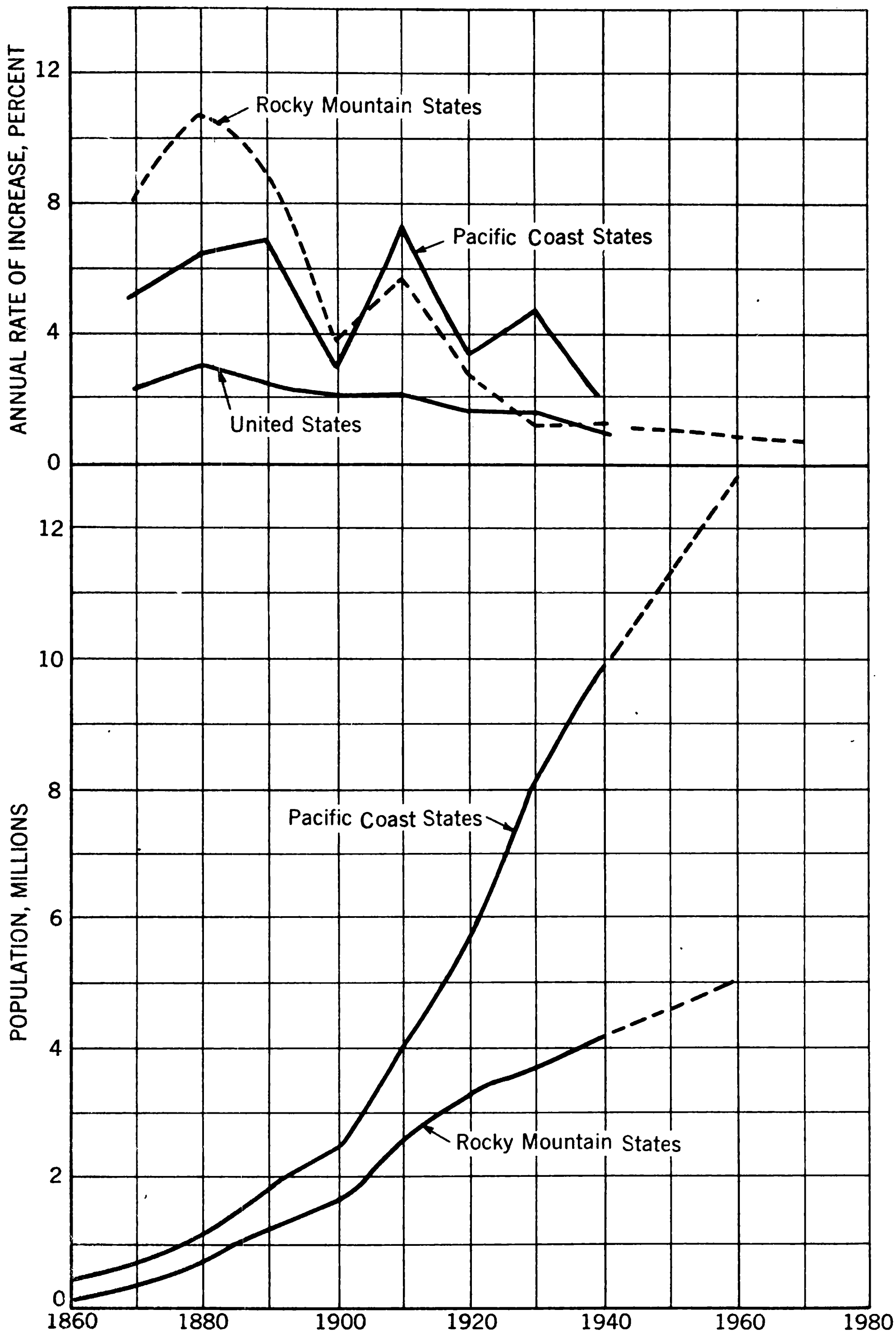


Figure 7.- Population trends, Western States. Rocky Mountain States are Montana, Wyoming, Colorado, New Mexico, Arizona, Utah, Idaho, and Nevada. Pacific Coast States are California, Washington, and Oregon.

sequently are more desirable. The following arbitrary listing of the different kinds of energy shows, from the author's point of view, the order of preference of types of energy:

Listing of Fuels With Respect to Form and Utilization Value

Electric power.
Oil.
Natural gas.
Water gas.
Producer gas.
Pulverized coal.
Anthracite.
Coke.
Briquetted low-volatile coal.
Bituminous coal, low-volatile.
Bituminous coal, high-volatile.
Subbituminous coal.
Lignite.

Lignite is at the bottom of this list and different higher-rank coals ascend towards the top. If coal is to displace the higher forms of energy it must acquire both standardized quality and uniformity of form value. Pulverized coal approaches these requirements. Much research will be necessary to define all the properties of coal to meet these ends. Research to improve both form value and our knowledge of properties of coal, especially the physical properties, is the best insurance for increasing the use of coal.

Natural gas appears to be a more direct competitor of coal than is petroleum. Oil is a form of mobile energy and has additional value because of that property, but natural gas must be used almost entirely in stationary equipment supplied through pipes. Although much natural gas is used for industrial purposes, the preferred use is for domestic heating, and eventually it will probably be used only in that way, except for industrial applications requiring gas. Therefore, in viewing competition of natural gas with coal, producers of coal must have patience and realize that eventually the higher form value of natural gas will cause it to be taken from the industrial market because it is an ideal fuel for domestic heating. Figure 2 indicates that reserves of gas are not too plentiful. Restrictions now appearing to conserve oil may also be applied to limit the use of gas in the future.

CHARACTERISTICS OF THE COAL INDUSTRY IN THE WESTERN STATES

The Western States have 8.6 percent of the mines, about 10 percent of the population, and they now supply about 5 percent of the coal produced in the United States. This is revealed in table 2, which gives statistics and comparisons from the Bureau of Census on production, employment, value, and output per man in western coal fields and in the United States. The mine value, or the cost of production, is higher on the average than that of eastern coal, even though some western mines have lower costs than any eastern mines and the average production per man day is higher in the West. The low cost of production of railroad coal in Montana and Wyoming through stripping operations and mining in easily worked seams is not indicative of mining costs in Colorado and Utah, where many smaller mines operate to supply domestic fuel. Utah has favorable mining conditions in thick beds and enjoys the highest average production per man day in underground mines. In general, the costs of producing bituminous coal are revealed more accurately by the figures for Utah and Colorado, where underground mining is practiced. Although approximately 10 million tons of bituminous coal was mined in 1940 in Colorado and Utah, only 12 percent of it was coked for industrial purposes.

The amount of coal produced is shown in figure 8 and the relative tonnage production in each of the Western States is shown in figure 9, which reveals that relative production of coal in Utah has increased steadily, it has remained about constant in Wyoming, and in Colorado it has decreased. The proportional production in Washington has decreased steadily for 50 years, whereas in Montana it has expanded, principally on account of the increased production of railroad fuel from the Colstrip mine operated for the Northern Pacific Railroad.

Size of Mines

A study of the relationship between coal production and size of mines is given in figure 10, which compares mining in Colorado and Utah with mining in Pennsylvania, West Virginia, and Illinois during 1938-39. This graph shows that coal mining in Utah is similar to that in Illinois, or, in other words, most of the production is from a few relatively large mines. Likewise, coal mining in Colorado is similar to that in Pennsylvania, but the average size of mine is considerably smaller in Colorado. This study shows that approximately 50 percent of the coal produced in Colorado is from 19 mines having an average output of about 150,000 tons a year each, whereas half of the coal produced in Utah (1,600,000 tons) is from 4 mines having an average output of about 400,000 tons a year. Mines in the East

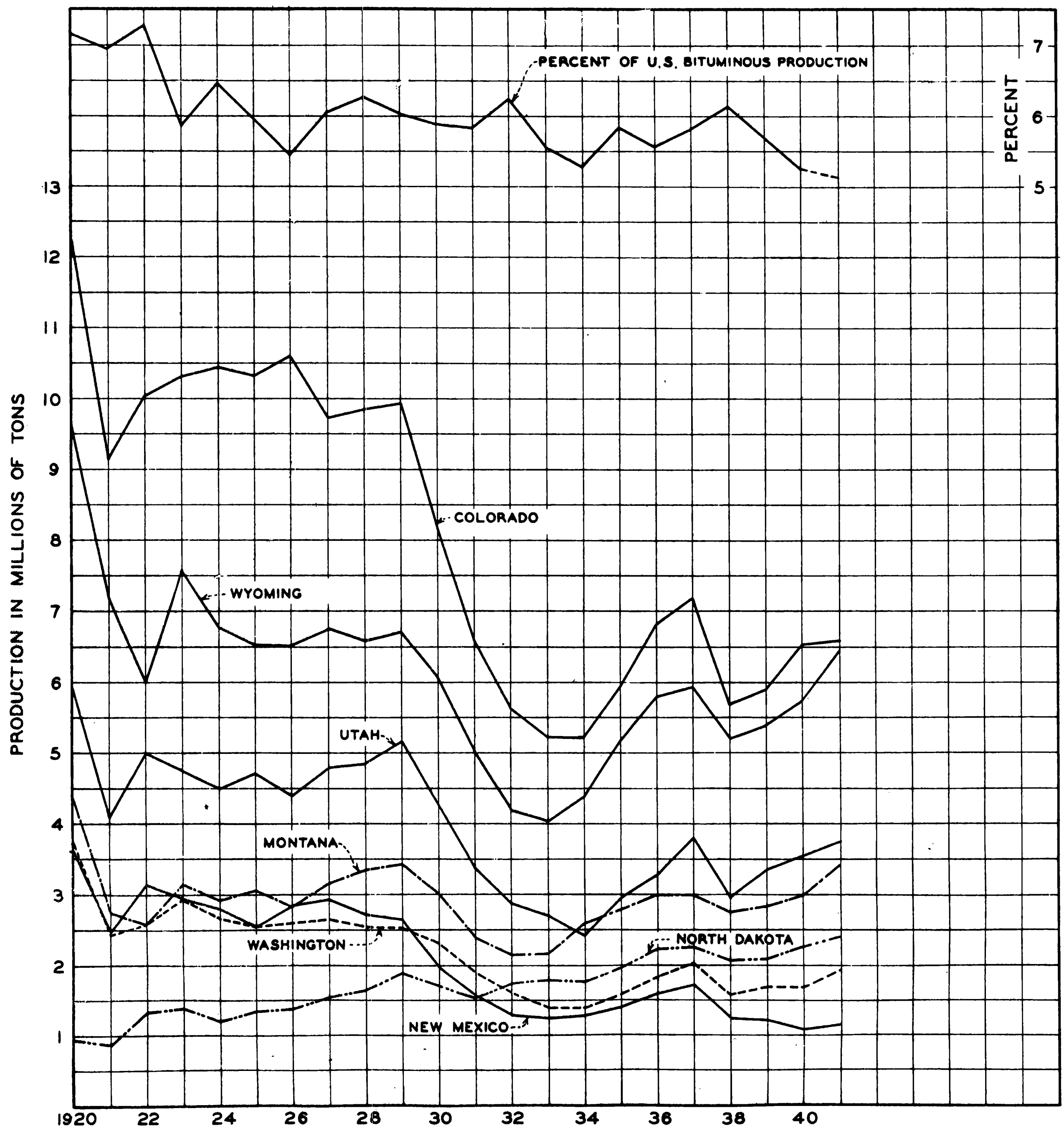


Figure 8.- Production of coal, Western States, 1920-41.

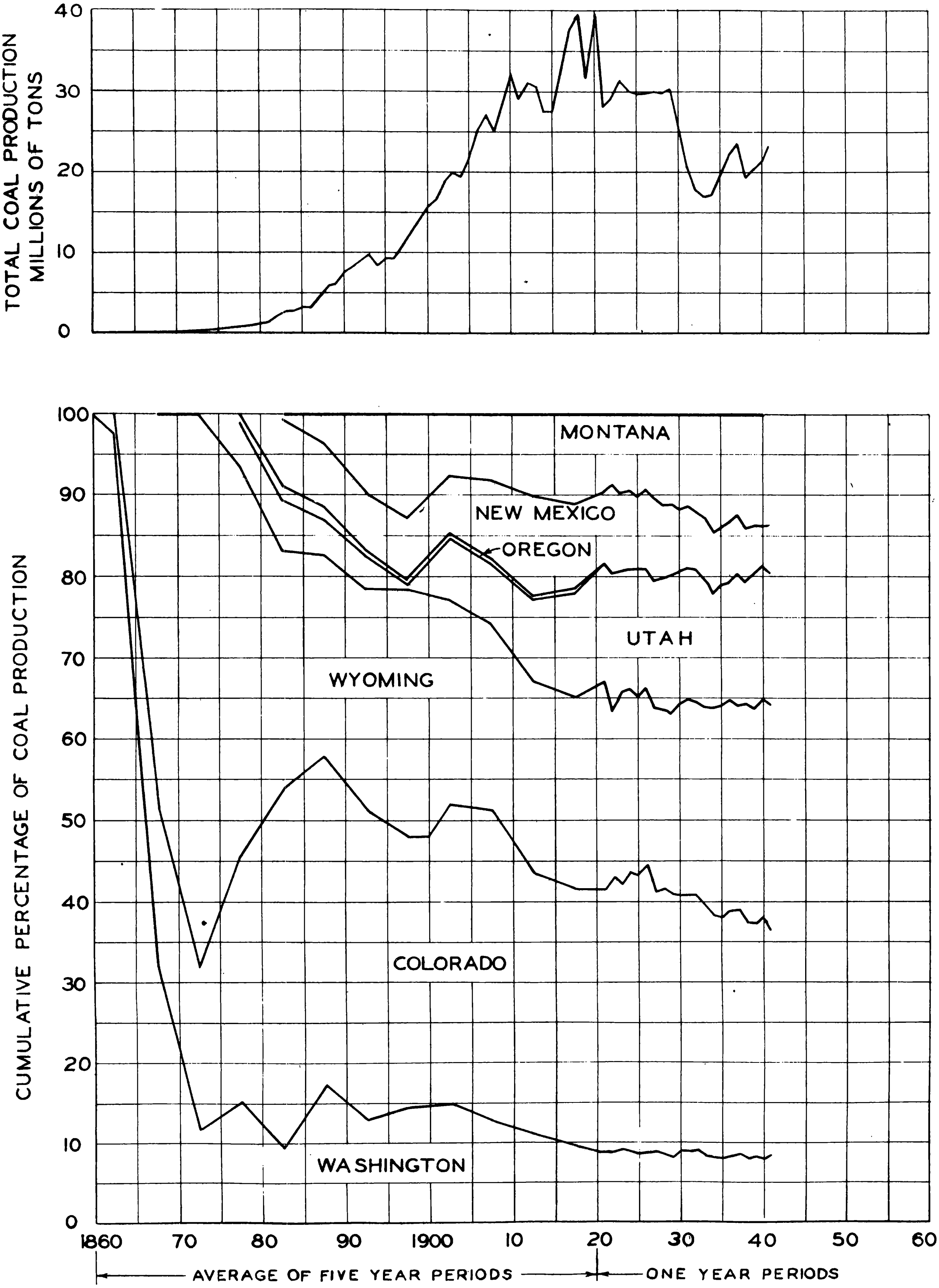
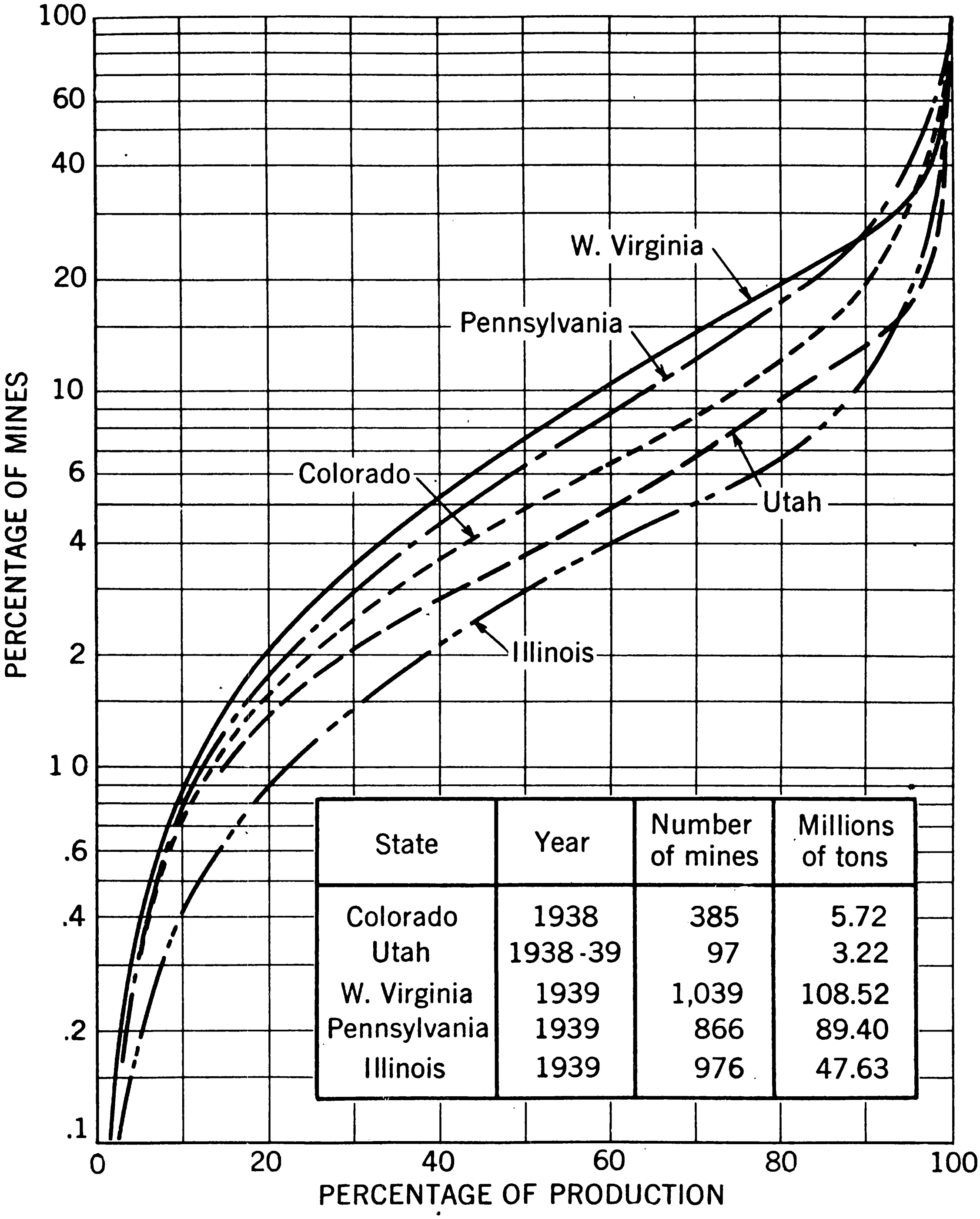


Figure 9.- Production of coal, Western States, 1860-1941, tonnage basis.



State	Year	Number of mines	Millions of tons
Colorado	1938	385	5.72
Utah	1938-39	97	3.22
W. Virginia	1939	1,039	108.52
Pennsylvania	1939	866	89.40
Illinois	1939	976	47.63

Figure 10.- Relation between number of mines and relative production of coal. Sources of data: Colorado: Twenty-sixth Annual Report, State Inspector of Coal Mines, 1938. Utah: Report of Industrial Commission, Fiscal Year 1938-39; Survey for the Denver & Rio Grande Western Railroad, Fiscal Year 1938-39, by Durbin Van Law. West Virginia: Annual Report, Department of Mines, 1939. Pennsylvania: Annual Report, Department of Mines, 1939. Illinois: Coal Report, State of Illinois, 1939.

TABLE 2. - Production, employment, and output per man in the bituminous-coal industry, Western States, 1939 1/

	Colorado	Utah	Montana	Wyoming	Washington	New Mexico	California, Oregon, Nevada, Arizona, and Idaho 2/	Total or weighted average	United States
Population (1940 census) ..thousands	1,123	550	559	251	1,736	532	9,131	13,881	133,669
Operating companies	197	50	58	23	42	37	5	412	4,979
Mines	211	51	59	66	52	42	5	486	5,686
Production .thousands tons	5,923	3,284	2,756	5,373	1,690	1,230	2/ 9	20,265	391,728
Men employed	8,294	2,618	1,331	4,353	2,409	2,387	2/ 100	21,492	393,308
Men employed, percent of population 3/....	0.74	0.47	0.24	1.73	0.14	0.45	2/ 0.01	0.15	0.29
Days operated	176	171	168	207	191	166	2/ 88	182	178
Tons per man shift 4/.	4.12	7.53	11.87	6.92	3.90	3.37	2/ 1.59	4/ 5.50	5.24
Tons per man hour 5/..	0.588	1.069	1.661	0.986	0.557	0.481	2/0.204	5/ 0.784	0.745
Value of coal produced dollars/ton..	2.47	2.14	1.46	2.00	3.11	2.85		6/ 2.23	1.85

1/ Sixteenth Census of the United States, Mineral Industries 1939, p. 3.
2/ Estimated.
3/ Based on 1940 census.
4/ Quantity of coal produced in State or area, divided by number of man-shifts worked.
5/ Quantity of coal produced in State or area, divided by number of man-hours worked.
6/ Total value divided by production.

which together produce half the total production, have an average annual production of 700,000-850,000 tons a year each. Further comparisons of relationships shown by this graph are discussed in the appendix.

Rate of Production

Mines in the Rocky Mountain area have a poorer load factor and apparently supply a greater proportion of domestic fuel. The characteristics are shown in figure 11 and table 3, which compare per capita production of coal corrected for heating value. The ratio of maximum production to average summer production (April, May, June, and July) in the Rocky Mountains is about 2.4, whereas the ratio for the United States is about 1.5. The comparison indicates that mines in the West are equipped to supply 20 to 25 percent more coal than they now produce, and it would argue against opening new mines in the near future to meet a sudden industrial demand. The load factor can be improved by storing part of the summer production or by creating new industrial outlets.

The continued growth of lignite production in North Dakota, shown in figure 8, affected little by the 1932 depression, is evidence that lower-rank fuels are competing more successfully with the higher-rank coals. The sustained production is probably due to improvement in equipment to burn lignite more efficiently and to favorable freight rates on lignite.

TRENDS IN DISTRIBUTION, SIZES, AND VALUE

The steady decline of markets for coal on the Pacific coast during the last 11 years is shown in figure 12, which gives the distribution of coal mines in Utah. This information was obtained from a special report by Durbin Van Law.7/ The relative market in California has decreased from 9 percent to 3 percent in 11 years, and the market on the Pacific coast, including Nevada, has been cut in half.8/ These reductions in markets are due to increased use of oil and gas on the west coast.

7/ Van Law, Durbin, Utah Coal Industry, 1941: Unpublished report.

8/ On a tonnage basis, the California market declined from 489,133 tons in 1929 to 83,358 in 1940, or 467 percent, and the west-coast market, including Nevada declined from 1,349,560 tons in 1929 to 484,713 in 1940, or about 178 percent. This decrease occurred while the population increased 26 percent on the Pacific coast, making the actual reduction in the former market 590 percent in California and 225 percent in the West Coast States.

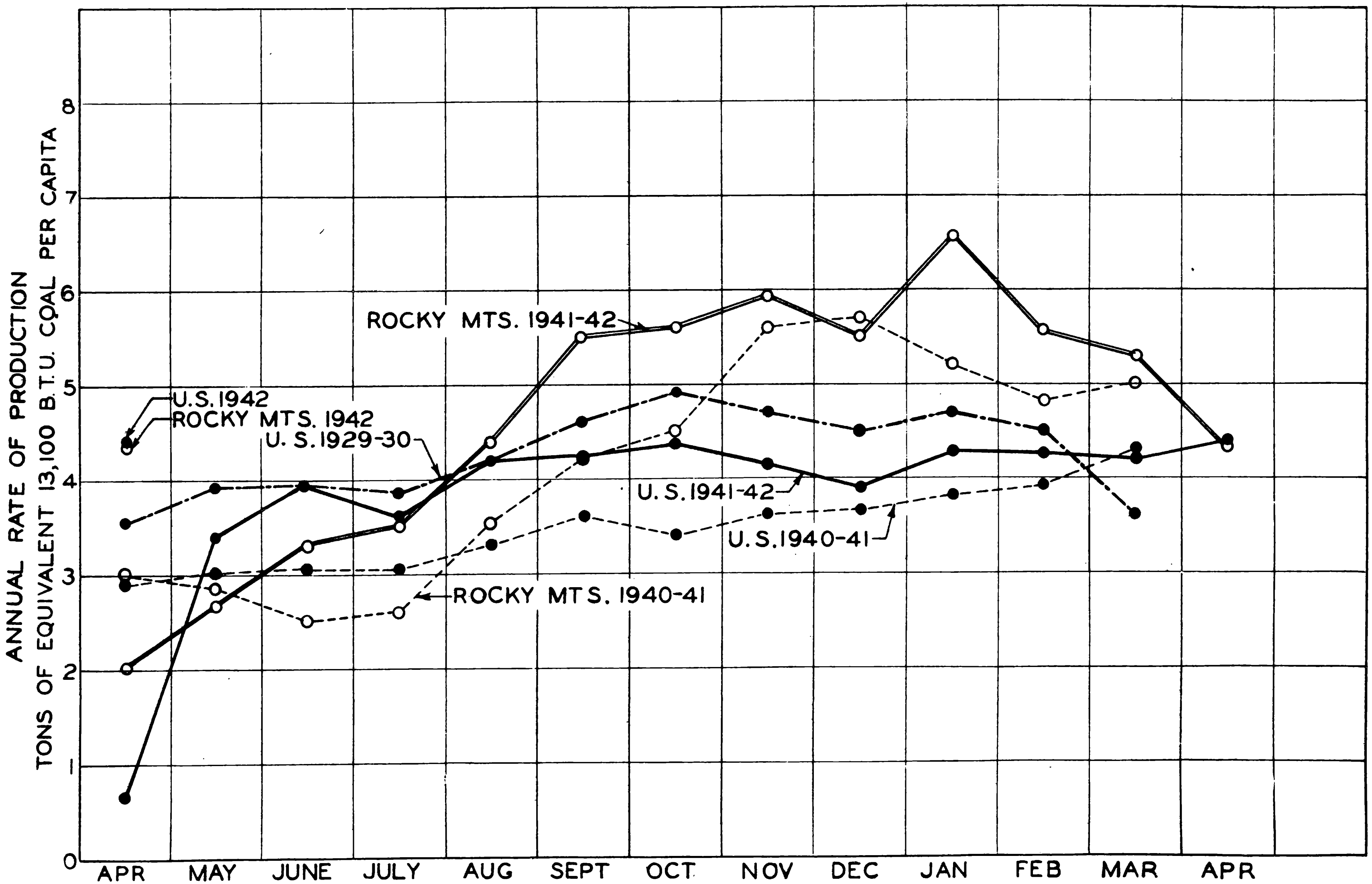


Figure 11.- Rate of production of bituminous coal, tons of equivalent 13,100 B. t. u. coal per capita per year.

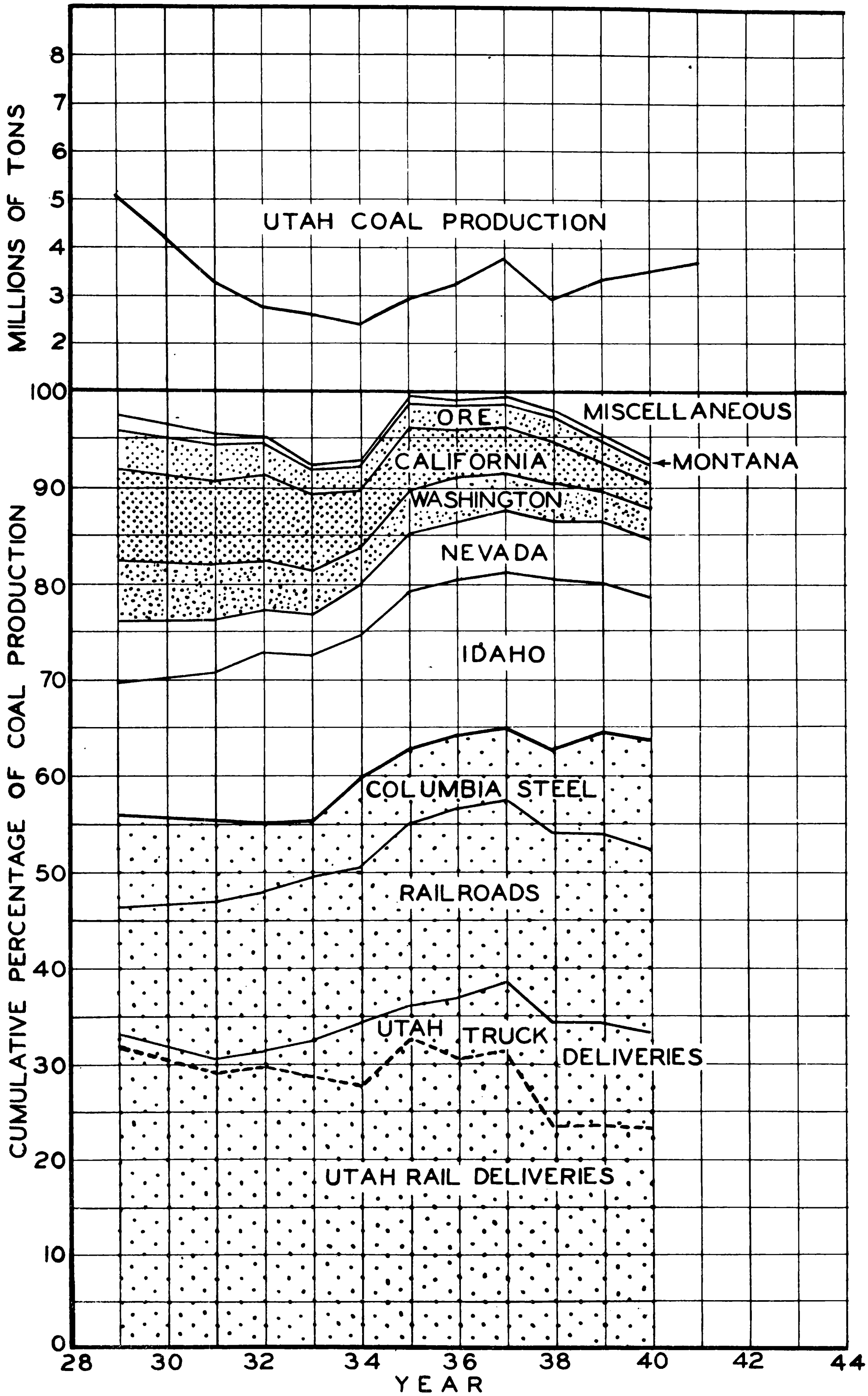
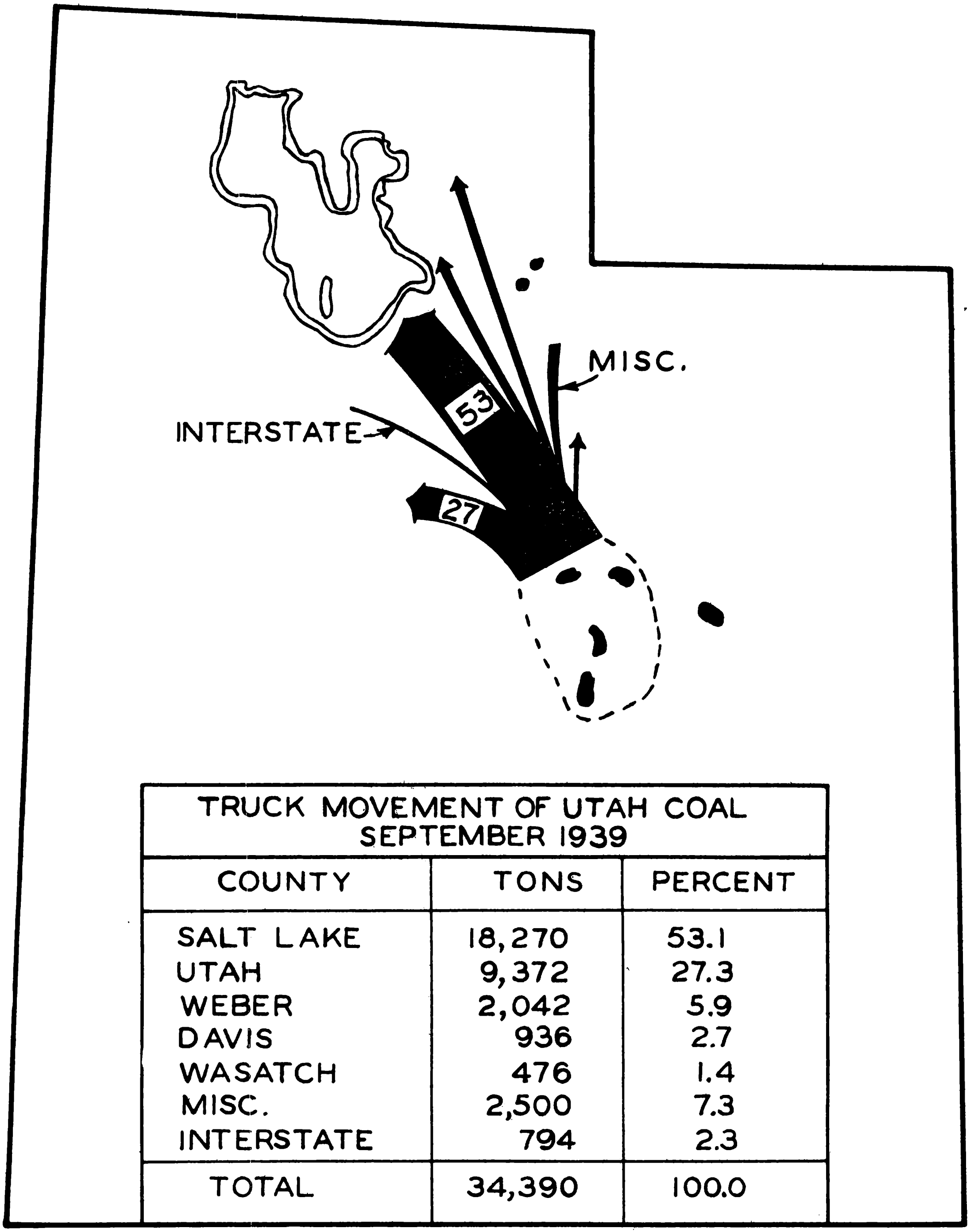


Figure 12.- Distribution of Utah coal.



TRUCK MOVEMENT OF UTAH COAL SEPTEMBER 1939		
COUNTY	TONS	PERCENT
SALT LAKE	18,270	53.1
UTAH	9,372	27.3
WEBER	2,042	5.9
DAVIS	936	2.7
WASATCH	476	1.4
MISC.	2,500	7.3
INTERSTATE	794	2.3
TOTAL	34,390	100.0

Figure 13. Truck movement of Utah coal.

TABLE 3. - Annual rate of bituminous-coal production,1/ tons of 13,100 B.t.u. coal per capita

	Wyoming	Utah	Colo-rado	Montana	New Mexico	Rocky Moun-tains	United States
Summer, 1940 2/	14.17	3.08	3.09	2.93	1.74	2.72	3.0
Maximum, 1940-41 3/..	29.6	10.6	8.0	6.4	2.7	6.3	4.3
Ratio maximum/ summer, 1940-41 ...	2.09	3.44	2.59	2.18	1.55	2.32	1.43
Summer, 1941 2/, 4/ ...	16.16	3.34	2.92	3.18	1.73	2.87	2.91
Maximum, 1941-42 3/..	33.4	11.5	8.7	7.5	3.1	7.1	4.4
Ratio maximum/ summer, 1941-42 ..	2.07	3.44	2.98	2.36	1.79	2.47	1.51
Average 1940 5/						6/ 4.17	7/ 3.44
Average 1941 5/						4.69	3.74
Average 1929 5/						6.48	4.41
Average 1920 5/						9.50	5.40
Maximum, 1929							5.27

1/ Bituminous Coal Division, Weekly Coal Report 1231, February 15, 1941, and others for 1940-42. Original data are estimates and subject to slight revision.

2/ Summer: April, May, June, July.

3/ Year: April 1 to April 1.

4/ Strike.

5/ Calendar year.

6/ This figure calculated as follows:

$$\frac{\text{Production x heating value}}{\text{Population x 13,100}} = \frac{19{,}843{,}000 \times 11{,}430}{4{,}150{,}000 \times 13{,}100} = 4.17.$$

All other calculations for Western States made in same manner, using following weighted average heating values for each State: Wyoming = 11,000 B.t.u./pound; Utah = 12,700; Colorado = 11,600; Montana = 10,200; New Mexico = 12,200; Rocky Mountains, average = 11,430 B.t.u./pound.

7/ This figure calculated as follows:

$$\frac{\text{Production}}{\text{Population}} = \frac{453{,}500{,}000}{131{,}700{,}000} = 3.44.$$

Another interesting trend is the increase in amount of coal transported by truck from mines in Utah. In a period of 8 years the proportion transported by truck has increased 720 percent, and in 1940 trucks delivered almost half as much coal as the railroads delivered in Utah. Figure 13 gives destinations of truck shipments and shows that more than half of all truck deliveries go into Salt Lake County. These trends may be changed considerably owing to the tire shortage and probable rationing of gasoline.

Sizes

The steady decrease in preparation or sales of lump coal is shown in figures 14 and 15. Previous to 1934, virtually half of the coal sold was prepared lump, but in 1940 this amount had decreased to about 35 percent. The steady increase in proportion of slack sold indicates either a declining market for the prepared sizes (owing to competition from other domestic fuels) or a greater relative demand for the lower-priced slack for industrial purposes. It appears to the author that the number of prepared sizes might be reduced without sacrificing service. The trend of sizes prepared in the northern Colorado field is similar to the trend in the Utah field, but the decrease in prepared sizes is not quite as great.

In chart 15 the size distribution indicated on the right-hand edge shows the relative proportion of small sizes that may come into use as stoker fuel reaches greater proportions. Experimental work at the Bureau of Mines Field Station at Golden, Colo., has shown that 1/4-by 3/4-inch size is preferable for subbituminous coal used in domestic stokers. In both figures it appears that coal has been losing ground in the domestic heating field. Figure 17 shows the growth of natural-gas sales in Utah.

Value

The steady decline in mine value of stove and nut sizes and the increase in mine value of slack coal in district 20 is shown in figure 16. The mine value of coal produced in Utah, reported by the Bureau of Census, is $2.14 for 1939; and the cost in 1940, reported to the Bituminous Coal Division, is $2. If increasing quantities of slack are sold, the price will have to approach mine value to meet the provisions of the Bituminous Coal Act. The trends in figure 16 indicates that prices are approaching this limit.

Utilization of Various Sizes by Railroads

Previous to 1920 the Rio Grande used mine-run coal, as only 11 stoker engines were in service; but the size of coal was reduced gradually every year after 1920, as indicated by the fuel statistics in the following table. During 1941, 62 percent of the total coal used in locomotives was 1-5/8 by 0 and smaller. This has reduced the cost of railroad fuel, and it has helped the operating coal companies by creating markets for smaller sizes, which are difficult to move at certain times of the year. Costs of storing coal in Utah also have been avoided.

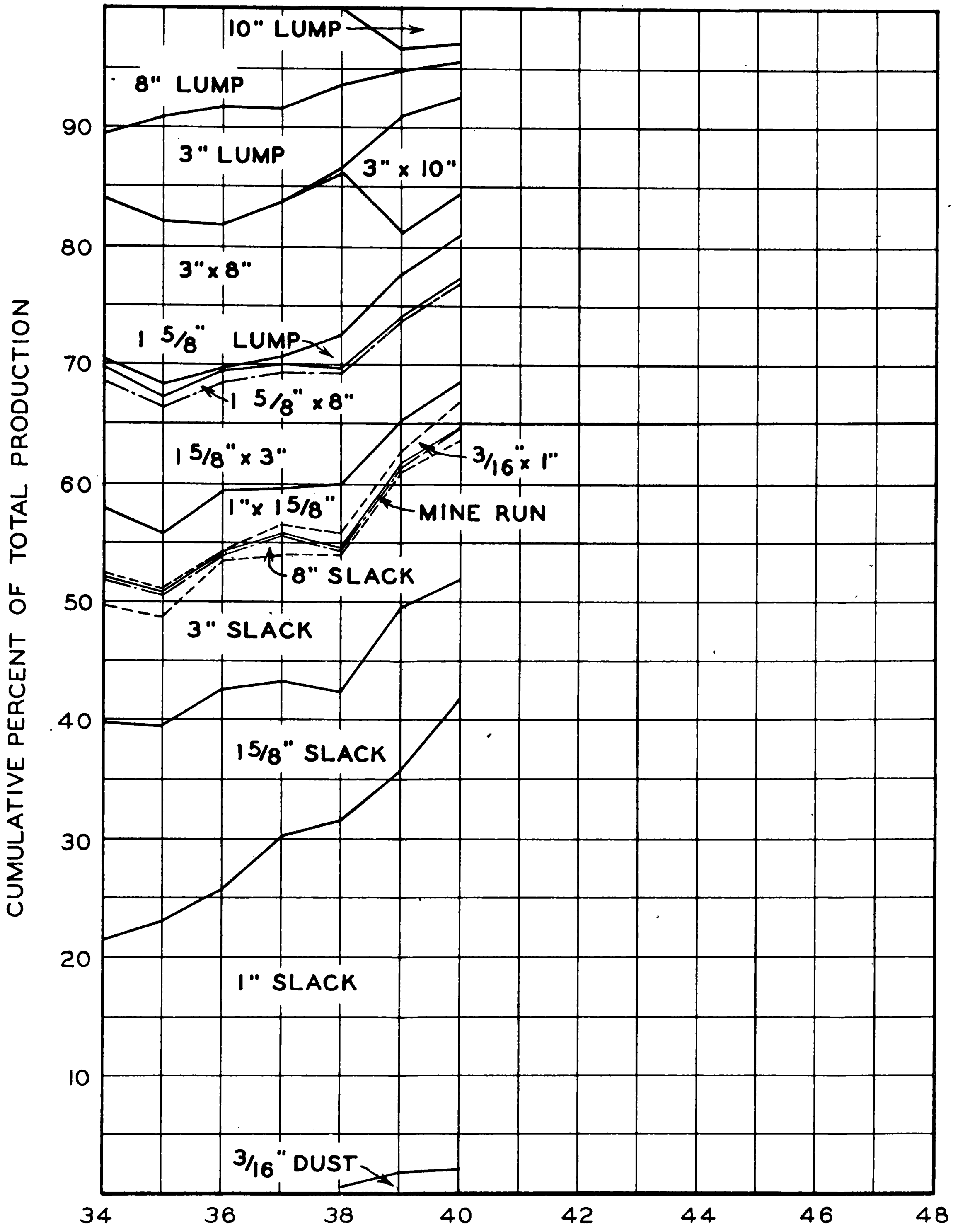


Figure 14.- Demand for sizes of Utah coals (based on data available January 1942).

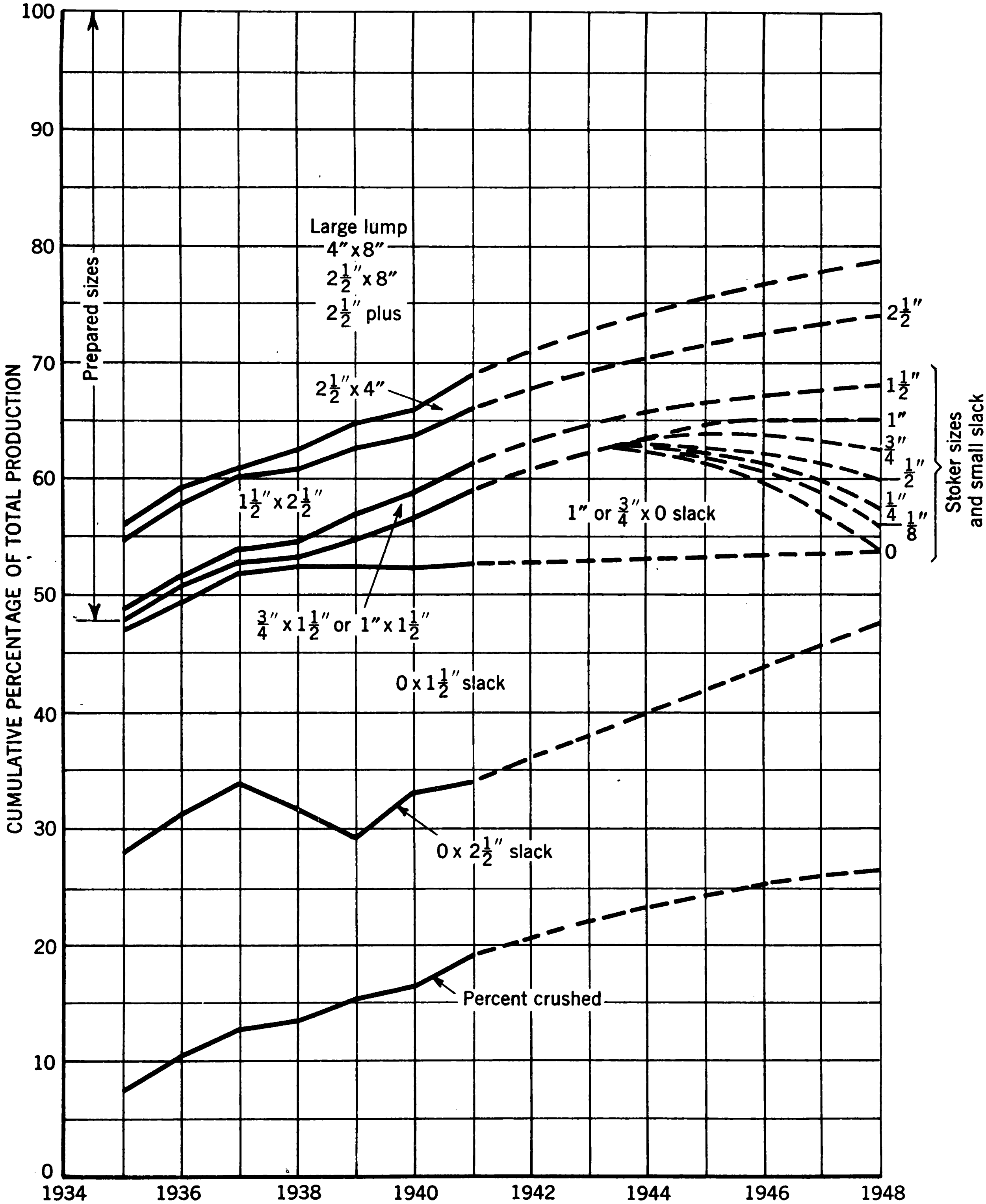


Figure 15.- Estimated market demand for sizes of subbituminous coal, Northern Colorado Field, District 16, 1934-48 (based on data available April 1942).

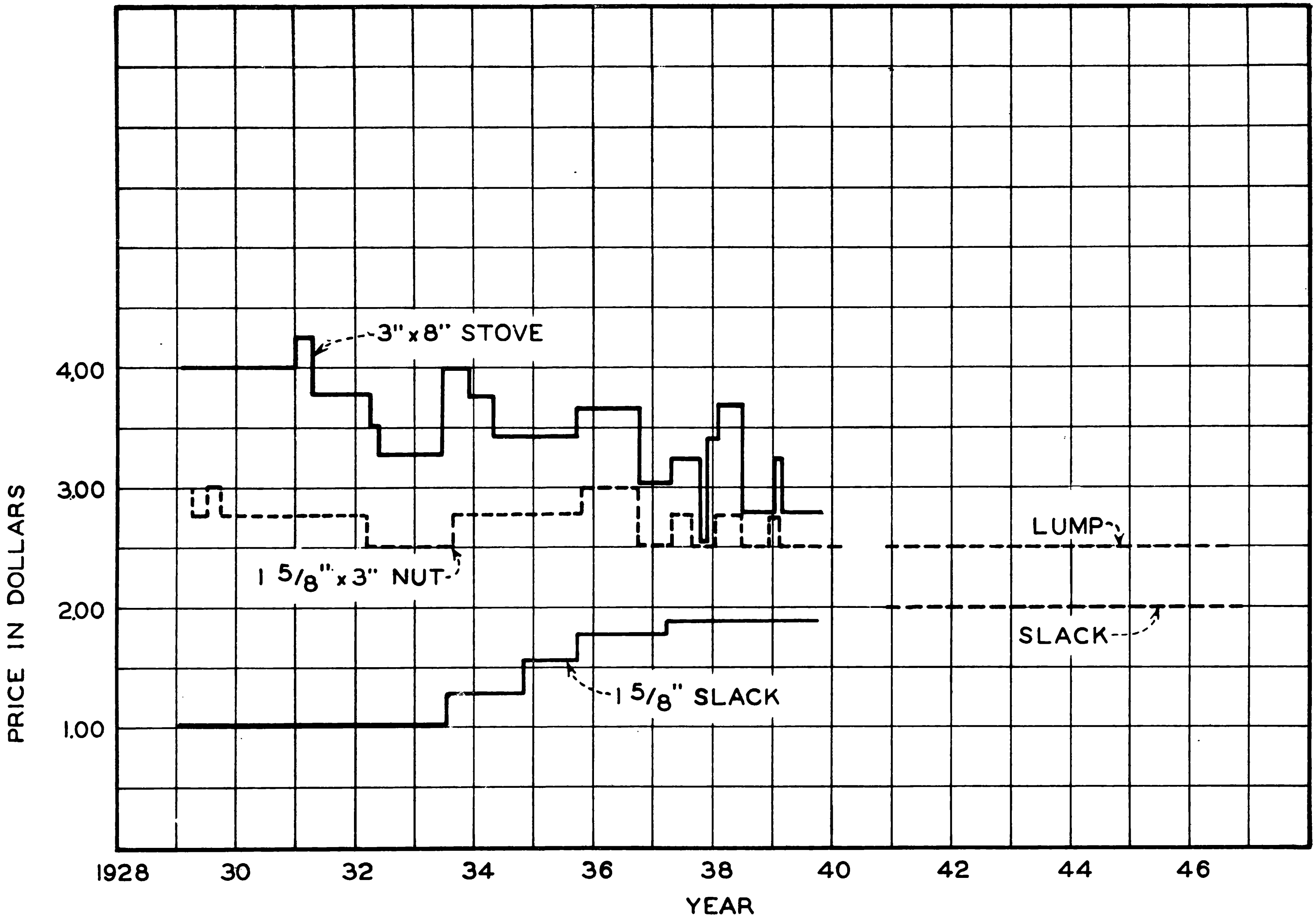


Figure 16.- Mine prices, District 20.

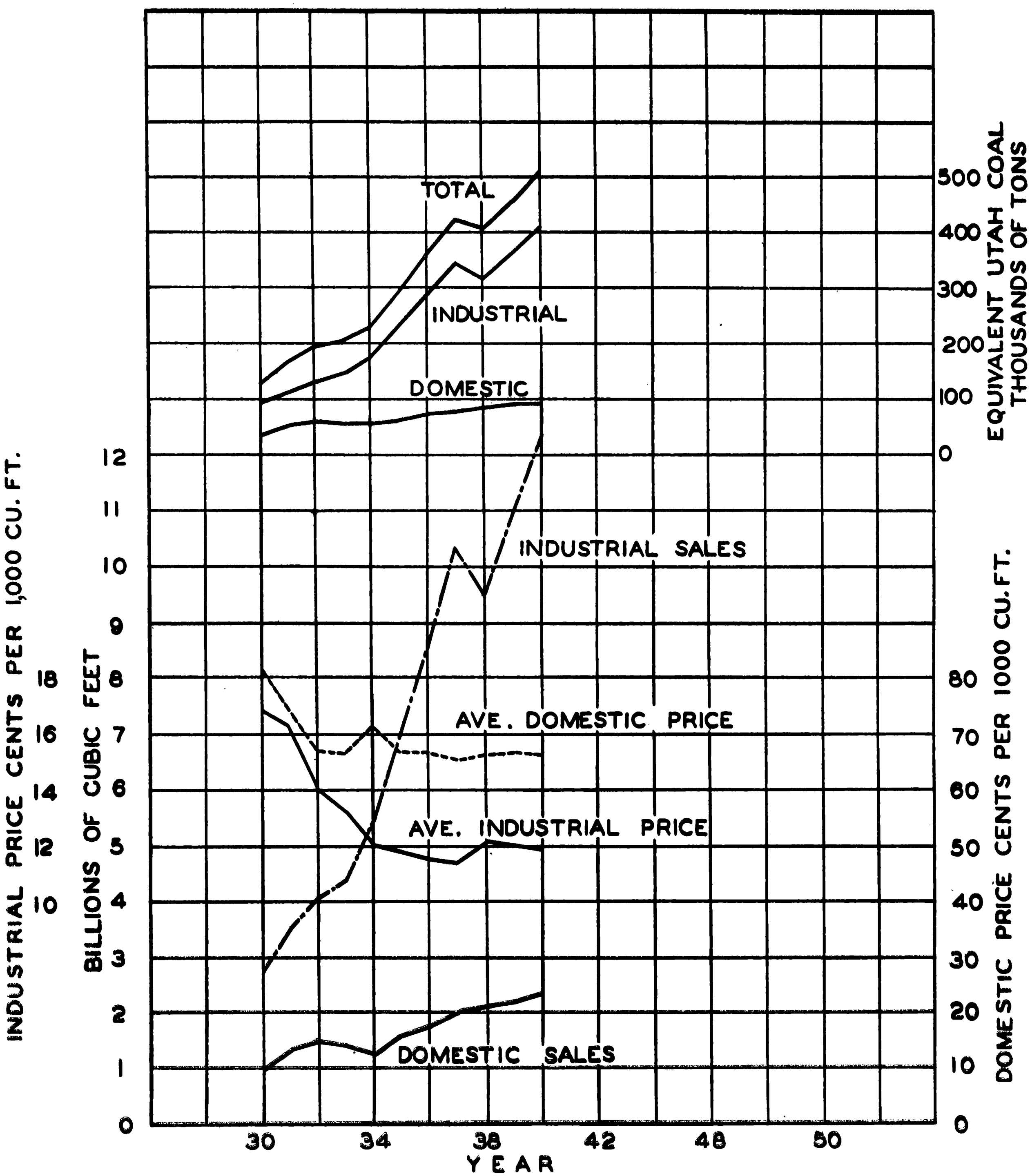


Figure 17.- Sales of natural gas in Utah.

Fuel statistics; freight service,1/ 1920-41

Year	Size of coal used	Pounds per unit 1,000 GTM	Speed of trains	Style of grates	Stoker engines in service
1920	Mine run	282	8.8	Finger	11
1921	Mine run and 8 inch	271	9.3	do	16
1922	do	272	9.2	Table	28
1923	Mine run, 8-and-3 inch	294	9.4	do	61
1924	do	260	10.0	do	72
1925	do	248	9.9	do	72
1926	20% slack	231	10.3	do	76
1927	25% slack	226	10.3	do	100
1928	25% slack	217	11.1	Round hole	100
1929	25% slack	209	11.6	do	114
1930	30% slack	203	12.8	do	124
1931	30% slack	200	14.0	do	124
1932	32% slack	218	14.7	do	124
1933	35% slack	216	14.8	do	124
1934	36% slack	216	15.3	do	124
1935	37% slack	218	15.1	do	124
1936	39% slack	212	15.4	do	124
1937	45% slack	210	15.6	do	124
1938	53% slack	202	15.8	do	138
1939	55% slack	198	16.1	Round-hole and 5 tuyere	138
1940	59% slack	194.5	16.5	Round-hole and 14 tuyere	138
1941	62% slack	198.3	16.8	Round-hole and 20 tuyere	153

1/ Tapp, W. J., Supervisor of Fuel Conservation, Denver & Rio Grande Western Railroad: Proceedings, Railway Fuel and Traveling Engineers Association, 1941.

The advisability of using smaller sizes for locomotive fuel also is indicated by recent tests to determine the breakage of lump coal in locomotive stokers. A large eastern railroad company9/ made tests on the amount of degradation that occurs when lump coal is fed through a stoker worm and found that 2- by 4-inch lump was crushed to approximately 1-1/2-inch slack while passing through the stoker.

9/ Pittsburgh Coal Co. and the Standard Stoker Co. for New York Central Railroad, Standard H. T. Stoker Coal Classification Tests, 1941, p. 40.

Size, inches	Before entering stoker, percent	After passing through stoker, percent
2 by 4	88.1	9.4
1-1/4 by 2	7.0	25.6
3/4 by 1-1/4	1.7	20.1
3/8 by 3/4	1.0	14.1
0 by 3/8	2.2	30.8
	100.0	100.0

From experience in the use of smaller sizes, the Denver & Rio Grande Western Railroad has concluded that it is not profitable to use large coal in stoker-fired locomotives and that the trend of utilization is continuing toward smaller sizes. In addition to the savings indicated above, the costs of handling are reduced as much as 5 cents per ton, and this saving amounted to $50,000 in 1941.

Although coal has been the only fuel used by the Denver & Rio Grande Western Railroad since the system commenced operation, recent technological advances indicate that greater economy and better service can be obtained from Diesel locomotives in some instances. One gallon of Diesel fuel, or 7.3 pounds of oil, will do as much work as 65 pounds of coal in hauling passenger trains.[10] This greatly increased efficiency permits longer runs, improves the service, and reduces the cost of moving certain trains, and it may affect the future consumption of coal by the railroad.

PROPERTIES AND TRENDS IN UTILIZATION OF WESTERN COAL

Coal is mined in about 60 separate mining fields in the Western States. Table 4 lists these fields, classifies the coal, and briefly describes their properties. The great variety of coal in western Colorado, should be noted. These differences are due to irregular folding of the beds, which has advanced the rank of coal in small, irregular areas, particularly near Crested Butte, Gunnison, and Durango, and near Los Cerrillos, New Mexico.

10/ Association of American Railroads, Bureau of Railway Economics, Washington, D. C.: Unit Fuel and Power Consumption of Locomotives and Rail Motor Cars, Railways of Class I in the United States, calendar years 1941 and 1940, Feb. 17, 1942.

Table 4.- Mining fields and properties of western coals

MINING FIELD	CLASSIFICATION AND PROPERTIES	
COLORADO		
TRINIDAD	9 8	A B
WALSENBURG	7 6	B C
CANON CITY	7 6 5	
EL PASO	3	I
DENVER	4	I
SOUTH PARK	6	
NORTH PARK	4	I
DURANGO	9 6 5	B C H
TONGUE MESA	6 5	
CRESTED BUTTE	12 8 7 6 5	B C D E H
PAONIA	8 7 6	B C D E
GLENWOOD	10 9 7	B D
GRAND JUNCTION	12 7 6 5	
ROUTT	12 6	
WYOMING		
BLACK HILLS		B
GILLETTE	3	J
SHERIDAN	4	I
BUFFALO	4	I
HANNA	6 5	F
GEBO	5	
ROCK CREEK	4	
ROCK SPRINGS	6 5	E F
KEMMERER	7 6 4	E F H
EVANSTON	5 4	H
HUDSON	4	
MONTANA		
ROSEBUD	4 3	J
RED LODGE	5	
ROUNDUP	5	
LEWISTON	6 5	C
WINIFRED	3	
BIG SANDY	4	
MILK RIVER	4 3	
TRAIL CREEK	9 6	B
GREAT FALLS	7 6 5	B
ELECTRIC	9	B
CUT BANK	6	
NEW MEXICO		
RATON	9 8	B
LOS CERRILLOS	12 9 8	
CAPITAN		
CARTHAGE	8	B
MONERO	9 8	B
GALLUP	6 5	
DEER CREEK*		
ARIZONA		
BLACK MESA	5	
CALIFORNIA		
STONE CANYON*	7	
MENDOCINA*	2	
MONTEREY*	2	
NEVADA		
ESMERALDO*	8	
GOOSE CREEK*	3	
UTAH		
GRAND	7	D
VERNAL	6	F
COALVILLE	6 5	F H
SUNNYSIDE	8 7	B C D
CASTLEGATE	8 7	B D
WINTERQUARTER	7	
EMERY	7	D
HENRY MT.		
KANAB	7	
HARMONY	12 6	F
WASHINGTON		
KING COUNTY	8 7 6 5 4	A B C D E F H I
KITTITAS COUNTY	8 7	A B C D
PIERCE COUNTY	10 9 8 7 5	A B H
SOUTHWESTERN	12 11 8 7 6 4 3 2	F H I J
NORTHWESTERN	12 6	D F
OREGON		
COOS BAY	4	H
EDEN RIDGE*		
ROGUE RIVER*		

CLASSIFICATION KEY

NUMBER	RANK
13	ANTHRACITE-META
12	ANTHRACITE
11	" -SEMI
	BITUMINOUS:
10	LOW-VOLATILE
9	MEDIUM "
8	HIGH " -A
7	" " -B
6	" " -C
5	SUBBITUMINOUS -A
4	" -B
3	" -C
2	LIGNITE
1	BROWN COAL

LETTER	PROPERTIES
A	STRONGLY COKING
B	COKING
C	WEAKLY COKING
D	WILL FUSE WITH SPECIAL HEATING.
	NON-WEATHERING AND:
E	AGGLOMERATING
F	NON-AGGLOMERATING
G	AGGLOMERATING AND WEATHERING
H	LOW SLACKING
I	MEDIUM "
J	HIGH "

* NOT OPERATING

Coals east of the Continental Divide are predominently of subbituminous and lignitic rank. These are characterized by high bed moisture, ranging from 18 to 42 percent, which lowers the heating value and causes slacking when the coal is exposed to weather. They are free-burning and noncoking. It was not until about 1924 that lignite in North Dakota was utilized efficiently for industrial and heating purposes. It is difficult to obtain high ratings or high efficiencies from lignite in hand-fired furnaces. Industrial users and many domestic consumers in the center of the lignite fields have imported higher-rank coals from West Virginia, Pennsylvania, and Kentucky. However, at the present time, through research and improvements in mechanical equipment, particularly the development of the spreader-type stoker, lignite can now be burned at efficiencies and rates approaching those obtained with the highest-rank coals. The improved combustion equipment and lower freight rates on lignite are probably responsible for the increased production of lignite in North Dakota.

Subbituminous coal, which contains approximately 25 percent moisture, was also difficult to use properly until modern equipment was developed. Recent tests conducted at the boiler heating plant of the Army Air Corps Technical School at Lowry Field in Denver, Colo.,[11] have shown that boiler output in excess of 200 percent of rating can be attained with slack subbituminous coal burned at 78 percent efficiency with a spreader stoker. The Northern Pacific Railroad, after years of development work, is using subbituminous C coal successfully as railroad fuel, attaining performance almost equal to that with high-rank coal. The Union Pacific and Burlington railroads have also used subbituminous coal successfully for many years. Similar advances have been demonstrated in industrial plants throughout the West, and there now appear to be no major problems connected with the efficient and economical use of lower-rank fuels for industrial power and heat.

Domestic Fuel

Much of the subbituminous coal mined in the northern Colorado field is used for domestic heating, both in hand-fired furnaces and with mechanical stokers, which burn them efficiently and economically.[12] The subbituminous coals are reactive, and they burn with relatively little smoke. There is a trend toward better preparation both as to size and cleanliness, and appreciation of these factors by coal producers and consumers will advance the use of these fuels.

11/ Van Law, Durbin, Boiler Performance Tests Made at Air Corps Technical School, Lowry Field, Denver, Colo., March 19-20, 1941: Unpublished report.

12/ Parry, V. F., and Segur, R. D., Performance of Subbituminous Coal in a Typical Underfeed Domestic Stoker: Bureau of Mines Rept. of Investigations 3557, 1941, 16 pp.

West of the Continental Divide the available coals are predominantly bituminous in rank from the Mesaverde formation. The beds are more irregular, less accessible, and have been affected more by geological processes than the flatter beds of the Laramie formation on the eastern slope. However, favorable conditions for low-cost mining exist in the Uinta Region in Carbon County, Utah, and in the extension of the field east to Paonia and Crested Butte, Colorado. All ranks of bituminous coal and some anthracite are available in the region extending from New Mexico to Montana. These bituminous coals are characterized by high-oxygen content, high-volatile matter, low ash, and more often are free burning, although coking coal appears in many places.

When these high-volatile bituminous coals are burned in hand-fired furnaces they usually smoke excessively, because of their free-burning properties and high-volatile content. Mechanical stokers overcome this nuisance and loss in efficiency to a considerable extent, but in congested areas smoke is a troublesome factor, because many hand-fired furnaces are operated. This led to legislation in Salt Lake City, Utah, amined at elimination of the smoke nuisance, and might lead to the development of new industries for processing high-volatile coal with attendant use of byproducts. Smoke is caused by incomplete combustion of volatile matter. A coal having 40 percent volatile matter can be distilled to produce more than 40 gallons of oil or tar from a ton of coal, leaving a smokeless residue. This fact, together with the desire of residents of Salt Lake City and Ogden to rid the cities of smoke, has encouraged many inventors to develop processes for treating the coal before use in the home.[13/]

It appears to the writer, after years of observing the growing smoke problem in Salt Lake City, that alleviation of the trouble might be achieved by a combination of the following:

1. Develop a simple stoker designed for smokeless combustion of available coals and built to sell for $75 or $100. Make these stokers available through easy financing, and pass ordinances requiring all hand-fired furnaces to be converted to stoker firing.

2. Develop a space heater for smokeless combustion of high-volatile, free-burning coal through cooperative work with a fuel-research laboratory. Make these heaters available at a reasonable price and pass ordinances requiring their use. The Battelle Institute, through Bituminous Coal Research, Inc., has developed smokeless space heaters for eastern high-volatile coking coal.[14/]

13/ Utah Conservation and Research Foundation, Low-temperature Carbonization of Utah Coals: 1939, 872 pp.

14/ Bituminous Coal Research, Inc., Research for the Bituminous Coal Industry: Special Bull., 1942, p. 7.

3. Develop a distillation process to extract volatile matter from coal before delivery to consumer. Through research the oils and tars could be used for plastics, motor fuel, road-building materials, and other industrial outlets requiring tar products, and their value might defray processing costs. If possible, somkeless fuel should be sold at the same price as coal on a heat-utilization basis, and it could be used in present burning equipment.

Fuel Equivalents

The great variety of coals available in the West have different heating values. Furthermore, the competing fuels, such as oil and gas, have heating values that vary in different localities. The equivalent value of fuels on a gross heating-value basis or on an efficient utilization basis is given in tables 5 and 6. Table 5 shows gross fuel equivalents of gas, oil, electric power, and the different coals mined in the West. The weighted average heating value of coal mined in the several States differs considerably, and these differences are appreciable when considering energy production. Table 6 gives comparative figures on fuel-utilization factors for types of coal and other fuels sold in the West. These factors can be used to judge the relative value of different ranks of coal and grades of oil and gas. The efficiencies calculated in column 7 show the relative maximum efficiency that can be attained when burning any of the fuels enumerated therein.

Carbonization

Coal from New Mexico, Colorado, Utah, Washington, and Montana has been coked for industrial purposes for many years. Beehive ovens were used originally, but in recent years these have been displaced by modern byproduct ovens, and now most of the coke for metallurgical and foundry purposes is made in byproduct ovens at Pueblo, Colo., and at Provo, Utah; but production of coke from beehive ovens at Sunnyside, Utah, is no increasing. In recent years only a small amount of coke has been made in the State of Washington.

TABLE 5. - Fuel equivalents

Basis	Million B.t.u.	Tons of 13,100 B.t.u. coal	Tons of 11,430 B.t.u. coal[1]
GROSS HEATING-VALUE BASIS:			
1 ton of average bituminous coal, high-volatile	27.8	1.06	1.216
1 ton of average coal produced in United States	26.2	1.000	1.146
1 ton of average coal produced in Rocky Mountain Region, weighted average[1]	22.86	.873	1.000
1 ton of Utah coal (weighted average B.t.u.)	25.4	.970	1.11
1 ton of Colorado coal (weighted average B.t.u.)	23.2	.886	1.015
1 ton of Wyoming coal (weighted average B.t.u.)	22.0	.840	.962
1 ton of Montana coal (weighted average B.t.u.)	20.4	.779	.892
1 ton of New Mexico coal (weighted average B.t.u.)	24.4	.931	1.066
1 ton of Washington coal (weighted average B.t.u.)	22.8	.870	1.000
1 ton of Average subbituminous coal	19.0	.725	.831
10,000 cu.ft. 1,075 B.t.u. natural gas, 60°F., 30 in. Hg	10.75	.41	.471
10,000 cu.ft. 1,000 B.t.u. natural gas, 60°F., 30 in. Hg	10.00	.382	.437
10,000 cu.ft. 1,000[2] B.t.u. natural gas, 60°F., 26 in. Hg	8.67	.331	.379
10,000 cu.ft. 1,000 B.t.u. natural gas, 60°F., 25 in. Hg	8.33	.318	.365
10,000 cu.ft. 1,000 B.t.u. natural gas, 60°F., 24 in. Hg	8.00	.305	.350
1 barrel fuel or crude oil	6.0	.229	.262
1 barrel gasoline	5.2	.198	.227
1,000 kw.-hr. at 1.35 pounds per kw.-hr.		.675	.774
UTILIZATION BASIS (maximum efficiency):[3]			
1 ton of average bituminous coal, high-volatile	23.5	1.068	1.243
1 ton of average coal produced in United States	22.0	1.000	1.164
1 ton of average Rocky Mountain coal[1]	18.9	.859	1.000
10,000 cu.ft. 1,075 B.t.u. natural gas, 60°F., 30 in. Hg.	8.44	.384	.447
10,000 cu.ft. 1,000 B.t.u. natural gas, 60°F., 25 in. Hg.	6.46	.294	.342
100 gallons of fuel oil	11.34	.516	.601
1,000 kw.-hr. at 0.80 pound coal per kw.-hr.		.400	.466
RAILROAD UTILIZATION:[4]			
100 gallons of fuel oil		.700	.815
1,000 kw.-hr.		2.25	2.62
100 gallons of oil used in Diesel engines		3.250	3.78

FOOTNOTES TO TABLE 5.

1/ Weighted average determined from heating value of coal from mines producing 90 percent of output. Heating value varies in each State, as follows: Montana, 9,000 to 10,800 B.t.u. per pound; Colorado, 9,500 to 13,700; Wyoming, 8,000 to 13,000; Utah, 11,500 to 13,500; New Mexico, 11,500 to 12,300; Washington, 9,700 to 12,300.

2/ Heating value of natural gas varies in different parts of the United States. Average for United States is 1,075 B.t.u. per cu.ft. at 60°F. and 30 inches of mercury, saturated. Heating value of natural gas distributed in Colorado and Utah is about 975 B.t.u. per cu.ft. at 60°F. and 30 inches mercury. 1,000 B.t.u. gas selected for this table.

3/ Burned completely with 30 percent excess air; products leave at 500°F., 32°F. basis.

4/ Association of American Railroads, Bureau of Railway Economics, Unit Fuel and Power Consumption of Locomotives and Rail Motor Cars, calendar years 1940 and 1941: Feb. 17, 1942.

TABLE 6. - Fuel-utilization factors

Type of fuel	Gross heating value, B.t.u. per pound	Available heating value, B.t.u. per pound 2/	Factors based upon net available heat 1/: B.t.u. per pound	Factor 3/	Volume factor 4/	Maximum efficiency 5/	Equivalent prices of fuels 6/		
1	2	3	4	5	6	7	8	9	10
							Dollars per ton		
Noncaking coals, 7/ percent moisture, as received:									
50	5,175	4,447	3,732	3.15	0.30	72.1	0.63	1.59	2.73
36.8	6,920	6,260	5,320	2.21	.43	76.9	.91	2.26	3.89
24.7	8,610	8,016	6,915	1.70	.56	80.3	1.18	2.94	5.06
20.5	9,520	8,935	7,714	1.52	.63	81.0	1.32	3.29	5.66
16.0	10,220	9,645	8,343	1.41	.68	81.6	1.42	3.55	6.10
11.0	11,460	10,904	9,486	1.24	.78	82.8	1.61	4.03	6.94
8.9	11,980	11,424	9,938	1.18	.83	83.0	1.70	4.24	7.29
5.9	12,490	11,944	10,436	1.12	.88	83.6	1.79	4.47	7.68
3.9	12,910	12,373	10,805	1.09	.91	83.7	1.84	4.58	7.89
Bituminous coal	13,910	13,412	11,736	1.00	1.00	84.4	2.00	5.00	8/8.60
Anthracite	13,590	13,360	11,704	1.00	1.26	86.1	2.00	5.00	8.60
Coke 9/	13,680	13,574	11,912	.99	.69	87.1	2.02	5.05	8.69
							Cents per gallon		
100 gallons No. 1 fuel oil	10/136,000	10/128,420	10/111,640						
	19,800	18,593	16,251	2.10	1.42	82.1	.95	2.39	4.10
100 gallons No. 2 fuel oil	138,500	130,120	113,370						
	19,610	18,423	16,069	2.06	1.45	82.0	.97	2.43	4.17
100 gallons No. 3 fuel oil	141,000	132,560	115,710						
	19,450	18,282	15,958	2.03	1.49	82.0	.98	2.46	4.24
							Cents per 1,000 cu. ft.		
1,000 cu. ft. natural gas, 60°F., 30 in. Hg. 11/	1,075	970	840	27.8	-	78.1	7.2	18.0	30.9
1,000 cu. ft. natural gas, 60°F., 30 in. Hg.	1,000	902	779	30.1	-	77.9	6.6	16.6	28.6
1,000 cu. ft. natural gas, 60°F., 26 in. Hg.	864	780	674	34.8	-	77.9	5.7	14.4	24.7
1,000 cu. ft. natural gas, 60°F., 25 in. Hg.	830	749	646	36.3	-	77.9	5.5	13.8	23.7
1,000 cu. ft. natural gas, 60°F., 24 in. Hg.	797	719	621	37.8	-	77.9	5.3	13.2	22.7
1,000 cu. ft. coke oven gas, 60°F., 30 in. Hg.	564	504	440	53.3	-	78.0	3.8	9.4	16.1
1,000 cu. ft. blast furnace gas, 60°F., 30 in. Hg.	90	89	72	326.0	-	80.0	.6	1.53	2.64

FOOTNOTES TO TABLE 6

1/ Net available heat is total heat available for useful work when fuel is burned completely with 30 percent excess air and stack gases leave the furnace at 500°F. (32°F. basis). Heat capacities, in B.t.u. per pound mol. of flue-gas constituents from 32°F. to 500°F.: O_2 and N_2 = 3,259, CO_2 and SO_2 = 4,606, and H_2O = 3,977. Latent heat as in footnote 2.

2/ Available heating value B.t.u. is the gross heating value minus the latent heat of vaporization of all water formed from combustion of H_2 and vaporization of free moisture. Latent heat in fuel is equal to total hydrogen as burned x 18.016/2.016 x 1,071.7 (the heat of vaporization or latent heat of water at 32°F.).

3/ These are equivalent factors. Examples: 1 ton of bituminous coal is equivalent to 2.20 tons of 37-percent moisture lignite; or, 1 ton bituminous coal is equivalent to 206 gallons of No. 2 fuel oil. Likewise, 1 ton of 16-percent moisture coal is equivalent to 3.15/1.41 = 2.23 tons of 50-percent moisture lignite; and 100 gallons of No. 3 fuel oil = 1,000 x 27.8/2.03 = 13,700 cubic feet of 1,075 B.t.u. natural gas at 60°F. and 30 inches of mercury.

4/ These are the same-type factors in terms of B.t.u. available per cubic foot of storage space, assuming the same size coal is used and specific gravity of coal ranges from 1.26 for 50-percent-moisture lignite to 1.35 for average bituminous coal, anthracite sp. gr. = 1.70 and coke sp. gr. = 0.92. Weight of bituminous coal in storage taken as 50 pounds per cubic foot. Example: 1 cubic foot of 36.8-percent moisture coal (average lignite) will have 0.43 as much available heat per cubic foot as 1 cubic foot of bituminous coal. Likewise, 1 cu. ft. of No. 3 fuel oil will have 1.49/0.43 = 3.47 times as much heat as 1 cu. ft. of average lignite (36.8 percent moisture).

5/ Maximum furnace efficiency when burning fuel completely with 30 percent excess air and products leave stack at 500°F. (Column 4 divided by column 2), 32°F. basis. Note: Owing to carbon loss in refuse and unburned carbon and volatile leaving stack when solid fuels are burned, efficiencies noted cannot be reached, but they can be approached as the theoretical maximum for these conditions.

6/ These figures are inversely proportional to factors in column 5. They are expressed as dollars per ton, cents per gallon or cents per 1,000 cubic feet. Example: Bituminous coal at $8.60 per ton (average retail price of coal in 1940) equals oil at 4.2 cents per gallon or natural gas (1,075 B.t.u.) at 30.9 cents per 1,000 cu. ft., or 22.7 cents per 1,000 cubic ft. of 1,000 B.t.u. gas measured at 60°F. and 24 inches of mercury pressure. Likewise, bituminous coal at $13.50 per ton would equal oil at 6.6 cents per gallon or average natural gas at 48.4 cents per 1,000 cu. ft.

FOOTNOTES TO TABLE 6 (Cont'd)

7/ Noncaking coals selected for this table are representative of coals mined in western United States, except the 50-percent moisture lignite, which is mined in Canada. Moisture contents listed are normal bed moistures of different types of noncaking coal.

8/ Average retail price of coal in 38 cities in 1940.

9/ 6.2 percent ash coke made at 800°C.

10/ B.t.u. per gallon.

11/ B.t.u. per cubic foot saturated with water vapor, applies to heating value of all gases. Note: Average natural gas in the United States has heating value of 1,075 B.t.u. per cubic foot. Gas marketed in the Rocky Mountains has heating value of about 1,000 B.t.u. per cubic foot at 60°F. and 30 inches of mercury, but it is sold at pressure ranging from 24 to 26 inches of mercury, which lowers heating value per cubic foot to average amounts given in this table.

Certain fundamental properties of coke made from western coal are shown in tables 7, 8, and 9, which give a summary of the distribution of coke made, imported, and used in the Western States during 1940. About 10 percent of the coke used for industrial purposes in blast furnaces and foundries was imported from the East or from Canada in 1940. Most of the imported coke is used for foundry purposes and is large, blocky, nonreactive, and low in ash. Small foundries seem to be willing to pay more for imported coke rather than to buy the local grade, which apparently has less desirable physical properties. During 1937 the Western States imported 120,000 tons of coke in addition to shipments from the East for these special uses. Part came from Canada, but a quantity was shipped from Belgium, Germany, Netherlands, and the United Kingdom. Evidently coke made abroad is more desirable for certain purposes than that now being made from western coal, even though the cost is considerably higher. During 1940 imports from Canada and the United Kingdom into the Western States declined to 36,252 tons, but 84,295 tons was shipped into this area from the Eastern States. As the war decreases imports, the better coke formerly imported for industrial purposes in the West will have to be shipped from the East, with attendant railroad congestion, or local industries will have to use the apparently inferior foundry coke made from western coal. This situation emphasizes the need for processes and research to make more desirable coke from western high-oxygen coking coals.

TABLE 7. - Distribution of coke, Western States, 1940[1/]

State	Consumption, tons		Production, tons				Total coal used for coking
	Coke	Breeze	By-product	Beehive	Breeze	Total	
New Mexico	1,237	26	-	-	-	-	-
Arizona	4,348	28	-	-	-	-	-
Colorado	545,894	2/45,324	543,548	62,417	68,233	674,198	945,712
Utah	231,474	23,213	218,949	7,398	19,457	245,804	383,682
Nevada	57	-	-	-	-	-	-
Wyoming	2,472	-	-	-	-	-	-
Montana	24,793	9,845	-	-	-	-	-
Idaho	3,900	345	-	-	-	-	-
Oregon	4,609	-	-	-	-	-	-
Washington	4,719	-	-	-	-	-	-
California	67,680	60	-	-	-	-	-
Undistributed	-	-	-	-	-	-	-
Total	891,183	78,841	762,497	69,815	87,690	920,002	1,329,394

1/ Bureau of Mines, Minerals Yearbook, 1940, and Mineral Market Survey, 942.

2/ Includes breeze wasted at plant, total 17,008 tons.

TABLE 8. - Distribution of coke and coke breeze, 1940[1]

From -	To - Rocky Mountains Coke	Rocky Mountains Breeze	Pacific Coast, coke	Iowa Nebraska South Dakota	Kansas Oklahoma	Texas	Total
Alabama	3,601	-	20,277	-	-	-	23,878
Illinois	7,828	-	2,510	-	-	-	10,338
Indiana	2,990	-	16,009	-	-	-	18,999
Kentucky, Missouri, Tennessee, Virginia	3,215	-	3,322	-	-	-	6,538
Michigan, Minnesota, Wisconsin	5,395	-	2/18,064	-	-	-	23,459
West Virginia	145	-	943	-	-	-	1,088
Colorado, Utah, Washington	789,348	61,428	3/18,071	4/2,231	4/14,828	4/22,813	4/908,719
Great Britian	-	-	9,367	-	-	-	9,367
Canada	26,885	-	-	-	-	-	26,885
Undistributed	298	-	-	-	-	-	298
Totals	839,705	61,428	88,564	2,231	14,828	22,813	1,029,569
	901,133		88,564		39,872		
	989,697						

1/ Bureau of Mines, Minerals Yearbook, 1940, and Mineral Market Survey, 942.

2/ Includes 2,979 tons of Oregon, Texas, and Wyoming.

3/ Includes 54 tons of breeze.

4/ Includes breeze amounting to 17,439 tons for all eastern destinations.

TABLE 9. - Consumption of coke in the Western States, 1940[1/]

	Blast furnace		Foundry		Other 2/		Total coke 3/		Breeze,
	1929	1940	1929	1940	1929	1940	1929	1940	1940
New Mexico	273	-	1,411	-	215	-	1,899	1,237	-
Arizona	29,792	-	3,252	4,053	295	295	33,339	4,348	
Colorado	537,442	521,698	6,302	11,604	45,943	12,592	589,697	545,894	23,316
Utah	260,915	163,790	11,203	10,337	4,896	55,234	277,014	231,474	23,213
Nevada	-	-	-	28	3,559	29	3,559	57	-
Wyoming	-	-	-	-	-	-	2,062	2,472	-
Montana	4/ 33,849	19,494	2,900	2,060	183	3,239	36,932	24,793	9,845
Idaho	-	-	358	-	2,136	6/3,900	2,494	3,900	-
Oregon	-	-	-	2,821	330	1,788	330	4,609	-
Washington	25,429	-	965	3,089	50,763	1,609	77,157	4,719	-
California	9,969	5/ 9,900	22,343	36,426	7,511	18,972	39,823	67,680	-
Undistributed	-	-	-	-	-	-	-	-	459
Total	897,669	714,882	48,734	70,418	115,831	97,658	1,064,306	891,183	61,833
United States		42,401,997		2,061,438		2/12,707,198		57,170,633	4,069,693
Per capita, tons:									
United States	-	0.317	-	0.0154	-	0.095	-	0.427	-
Western States	0.079	.051	0.0043	.0051	0.010	.007	0.102	.064	-

1/ Bureau of Mines Minerals Yearbook and Mineral Market Survey 942
2/ Includes other industrial coke for gas making and domestic coke United States used 7,974,308 domestic coke.
3/ Excludes coke breeze.
4/ Includes some "other industrial."
5/ Estimated.
6/ Includes foundry.

Colorado. - The byproduct ovens operated by the Colorado Fuel & Iron Co. Pueblo, Colo., are similar to the older ovens in use in the eastern part of United States. The base coal used is mined in the Trinidad field in southern Colorado. It is strongly coking and has carbonizing properties similar to those of coal from the Pittsburgh seam. The coal is washed, and some noncoking coal is blended with it to improve coke properties. During the last 3 years, the Colorado Fuel & Iron Co., through cooperation with the Koppers Co., has succeeded in making a blocky coke that is virtually equal in physical properties to the best furnace and foundry cokes made in the East. This has been accomplished by blending a low-temperature char made from the base coal. This development has improved the physical properties of the coke materially and has demonstrated that coke nearly equal to the best made in the East can be made in Colorado entirely from local coals.

Although there have been advances in making coke from Washington coals by improvements in washing and operation of ovens, the production of byproduct coke in that State has not increased in recent years.

Utah. - Utah coal was coked initially in beehive ovens in Emery County and at Castlegate, but after mines were opened at Sunnyside in 1903 the coking industry moved there because of the better coking properties of the coal. In 1925, 800 large beehive ovens were in operation, but production from these decreased after byproduct ovens were built at Provo in 1924. At present 817 beehive ovens, one of the largest single units in the United States, are available at Sunnyside, Utah, for the manufacture of coke but only 50 were in operation and 7,398 tons of coke were made in these during 1940. More ovens are expected to go into operation in 1942. It is estimated that Colorado, Utah, Montana, and Washington have 1,229 beehive ovens with an annual capacity of 611,000 tons, but only 171 ovens are in operation, most of which are in Colorado. Montana had 451 ovens in 1911 but only 5 operated in 1940. The reduced output of beehive coke previous to 1941 from the large batteries at Sunnyside is probably due to competition from local and imported by-product coke for the markets formerly supplied by coke made in these ovens. Two kinds of coke are made in the beehives at Sunnyside. Finger coke is made from minus-1/16 and minus-3/8-inch screenings, and lump coke is made from 3- by 6-inch coal. The finger coke is similar to byproduct coke made at Provo, and the lump coke has special properties suiting it for use in foundries and sugar factories. It is slightly stronger than finger coke.

The 56 modern Becker ovens in Utah enjoy the distinction of carbonizing the lowest-rank coking coal in the United States, yet they make satisfactory furnace coke from 100-percent Carbon County coal, which contains about 10 percent oxygen in the coal substance and about 40 percent volatile matter. The successful commercial carbonization of this borderline coking coal has been made possible through the development of the new Becker 14-inch oven, which permits high-speed carbonization. These ovens made coke in less than 13 hours at a coking temperature of about 1,900°F. and a flue temperature of 2,650°F.[15] High wall temperatures were considered necessary to produce satisfactory coke from this high-oxygen coal, and these ovens operated for about 10 years at temperatures approximately 150°F. higher than in any other plants.[16] In 1934 oven failures were experienced, owing to reaction of the coal ash with refractories, and since that time flue temperatures have been reduced to under 2,630°F. to avoid formation of fayalite. The ovens now make satisfactory coke in about 17 hours at a temperature about 100°F. higher than used in average byproduct ovens. These operating conditions apparently are necessary to carbonize the high-oxygen coking coals of the Uinta region, and they indicate the trend that research must follow if other high-oxygen coking coals are to be carbonized successfully.

The large blast furnace at Ironton[17] has performed efficiently on the coke made in the byproduct plant and has consistantly made 10,000 to 12,000 tons of iron a month. The fuel consumption per ton of iron compares favorably with any practice in the country. It has achieved this record with coke that has poorer physical properties than ordinarily considered necessary for equal production. Utah coke is characterized as small and fingery. The shatter and tumbler indexes are about half those of imported foundry coke, but its porosity is about equal to that found in the best grades of coke. The physical properties of foundry cokes made at Pueblo, Colo., are about midway between those of Utah and the best imported cokes. The success of the coke oven and blast furnace at Sunnyside has shown that high-oxygen coal, formerly considered unsuitable for byproduct coking, can now be coked commercially. Many other borderline coking coals in the West may be coked equally well, thus insuring an unlimited supply for furnace and foundry coke at reasonable prices; but to meet competition from eastern and foreign cokes, much research will have to be done to determine how physical properties can be improved. It may be necessary to develop new types of byproduct ovens to treat these coals successfully, as the high temperatures now employed on present byproduct ovens have about reached the endurance limit fixed by materials of construction.

15/ Keighley, C. T., The New By-Product Coke Plant of the Columbia Steel Corporation: Min. and Met., vol. 6, 1925, pp. 422-424.

16/ Rueckel, W. C., Failure of Coke-Oven Walls by Reaction with Coal Ash: Amer. Ceram. Soc. Jour., vol. 21, 1938, pp. 354-360

17/ Jackson, P. W., Blast-Furnace Plant of the Columbia Steel Corporation: Min. and Met., vol. 6, 1925, pp. 420-422.

Location of coking coal. - The coking properties of western coal have been investigated by several research agencies.[18/] From results of laboratory tests on various coals and from commercial experience, the location of probable coking coals in the Western States has been determined, as shown in table 10. The Bureau of Mines has conducted studies and is now making new investigations on the carbonizing properties of coals from several sources in the Western States. It appears from a study of all available experimental data on carbonizing high-oxygen coal from the Rocky Mountain area that coking properties are related in some way to oxygen content, fuel ratio, hydrogen-oxygen ratio, and heating value of ash-free, moist coal. Many inquiries have been made by western operators as to coking properties of certain coals. Experimental data thus far examined indicate that the following formula can be used as a guide to determine whether a high-oxygen coal possesses possible coking properties:

$$\text{Coking index} = \frac{a + b + c + d}{5}$$

a = 22/ oxygen content on ash- and moisture-free basis.

b = 2 times the hydrogen divided by oxygen content on moisture- and ash-free basis.

c = fixed carbon/1.3 x volatile matter.

d = heating value on moist, ash-free basis/13,600.

If a coal has an index greater than 1.0, it is likely that it can be made to coke under special conditions; and if the index is more than 1.10, the coal is probably a fairly good coking coal.

Results of carbonization tests on Utah coal and on a good coking mixture of Eastern coals are compared in table 11. It is encouraging to note that when Utah Sunnyside coal is carbonized under favorable conditions in the laboratory, the physical properties of coke differ only slightly from those of coke made from the best Eastern coals.

18/ Parr, S. W., and Laying, T. E., The Coking of Utah Coals: Bureau of Mines Rept. of Investigations 2278, 1921, 13 pp.
Monnett, Osborn, Low-Temperature Coking of Utah Coals: Chem. and Met. Eng., vol. 23, 1920, pp. 1246-1249.
Utah Conservation and Research Foundation, Low-Temperature Carbonization of Utah Coals: 1939, 872 pp.
Carpenter, C. B., and Manuel, W. A., Studies in Colorado Coals: Colorado School of Mines Quarterly, vol. XXIII, no. 3, sup. A., July 1928, 59 pp.

TABLE 10. - Location of coking coal in the Rocky Mountain area

State and County	Mining field	Area having coking coal 1/	Coking properties 2/
New Mexico:			
Colfax	Raton	Dawson north to State line.	Good; coked in beehives.
Santa Fe.	Los Cerrillos	-	do
Socorro	Carthage	-	Good; coked in beehives (worked out)
Rio Arriba	Monero	-	Medium.
Colorado:			
Las Animas	Trinidad	From State line north to about 5 miles south of Walsenburg	Very good to poor; coked in byproduct ovens.
La Plata and Montezuma	Durango	Durango west of Montezuma	Good to poor; coked in beehives.
Montrose	Norwood......	-	Good.
Gunnison	Crested Butte	Near Crested Butte	Fair to poor.
Gunnison Delta	Paonia	From Bowie east to Hawk's Nest and south 8 miles	Good to poor.
Mesa	Grand Junction	From Palisade 15 miles northwest	Poor.
Pitkin	Glenwood.....	From Marble 16 miles north	Very good to poor.
Wyoming:			
Weston	Black Hills	-	Coked in beehives (worked out)
Sweetwater	Rock Springs	Portions of No. 7 bed	Poor.
Lincoln	Kemmerer...	At Sublet	Good to poor.
Montana:			
Park	Trail Creek	-	Poor; coked in beehives.
Cascade	Great Falls	Around Eden	Fair; coked in beehives.
Park	Electric	-	Good; coked in beehives.
Utah:			
Carbon	Sunnyside	3 miles south of Columbia to 2 miles north of Sunnyside.	Good to fair; coked in byproduct ovens.
Carbon 3/	Castlegate	Kenilworth, west through Standardville.	Medium to poor.
Iron	Kanab	-	Fair

1/ Extent is approximate, as analyses and available information do not cover entire field.

2/ This estimate is based on correlation with analysis, on laboratory tests, and on historical data from Bureau of Mines technical data in Technical Papers, 345, 484, 529, 569, and 574, and from McGraw-Hill Coal-Buyers' Manual.

3/ Seams in this field other than Castlegate "A" appear to have better coking properties than the Castlegate "A."

TABLE 11. - Summary of carbonizing tests made by Federal Bureau of Mines on Utah coal and on an eastern coking mixture1/

	Utah, Lower Sunnyside coal	80 percent Pittsburgh, 20 percent Pocahontas2/		Utah, Lower Sunnyside coal	80 percent Pittsburgh, 20 percent Pocahontas
Proximate analysis, as-carbonized:			Analysis of products:		
Moisture	4.6	1.3	Volatile matter in coke, percent	1.7	2.1
Volatile matter	38.8	32.5	Fixed carbon in coke, percent	88.2	89.6
Fixed carbon	50.6	60.3	Ash in coke, percent	10.1	8.3
Ash	6.0	5.9	Heating value, B.t.u. per pound	12,910	13,330
Ash softening temperature, °F.	2,440	2,340	Specific gravity of gas	.435	.379
Sulfur	1.0	0.6	Heating value of gas, B.t.u./cu. ft.	559	561
Oxygen	12.9	6.8	B.t.u. in gas per lb. of coal	3,620	3,280
Carbon	72.9	80.0	H_2S in gas, grains/100 cu. ft.	265	190
Heating value, B.t.u. per pound	13,030	14,170	Specific gravity of tar	1.18	1.17
Oxygen, percent, moisture - and ash-free	9.8	6.1	Tar acids, percent of tar	2.6	5.7
Carbon/hydrogen ratio, moisture - and ash-free	14.1	15.7	Distillate to 350°C., percent by		
Hydrogen/oxygen ratio, moisture - and ash-free	.59	.90	volume	40.8	44.8
Oxygen/hydrogen ratio, moisture - and ash-free	1.69	1.11	Properties of the coke:		
Fuel ratio3/	1.30	1.86	True specific gravity	1.91	1.84
Yields of products at 1,000°C., percent as			Apparent specific gravity	.78	.87
carbonized:			Cells, percent	59.2	52.7
Coke4/	62.3	71.5	Shatter test, cumulative percent:		
Gas5/	21.2	16.7	On 2-inch screen	17.8	16.0
Tar6/	5.2	5.5	On 1-1/2-inch screen	40.7	57.2
Light oil	1.26	.90	On 1-inch screen	78.5	90.4
Ammonia	.15	.12	Tumbler test, cumulative percent:		
Liquor	8.5	4.6	On 2-inch screen	.0	.0
Tar per ton of coal, gallons 5/	10.6	10.6	On 1-1/2-inch screen	2.8	7.7
Gas per ton of coal, cu. ft. 4/	13,000	11,700	On 1-inch screen	36.9	56.9

1/ Fieldner, A. C., and Davis, J. D., Gas-, Coke-, and Byproduct-making Properties of American Coals and Their Determination: Bureau of Mines Mono. 5, 1934, 164 pp. 2/ Pittsburgh bed, West Virginia, and Pocahontas No. 4 bed, West Virginia. 3/ Fixed carbon to volatile matter. 4/ 18-inch retort. 5/ Stripped of light oil and hydrogen sulfide, saturated with water at 60° F. and 30 inches of mercury. 6/ Includes light oil that condensed with tar.

The physical properties of certain commercial and laboratory cokes, given in table 12, indicate that coke made from western coal is generally inferior in physical properties to coke made from eastern coal. Further laboratory investigations on methods to improve the physical quality of coke made from high-oxygen coal are needed.

TABLE 12. - Comparison of the physical properties of certain commercial and laboratory cokes 1/

Coke	Shatter index	Tumbler index	Porosity	Ash, percent
Average of three Eastern foundry cokes	92.8	61.6	50.2	7.5
German foundry coke	97.3	61.4	50.2	8.7
British foundry coke	94.3	58.0	51.8	7.7
Western, foundry "A"	62.5	31.3	46.9	11.2
Western, foundry "B"	42.6	29.4	50.1	10.8
Inland furnace coke	55.5	56.1	51.1	5.9
Eastern furnace coke - one plant	65.7	51.3	49.9	10.1
Western, furnace coke "C"	63.9	30.4	44.6	12.7
Western, blended furnace coke "D"	81.3	55.4	50.0	10.0
Coke made in BM-AGA retort 1,000°C. 5/				
Sunnyside coal	2/ 40.7	3/ 36.9	4/ 59.2	10.1
Pittsburgh coal with Pocahontas	2/ 57.2	3/ 56.9	4/ 52.7	8.3
Sunnyside coal	3/ 78.5	-	-	-
Pittsburgh coal with Pocahontas	3/ 90.4	-	-	-

1/ Tests on commercial cokes by A.S.T.M. methods.
2/ On 1-1/2-inch screen.
3/ On 1-inch screen.
4/ Cells, percent = 100 -(apparent specific gravity/true specific gravity) 100.
5/ Fieldner, A. C., and Davis, J. D., Gas-, coke-, and Byproduct-making Properties of American Coals and Their Determination: Bureau of Mines Mono. 5, 1934, 164 pp.

Production of Liquid Fuels from Western Coals by Hydrogenation

The Bureau of Mines has conducted extensive studies on methods for converting solid fuels to liquids.[19] [20] An essential chemical difference

19/ Storch, H. H., Hirst, L. L., Fisher, G. H., and Sprunk, G. C., Hydrogenation and Liquefaction of Coal. Pt. 1. Review of Literature, Description of Experimental plant, and Liquid-Phase Assays of Some Typical Bituminous, Subbituminous, and Lignitic Coals: Bureau of Mines Tech. Paper 622, 1941, 110 pp.
20/ Fieldner, A. C., and Schmidt, L. D., Annual Report of Research and Technologic work on Coal : Bureau of Mines Inf. Circ. 7190, 1941, 60 pp. 60 pp.

between coal and petroleum is the ratio of the number of carbon atoms to hydrogen atoms. Petroleum has a ratio of carbon to hydrogen atoms of about 0.6, but the ratio in coal is about 1.2. To liquefy solid fuel, additional hydrogen must be forced to combine with the carbon atoms. This is done by heating a paste made from oil and coal to about 450°C. while it is under hydrogen pressure and in contact with catalyst. The reaction causes the coal to dissociate or "crack" and the molecular weight of the fragments of the coal molecules decreases until it equals that of petroleum molecules. The process was discovered in 1913 by Berguis, and Germany now is producing more than 1,000,000 tons of gasoline annually from coal. England and Japan also make oil from solid fuel, and in 1939 the installed capacity of hydrogenation plants in those countries was 150,000 and 60,000 tons of gasoline per year, respectively. These plants operate with government subsidy to permit competition with cheaper imported gasoline from petroleum.

Hydrogenation of coal in the United States is not economically feasible at the present time because of immediate ample supplies of petroleum, but research has shown that large quantities of tar acids, useful for making phenolic-type plastics, and of aromatic solvents useful in the paint, varnish, and explosives industries, can be produced from the products of coal hydrogenation. The manufacture of these products may warrant commercial hydrogenation of coal before petroleum supplies are diminished or production of gasoline from coal is justified.

Research work conducted in the small experimental plant at Pittsburgh, Pa., has included hydrogenation studies on all rands of coal from the several producing areas in the Western States. Table 13 gives a list of 13 coals that have been studied in this plant and includes data on the yields of oil and gasoline. In addition to the experimental plants studied, many coals have been assayed in small autoclaves and examined petrographically to determine the probable yields of products. Hirst[21] surveyed 27 mines in the Rocky Mountain region, and estimates were made of the amount of liquid fuel that could be produced from the different ranks of coal. Generally speaking, 1 ton of average bituminous coal will make 2 barrels of motor fuel, and the efficiency of conversion is approximately 42 percent.[5]

21/ Hirst, L. L., Storch, H. H., Fisher, C. H., and Sprunk, G. C., Hydrogenation and Petrography of Subbituminous Coals and Lignites; Ind. Eng. Chem., Vol. 32, 1940, pp. 1372-1379.

TABLE 13. - Yields of oil and gasoline from American coals by hydrogenation[1/]

State	Mining field	Rank	Oil yield, gallons per ton[2/] liquid-phase	Gasoline yield, gallons per ton[3/]
Alabama	-	High-volatile A	135	105
do	-	do	175	134
West Virginia	-	do	164	126
Pennsylvania .	-	do	170	130
Utah	Sunnyside	High-volatile B	178	136
Indiana	-	High-volatile C	146	112
Illinois	-	do	159	122
Washington ...	-	do	156	120
Colorado	Denver (Weld County)	Subbituminous B	119	91
Wyoming	Sheridan -	do	130	100
Montana	Rosebud	Subbituminous C	106	81
North Dakota	Beulah	Lignite	82	63
do	Velva	do	85	65

1/ Determined by the Bureau of Mines in the experimental hydrogenation plant at Pittsburgh, Pa. See Fieldner, A. C., and Schmidt, L. D., Annual Report of Research and Technologic Work on Coal: Bureau of Mines Inf. Circ. 7190, 1941, 60 pp.
2/ Yields calculated on coal as mined.
3/ Gasoline predicted based on 70 percent liquid-phase oil converted to gasoline, and 290 gallons per ton of gasoline. Bureau of Mines Inf. Circ. 7190, 1941, pp. 54-57.

Fieldner, Rice, and Storch[22/] have discussed the present status of hydrogenation and have reviewed the estimated costs of producing gasoline from coal in the United States. The following excerpt from their report gives a brief outline of the economic factors that affect hydrogenation of coal:

> At present this process is operating on a large scale in Germany, and the cost is said to be approximately 18 cents per United States gallon. This cost is far above the present American cost of petroleum gasoline at the refinery. There is little doubt that when the time comes for the production of gasoline from coal,

22/ Storch, H. H., Hydrogenation: Chapter in Research and Progress in the Utilization of Coal, pp. 45-49, edited by Fieldner, A. C., and Rice, W. E., National Resources Planning Board Tech. Paper 4, 1941, 49 pp.

American costs may be as low as 12 cents per gallon if the program of research and development applied to this problem is as intensive as that conducted on the manufacture of gasoline from petroleum. However, that cost is more than twice the present price of gasoline at the refinery. The labor and equipment required for making gasoline from coal greatly exceed those necessary for manufacture of gasoline from petroleum and, what is more important, much energy is lost in the process of conversion. In round numbers, 4 to 5 tons of coal are consumed in making 1 ton of gasoline, and only 40 to 45 percent of the original heat units in the coal used remains in the resulting motor fuels.

It is believed that 1-1/3 times our present annual production of coal would be needed to yield our present annual requirements of gasoline. Such increase of consumption of coal would no doubt solve the immediate problem of the coal industry, but at the expense of a greater consumption of national fuel resources. A forward-looking national fuel policy would seek to delay the day of making gasoline from coal as long as possible by reserving the higher-value fuel, natural gas and petroleum, for those uses that cannot be met so efficiently by the direct combustion of coal.

Large-scale hydrogenation of coal in the United States would require an extended period of research on our particular coals to determine which coals would give the best yields and which locations would prove most economically desirable.

APPENDIX

Sources of Data and Construction of Charts

The main source of data for this report was the Bureau of Mines Minerals Year Books. Other sources are noted in the following description and analysis of each figure:

Figure 1. - Coal fields of Western States. Reprinted from Keystone Coal Buyers Catalogue. Original base coal map prepared by M. S. Campbell, Federal Geological Survey, 1917.

Figure 2. - Energy production per capita, - 5-year averages. Data from same source as in figure 3 but reduced to per-capita basis and averaged for 5-year periods to reveal trends. The 5-year average for a given year is for the 5-year period ending that year. The estimated per-capita reserve of oil is calculated for the 1940 rate of production from estimates

of proved reserves given in Minerals Year Book, 1940, page 938. The estimated life of gas reserves at present rate of recovery may be slightly greater than noted on this chart. Authorities differ on these estimates. In 1935 estimated reserves for the United States were 20 to 38 years at the prevailing rate of consumption. The dotted area represents estimated life of present reserve based on data of R. E. Davis, Report of the Energy Resources Committee to the National Resources Committee, 1939, page 297. All figures in this chart are calculated to equivalent gross heating value, expressed as tons of equivalent coal (26,200,000 B.t.u. per ton) and thermal equivalents used are listed in description of figure 3. For example: A billion cubic feet of 1,000 B.t.u. natural gas would equal 38,200 tons of coal, and 1,000 barrels of petroleum would equal 229 tons of coal. The use of an energy unit equal to the heating value of a ton of average bituminous coal is easier to visualize than a figure expressing energy in trillions of B.t.u. It should be remembered that the weighted-average gross-heating value of coal produced in the Western States is 22,860,000 B.t.u. per ton. The Western States discussed in this report comprise the Rocky Mountain States of Montana, Wyoming, Colorado, New Mexico, Arizonia, Utah, Idaho, and Nevada, and the Pacific Coast States California, Oregon, and Washington.

Figure 3. - B.t.u. equivalent of fuels produced. Prepared from data in Minerals Year Books and from Report S-20, Federal Power Commission, November, 1941. The chart for the United States is the same as appears in Minerals Year Book, except that hydropower coal equivalent is calculated from prevailing coal equivalent. For example: At the present time prevailing average coal required per Kw.-hr. is 1.35 pounds, and the best central stations report a fuel consumption of 0.8 pound of coal per Kw.-hr. At the present time, 1 ton of 13,100 B.t.u. coal can be considered to be displaced by 1,482 Kw.-hr. of hydropower (2,000/1.35), and the best plants displace 0.4 ton of coal per 1,000 Kw.-hr. (Refer to table 5). Likewise, 1 ton of average western coal is displaced by 0.859 x 1,482 = 1,272 Kw.-hr. of hydropower at the present time as explained in table 5. Thermal equivalents used in this graph are: Coal, United States average = 13,100 B.t.u. per pound; anthracite = 13,600 B.t.u.; natural gas in United States = 1,075 B.t.u. per cubic foot; natural gas in western United States = 1,000 B.t.u. per cubic foot; oil = 6,000,000 B.t.u. per barrel. Weighted average heating value of coal produced in 11 Western States, excluding Dakotas, is 11,430 B.t.u. per pound.

Figure 4. - Sales of competing fuels. Data for the figure obtained from Bureau of Mines Minerals Year Book, 1940. The method of converting different forms of energy to the basis of "tons of 13,100 B.t.u. coal per capita" used in figures 2 and 3 is used in this chart. This figure indicates that the per-capita consumption of energy in the Western States is about the same as it is in the East, but it is higher in the Rocky Mountains. This may

be due to proportionally larger requirements for railroad fuel. Coal sales for the Rocky Mountain area were assumed as total production minus shipments to Pacific coast and to Eastern States. This figure does not exclude eastern shipments of coal from Colorado or Montana as data are not available. Coal sales for the Pacific coast includes production plus shipments of coal from Utah and Wyoming, amounting to about 500,000 tons, and imports of coke of 67,000 tons. This chart does not differentiate equivalent hydropower produced in the Rocky Mountain area and transmitted to the Pacific coast, or coal mined in Wyoming for railroad use east of Wyoming.

Figure 5. - Relation of energy production to industrial activity, 1919-1941. This chart shows a direct relation between industrial production and amount of energy produced in the United States. Five-year averages are selected to avoid variations that obscure a correlation. The averages plotted are average for the 5-year period ending with the year noted. The Federal Reserve Board Index of Industrial Production is a relative measure of physical volume. The published index is not adjusted for changes of population, but in this graph the 5-year average index has been adjusted for changes in population to make the index a measure of physical volume of production per capita. This adjustment for population is made by increasing or decreasing the published index by the ratio 129.3/population in millions for the year considered. 129,300,00 was the average population of the United States from 1935 to 1939. The adjustment makes the 5-year indexes for 1926 and for 1939 almost equal to 100, and it makes it unnecessary to change the base year for calculating the index. For example: The Federal Reserve Board index of industrial production during 1939 was 108. The index adjusted for population was $108 \times \frac{129.3}{130.9} = 106.7$. Likewise, the Federal Reserve Board index for 1926 was 96, when using the 1935-39 base = 100, but when adjusted for population change the index becomes $96 \times \frac{129.3}{116.5} = 106.5$. At the present time, the rate of change of population in the United States is about 0.8 percent per year, whereas the 1925 rate of change was approximately 1.6 percent per year.

The correlation between energy production and industrial activity is shown on the upper plot. The points are obtained by dividing total energy by the adjusted index and multiplying by 2,000. This correlation shows that total energy required to support a given volume of industrial production per capita, including fuel for domestic heating, is decreasing each year. Furthermore, the energy required per unit of business per capita goes up during poor times and decreases during periods of high industrial activity, owing to greater efficiency of industrial utilization of energy and to virtually constant consumption of fuel for domestic heating. The slope of the correlating line is a measure of technologic improvement in the use of total energy.

Annual Demand for Energy in the United States

Figure 6. - Correlation of energy production and industrial production. Other studies by the author have shown that the amount of energy, including oil, gas, coal, coke, briquets, etc., required for domestic heating averaged 1.65 tons of equivalent coal per capita in the United States during the period 1917 to 1937. When this quantity of energy is deducted from total energy produced, the remainder should correlate with industrial activity. This chart shows a direct correlation:

$$\text{Total energy produced per capita} = 1.65 + \text{F.R.B. index}^{23/} \left[\frac{95 + 1.75\ (1939\text{-year})}{2{,}000}\right] \text{(tons of 13,100 B.t.u. coal)}$$

The constant 1.75 in the above equation is a measure of the rate of improvement in utilization of energy for industrial purposes. In normal times, when the industrial production index is 100, the amount of fuel required to produce normal industrial activity decreases 175 pounds per year per capita. This is a fundamental factor that reflects improvement in efficiency of use of fuel, efficiency of manufacture of higher-value fuels from coal, mass production, and other factors that go to make up our industrial economy. This equation also measures the demand for energy because most of the energy produced is used within the United States. The amount of energy exported during the last 9 years has averaged only 0.22 ton of equivalent coal per capita.

The equation can be used to estimate the rate of production of energy for any level of industrial activity. For example, the Federal Reserve Board index of Industrial Production has been approximately 170 for the period January to May, 1942. The population change since 1935-39 is estiamated to be 129.3/133.2 = 0.971. The adjusted index for 1942 to date is 170 x 0.971 = 165. Substituting the above formula gives a total energy requirement of 9.06 tons per capita per year. This is equivalent to an increase of 38.6 percent over the amount of energy produced per year during 1935-39. From figure 3 the proportion of this energy supplied by bituminous coal is estimated to be 49 percent. Therefore, the rate of production of bituminous coal should be 9.06 x 0.49 x 134,700,000 = 598 million tons per year up to May 1942. The actual rate, including withdrawal from stocks, was 582 tons per year. Slightly less coal was mined for domestic heating during this period and may account for the difference.

23/ Federal Reserve Board Index adjusted for population change as described in appendix for figure 5. Base 1935-39 = 100.

An estimate of the rate of production of coal in the Western States to meet a given industrial activity can be made as follows: During 1940, 21,531,000 tons of coal was produced in the Western States. This represented 16 percent of the total energy produced, according to figure 3. In figure 6 it is shown that the amount of all forms of energy required to heat homes is equal to 1.65 tons of 13,100 B.t.u. coal per capita. If western coal supplies 16 percent of domestic fuel, then the amount of coal used is estimated to be 0.16 x 1.65 x 14,200,00 (population of Western States) = 3,770,000 tons of 13,100 B.t.u. coal, or 4,320,000 tons of 11,430 B.t.u. coal. Industrial coal is therefore estimated to be 21,531,000 - 4,320,000 = 17,211,-000 tons during 1940. From the correlation of figure 6, it is shown that amount of industrial energy required is directly proportional to the Federal Reserve Board Index of Industrial Production. This index was 123 in 1940, and during the first 4 months of 1942 it was 170. Therefore, the rate of demand for industrial coal up to May 1942 should be 17,211,000 x 170/123 = 23,800,000 tons per year. If coal production in the West is holding its own with respect to competition with other fuels, the rate of total coal production should be equal to 23,800,000 + 4,320,000 = 28,120,000 tons per year. The actual rate of production in the Western States, according to weekly reports of the Bituminous Coal Division to May 15, 1942, was 28,200,000 tons per year. This calculation indicates that the proportion of energy supplied by coal is still about the same as it was in 1940 and that coal production is in proportion to industrial production.

Figure 7. - Population trends in Western States. (From Bureau of Census and statistical abstracts). Rate of increase or decrease is calculated as percentage of change from previous decade. This figure shows that the average rate of increase of population on the Pacific coast is about 2 percent per year, whereas in the Rocky Mountain area and in the United States the rate of change is now about 1 percent per year.

Figure 8. - Production of coal in Western States. All data from Bureau of Mines Minerals Year Books and Geological Survey reports.

Figure 9. - Coal production in Western States, 1860-1941. Cumulative percentage production by States, tonnage basis. Data from same source as figure 8.

Figure 10. - Relation between number of mines and relative production in Colorado, Utah, West Virginia, Pennsylvania, and Illinois, 1938-39. Data for this chart were obtained from the following sources: State of Illinois Coal Report, 1939; State of Utah Bulletin No. 4, Industrial Commission, July 1938 to June 1940; and from a special report by Durbin Van Law listing small mines in Utah. Annual Report of the Department of Mines, West

Virginia, 1939. Commonwealth of Pennsylvania, Department of Mines Annual Report, Bituminous Division, 1939. Twenty-sixth Annual Report of the State Inspector of Coal Mines, Colorado, 1938. Mines were listed in order of production to determine cumulative production versus number of mines. Data for Pennsylvania do not include anthracite or production from bituminous strip mines, amounting to 2,793,000 tons.

From this chart the following comparisons, referred to in the text, showing the structure of the coal-mining industry in the several States, can be obtained:

State	Mines producing 25 percent of total production			Mines producing 50 percent of total production			Mines producing 75 percent of total production		
	Percent of total mines	Number of mines	Average size of mine, tons/year	Percent of total mines	Number of mines	Average size of mine, tons/year	Percent of total mines	Number of mines	Average size of mine, tons/year
Colorado	2.0	7.7	185,000	4.8	18.5	155,000	10.0	38.5	111,000
Utah	1.66	1.6	500,000	3.7	3.6	447,000	8.0	7.8	310,000
West Virginia	2.7	28.1	966,000	7.5	78.0	695,000	16.5	172	474,000
Pennsylvania	2.25	19.5	1,146,000	6.3	54.6	819,000	14.0	121	554,000
Illinois	1.1	10.7	1,112,000	2.9	28.3	842,000	4.9	48	742,000

The above comparisons indicate that coal mining in Utah is similar to that in Illinois, or most of the production is from a fewer relatively large mines. Mining in Colorado is similar to that in Pennsylvania, except that the average size of mines in Colorado is smaller.

Figure 11. - Rate of bituminous-coal production, tons of 13,100 B.t.u. coal per capita per year. (Data from Bituminous Coal Division Weekly Coal Reports). The weighted average heating value of coal produced in the Rocky Mountain area is 11,430 B.t.u. per pound, whereas the average heating value of coal produced in the United States is 13,100 B.t.u. This chart corrects the difference in heating value and reduces production to a per-capita basis. The method used for calculating is as follows: For the week of August 2, 1941, the production of coal in Colorado, Utah, Wyoming, New Mexico, and Montana amounted to 367,000 tons of 11,430 B.t.u. coal, or 312,000 tons of 13,100 B.t.u. coal. The population of the 8 Rocky Mountain States in 1940 was 4,150,000. Therefore, the rate of production of 13,100 B.t.u. coal per

capita per year for the week of August 2 was $\frac{312{,}000 \times 52}{4{,}150{,}000} = 4.0$ tons. The annual rate of production during the next 4 weeks in August 1941 was 4.2, 4.3, 4.7, and 4.9, calculated in the same manner. The average annual rate of production during August 1941 was therefore 4.42 tons per capita, which is plotted in the graph.

This chart, in conjunction with table 3, shows that the Rocky Mountain States now produce about 25 percent more coal per capita than is produced in the United States, but the load factor is poorer in Western mines. If the load factor could be improved by storage or by increasing the demand for industrial fuel, it appears that an average annual production as high as 5.5 tons per capita could be attained from mines now operating in the Rocky Mountains. This is spproximately 20 percent more than was produced during 1941 and would amount to approximately 3-1/4 million tons of 13,100 B.t.u. coal.

Figure 12. - Distribution of Utah coal. Data for this figure were obtained from a report by Durbin Van Law, industrial engineer, Denver & Rio Grande Western Railroad, "Utah Coal Industry," 1941 (unpublished). This figure shows that although production has declined since 1930, the proportion of coal used in Utah has increased from 55 to 65 percent of the coal produced. The proportion of coal going to Idaho has increased slightly. The West Coast market, including Nevada, has decreased from 27 to 14 percent of the coal produced in Utah. In other words, the Pacific coast market has been cut in half, principally through competition with oil and gas. Figure 3 shows this change and indicates that oil is the principal competitor of coal. This figure shows that the percentage of coal delivered by railroads has decreased, whereas truck deliveries have increased steadily. The Utah market for Utah coal (including railroad fuel) amounts to about 2,600,000 tons at the present time and has not changed appreciably from the 2,800,000 tons sold in 1930.

Figure 13. - Truck movement of Utah coal. Utah Highway Patrol checking station at Spanish Fork. (From Van Law report.)

Figure 14. - Demand for sizes of Utah coals. From Utah Coal Operators Association, District 20. (Obtained from report by Durbin Van Law.)

Figure 15. - Demand for sizes of subbituminous coal, northern Colorado field. Data from Bituminous Coal Division, Northern Colorado Coals, Inc., District 16. The dotted lines beyond 1941 are not Bureau of Mines estimates of trends. They are inserted to show a possible trend and the use of size-consist data to estimate sizes of stoker coal and small slack.

Figure 16. - Mine prices, District 20. From above-mentioned report by Durbin Van Law.

Figure 17. - Sales of natural gas in Utah. Source: Mountain Fuel Supply Co. and report by Durbin Van Law.