UNITED STATES
DEPARTMENT OF THE INTERIOR
HAROLD L. ICKES, Secretary
GEOLOGICAL SURVEY
W. C. MENDENHALL, Director

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CIRCULAR 11

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REVIEW OF THE PETROLEUM INDUSTRY IN THE UNITED STATES APRIL, 1934

Compiled by
HALE B. SOYSTER

in collaboration with

G. B. Richardson, R.W. Richards, Foster Morrell, U. S. Geological Survey; H. C. Fowler, G. R. Hopkins, A. J. Kraemer, A. C. Fieldner, U. S. Bureau of Mines; and H. J. Struth, Petroleum Administrative Board, Department of the Interior

Washington

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Acknowledgments

The writer wishes to acknowledge the helpful assistance and advice of Dr. W. C. Mendenhall, Director, United States Geological Survey; Mr. Scott Turner, Director, United States Bureau of Mines; Mr. Herman Stabler, chief, Conservation Branch, United States Geological Survey; Mr. J. D. Northrop, assistant chief, Conservation Branch, United States Geological Survey; Mr. LeRoy H. Hines, assistant legal advisor, United States Geological Survey; Mr. Hugh D. Miser, geologist in charge, Section of Geology of Fuels, Geologic Branch, United States Geological Survey; and R. A. Cattell, chief engineer, Petroleum and Natural Gas Division, U.S. Bureau of Mines.

Petroleum reserves

Distribution

The oil-producing areas in the United States are widely distributed.1/ Production is obtained in 20 States, which for statistical purposes are grouped into 8 major districts:

1. Appalachian (New York, Pennsylvania, eastern and southeastern Ohio, West Virginia, Kentucky, and Tennessee.)

2. Lima-Indiana (northwestern Ohio and northeastern Indiana.)

3. Michigan.

4. Illinois-Indiana (Illinois and southwestern Indiana).

5. Mid-Continent (Kansas, Oklahoma, Arkansas, Louisiana excluding Gulf coast, Texas excluding Gulf coast, southeastern New Mexico).

6. Gulf coast (in Texas and Louisiana).

7. Rocky Mountain (Montana, Wyoming, Colorado, Utah, and northwestern New Mexico).

8. California.

Quantitatively, however, the distribution is not so widespread. Of the more than 15 billion barrels of petroleum that have been produced

1/ Map of oil and gas fields of United States, U.S. Geol. Survey, 1932.

in the United States from 1859 to 1933, 66 percent has come from California, Oklahoma, and Texas, and of the current output 83 percent is supplied by these three States, according to statistics of the Bureau of Mines.

The United States may be classified into proved, prospective, unfavorable, and impossible oil and gas areas on the basis of production and of the factors that control the occurrence of these hydrocarbons. Four factors are of major importance: (a) Source deposits--beds containing the remains of certain aquatic plants and animals from which oil and gas are generated: (b) reservoris -- porous, fractured, or cavernous rocks in which oil and gas are stored; (c) traps or structures constituting barriers to prevent the escape of the hydrocarbons from the reservoirs; (d) absence of geologic disturbance of the rocks sufficient to destroy oil or gas that may have been stored in them.

Several such classifications of the United States for oil and gas have been made, notably by the American Petroleum Institute in 1925,[2] by David White in 1928,[3] and by Arnold and Kemnitzer in 1931.[4] The fact is patent, however, that the location and productivity of fields to be found in the future remain unknown in advance of discovery by the drill.

In considering the reserves of petroleum, it should be borne in mind that (1) the reserves are irreplaceable, and production is a record of exhaustion; (2) because of the unknown number and unknown productivity of the fields yet to be discovered it is impossible to predict with assurance the quantity of these reserves; (3) it is essential that the reserves of the proved fields be distinguished from the reserves of the fields yet to be discovered.

Proved fields

Estimates of reserves in known sands in proved fields, recoverable by current methods, are on record as follows:

2/ American Petroleum Supply and Demand, American Petroleum Institute, 1925, pp. 58,59.

3/ White, David, Address (unpublished), Second International Conference on Bituminous Coal, Pittsburgh, Pa., 1928.

4/ Arnold and Kemnitzer, Petroleum in the United States and Possessions, 1931.

	Billion bbls.
1922 United States Geological Survey and American Association of Petroleum Geologists 5/	5.0
1925 American Petroleum Institute 6/	5.3
1926 Federal Oil Conservation Board 7/	4.5
1932 Federal Oil Conservation Board 8/	10.0
1933 Valentin R. Garfias 9/	12.0

Undiscovered fields

Consideration must be given to the uncertain but very important problem of production from undiscovered fields, because the "flush" output of new fields is depended on to meet our needs. An unknown field of today may become a proved field tomorrow.

The reserves of petroleum in the United States have long been debated. Some have held the supply to be practically inexhaustible; others have predicted early exhaustion.

Arnold and Kemnitzer forecast a total reserve of 39 billion barrels for the United States as of January 1, 1929. 10/

Whether our reserves of petroleum prove to be 12 billion, 39 billion, or some other figure of comparable magnitude, the reserves are indeed limited.

5/ The oil supply of the United States: Dept. Interior Press Notice, 1922.
6/ American petroleum supply and demand; p. 3, American Petroleum Institute, 1925.
7/ Federal Oil Conservation Board Report I, p. 8, 1926.
8/ Federal Oil Conservation Board Report V, p. 7, 1932.
9/ Am. Inst. Min. Met. Eng. Trans., vol. 103, p. 253, 1933.
10/ Arnold and Kemnitzer, op. cit., p. 5.

Depletion of reserves

Rapid depletion of reserves and wasteful utilization of petroleum through necessity to dump excessive output upon the market at demoralized prices are clearly recorded throughout the history of the oil industry.

Facts recorded by annual reports of the United States Bureau of Mines show a tremendous rise in petroleum production since 1859, when the American petroleum industry had its beginning with the discovery of oil at Titusville, Pa.

Official statistics of petroleum production from 1859 to 1933, collected by these Bureaus, place the total recovery of crude oil at 15,700,000,000 barrels. During this period the annual oil production increased from about 2,000 barrels in 1859 to 1,007,323,000 barrels in 1929. Production in 1933 was reported by the Bureau of Mines as 898,874,000 barrels.

A review of facts recorded by annual Bureau of Mines reports places particular emphasis upon the discovery and development of new fields. Competitive practices attending each new discovery are shown to have resulted not only in premature depletion of oil reserves, but also in successive economic disturbances that contribute to physical waste of natural resources through uneconomic utilization because of extremely low market prices.

Usually when a new producing area is discovered, competitive development brings an orgy of drilling that quickly brings a peak output of oil, in excess of normal market requirements, followed by sharp recessions in price and subsequent premature decline in productivity of the particular area. Moreover, the facts show not only local price demoralization, but also a decidedly general downward revision in values that extends into every producing area of the United States.

The effect of uncontrolled development of new, flush oil-producing areas can be clearly visualized by charting the course of production ensuing during the flush stage of each new field, in relation with posted prices of crude oil. More particularly since 1901 production peaks of new oil fields have consistently had a demoralizing effect upon the industry's market structure for both crude and refined oil. Yet the records reveal the adverse market influence of new oil finds from the very beginning of the industry. In fact, from 1859 to 1879 prices of crude fluctuated violently under the influence of alternate periods of feast and famine. Since 1901, however, when the famous Spindletop oil field was discovered in the Texas Gulf coast region, the advent of new producing areas, each accompanied by frenzied development and excessive supply, has been distinctly marked by low prices, wasteful utilization of petroleum and its products, and premature depletion of oil reserves and natural underground energy. As a matter of fact, every flush oil field brought into commercial production since 1901 has had a relatively short life of its flowing wells, owing to wasteful, uncontrolled, acutely competitive operation. Many such fields undoubtedly would have yielded greater quantities of oil under careful, orderly development and control of production. At the same time, extreme fluctuations in market prices could have been avoided.

Statistics indicate that competitive development of such fields as Spindletop, Sour Lake, Batson, Humble, Jennings, and Glenn Pool, brought into production between 1901 and 1908, had a severely depressing effect upon the oil industry's price structure. In fact, in the period from 1903 to 1909, during which the flush fields mentioned contributed successive peak periods of production, the average price per barrel of Mid-Continent crude declined from $1.02 to 33 cents. Later, there was a gradual rise in prices, which carried the average for 1913 to 94 cents per barrel.

Meanwhile, the rise of flush oil production at Caddo, La., and the discovery and competitive development of the Cushing area, Okla., brought a sharp recession in posted crude prices, lowering the average value to 58 cents in 1915.

In the lack of any important new discoveries until Mexia-Powell duplicated the Cushing peak in 1923, embracing the period when the United States engaged in the World War, oil prices advanced to an average of $3.30 in 1920. The peak production at Mexia-Powell, in 1923, again adversely affected the crude market, lowering the average price in 1924 to $1.45. Another decline in production of flush areas carried the crude price average to $2.31 in 1926.

The report of the Federal Oil Conservation Board, No. 5, October, 1932, states: "When large discoveries of oil and gas were made in the North Dome of the Kettleman Hills oil field, California (1928), threatening to demoralize the oil industry in California, the Secretary of the Interior, with the assent of Congress, took the initiative and with the cooperation of operators secured the adoption of a plan of unit operation in that field which drastically limited production, conserved the oil and gas resources and which will, it is believed, prolong the life of the field to the advantage of the State, the Nation, and the owners or lessees. The success of this experiment resulted in the enactment by Congress of a general and permanent act, March 4, 1931, authorizing the Secretary of the Interior to enter into unit or cooperative plans of development on any oil or gas field in the public domain. Several such units have been established and others are under consideration."

The benefits derived by the procedure thus followed with respect to the public domain are not confined wholly to the conservation of the resources nor the reduction of output at a time when it is neither needed nor profitable. The drilling on leases and on prospecting permits that were outstanding or would have been applied for had not the order of March 12, 1929, been issued, would have involved a very large outlay of money which, during the era of low prices, would have yielded no adequate return even if discoveries had been made. The adoption of the unit plan of development materially lessens the number of wells that are required to be drilled to extract the oil and gas from the land, thus effecting a large saving, and the limited and scientifically regulated production followed under such a plan prolongs the life of the field and results in the ultimate extraction of a much larger quantity of oil and gas from the underlying sands.

Although the existing conditions warranted the drastic limitation of exploration and production from the public and Indian lands, it is nevertheless true that the various States containing public lands or reservations subject to the leasing act naturally feel that they are entitled to have the oil and gas resources within their borders developed under proper methods.

Therefore, after the unit-operation law had been enacted by Congress and the procedure thereunder determined by the Department of the Interior, an order was issued under date of April 4, 1932, again opening the public domain to the filing of applications for prospecting permits - with the condition, however, that each applicant shall expressly agree to produce no oil or gas in commercial quantities except pursuant to a plan of unit operation or other cooperative plan approved by the Secretary of the Interior, and with the further express condition that the applicant shall comply with all State and Federal laws, regulations, and orders, affecting production and proration.

Developments in Oklahoma led to a renewed outburst of competitive drilling in the Seminole area, which registered an unusually high peak output in 1928, causing crude prices to drop sharply to an intermediate average level of $1.39. About this time oil was discovered in large quantities at Oklahoma City. Also, the effect of previous onslaughts of flush production upon oil prices began to crystallize thought and effort in the oil industry in the direction of some form of control of development and production. Groups of operators in new fields, such as Oklahoma City and Seminole, organized proration committees and launched concerted efforts to attain some degree of control of production that would act to stabilize the industry's price structure and prevent unnecessary waste of the natural resources.

Partial success in control plans was attained, only to meet with complete disruption on the discovery of the largest oil-producing area in the history of the American oil industry—East Texas, in the later part of 1930. Sporadic attempts to enlist the cooperation of operators in the East Texas area in effecting proration and control of development met with continual reverses. Meanwhile, both the Oklahoma City field and the East Texas area combined to show a record-breaking peak production that completely demoralized the industry's general market structure. Additional new oil finds, such as Conroe, in the Texas Gulf coast region and numerous salt-dome fields extending along the entire Texas-Louisiana Gulf coast, served to complicate proration efforts still further.

Commensurate with experiences of the past, the combined peaks of flush fields brought into the picture between 1928 and 1931 carried Mid-Continent oil prices down to 18 cents a barrel, and East Texas oil was posted for a short time at 10 cents a barrel.

It has been stated 11/ that new flush fields when allowed to produce without restriction show a rapid decline in production in the first 3 years of their life. In the first year after reaching the peak of production, these fields fall off on the average from 60 to 66 percent. Two years after the peak the average decline is more than 70 percent, and after 3 years production has declined about 80 percent. Some large individual fields show declines of as much as 92 percent within a year after the peak of production has been reached, and a maximum decline of 94 percent at the end of the third year. It is generally estimated that during the first year of the life of a well, if made to produce normally, it yields from 30 to 100 percent of its recoverable oil.

There is a general tendency to overestimate ultimate production of fields. Many estimates are extravagant, and some of the earliest estimates have little factual basis. 12/

The few large flush fields have created a fictitious picture. It might be supposed that there is a veritable flood of oil, but statistics show that most of the wells that are drilled and find oil are small wells.

11/ Facts and figures, pp. 111-112, American Petroleum Institute, 1928.

12/ Snider, L. C., 'A comparison of old and new fields': Am. Inst. Min. Met. Eng. Trans., vol. 103, pp. 71-86, 1933.

The following figures represent an annual average over a period of 7 years, 1920 to 1926: Of the total oil wells completed in a year in the area of the United States east of the Rocky Mountains, 31.7 percent had an initial daily production of 25 barrels or less; 8.2 percent produced between 26 and 50 barrels; 4 percent between 51 and 75 barrels; 3.9 percent between 76 and 100 barrels; 6.3 percent between 101 and 200 barrels; 2.7 percent between 301 and 500 barrels; 1.3 percent between 501 and 750 barrels; 1.2 percent between 751 and 1,000 barrels; 1.5 percent between 1,001 and 2,000 barrels; and 1.3 percent over 2,000 barrels.

It is significant that the estimated proved reserves of California January 1, 1933, were 180,880,000 barrels less than the estimated reserves January 1, 1932. During 1932 about 85 percent of the oil produced in California was from old reserves and only 15 percent from the more recently discovered reserves.13/ Known petroleum reserves in California do not appear adequate to sustain heavy withdrawals over a long period of time. In 1932 California's production was considerably greater than the reserves of newly discovered fields.

Dissipation of reservoir energy by blowing gas into the atmosphere results in increased costs of production and a reduced ultimate recovery --therefore a reduction in recoverable known reserves.14/

As the flush output of new fields is depended upon to maintain the current reserves, it is clearly apparent that planned and controlled development are needed, in order that the Nation's oil and gas resources may be conserved. Such a conservation program is essential, not alone because of the continued economic advance of the Nation but also because of the necessity of maintaining an adequate supply immediately available for national defense.

13/ Wilhelm, V.H., and Miller, H.W., Developments in the California petroleum industry during 1932: Am. Inst. Min. Met. Eng. Trans., vol. 103, p. 345, 1933.

14/ Hawthorn, D.G., Subsurface pressures in oil wells and their field of application: Idem, pp. 148-169.

Additional references: Pratt, Wallace, Industry must drill 20,000 wells yearly: Oil and Gas Journal, July 16, 1931. Barnes, R.M., and Bell, A.H., Proration of an oil field based on uniform allowable gas production: Am. Inst. Min. Met. Eng. Trans., vol. 103, p. 142, 1933.

Supply and demand

Production

The raw materials of the petroleum industry are crude petroleum, natural gas, natural gasoline, and benzol. Crude petroleum is by far the most important, constituting 96 percent of the total production of raw materials in 1933.

The first commercial production of crude petroleum was recorded in 1859, after the discovery of the Drake well on August 29, 1859. The output for that year amounted to the modest quantity of 2,000 barrels.15/ The annual production increased by leaps and bounds, however, so that by 1900 it was 63,621,000 barrels.15/ However, this increase over 40 years was small compared with that which has occurred during the first third of the present century. During that 33-year period the production of crude increased from 63,621,000 barrels in 1900 to about 900,000,000 barrels in 1933, or more than fourteenfold. This sensational increase was not continuous, as in 1906, 1924, 1930, 1931, and 1932 there was no increase over the preceding year. The peak year was 1929, when the production was 1,007,323,000 barrels.15/ Except in 1929, when production was unusually high, and 1932, when it was unusually low, our annual production for the last 7 years has been about 900,000,000 barrels, or a daily average of 2,466,000 barrels.

During the 7-year period 1927-33 crude-oil stocks increased 99,258,000 barrels, or an average of 39,000 barrels a day. Deducting this average from the average daily production (2,442,000 barrels) for that period leaves 2,403,000 barrels as a rough measure of the normal daily requirements for crude oil. The production rate for February, 1934, a period of relatively low consumption, as reported by the Bureau of Mines, was 2,338,000 barrels. The present rate (March 30, 1934) is about 2,440,000 barrels, or not far above the average of 2,403,000 given above.

The total of nearly 15,700,000,000 barrels of crude oil produced in the United States during the entire period 1859-1933 is equal to 65 percent of the total production of the world during that time.

15/ Mineral Resources of the United States, Part II, U. S. Geol. Survey.

The elements in the new supply of all oils are the production of crude, just described, natural gasoline and benzol, which at present amount to about 100,000 barrels daily, and imports of crude oil and refined products.

Imports

Oil has been imported into this country since about 1905. Crude oil has always constituted the bulk of the imports, although the disparity between receipts of foreign crude and foreign refined oils has lessened in recent years. The peak of imports was reached in 1921 and 1922, when Mexican production was at its height. In 1922, 127,308,000 barrels of crude oil and 8,665,000 barrels of refined products were imported into the United States.[16] Since 1922 the trend in imports of crude oil has been downward, although a material gain occurred in 1928, following the rapid rise of production in Venezuela. In June, 1932, when tariffs were placed on imports of mineral oils, the quantities brought in declined about 50 percent. Under an order supplemental to the oil code, imports were restricted to the average for the last six months of 1932, and in 1933 only 32,773,000 barrels of crude oil and 13,498,000 barrels of refined products were imported, a decline of 38 percent from 1932 and the lowest total since 1927. The total of imports from the beginning through 1933 has amounted to about 1,250,000,000 barrels of crude oil and 285,000,000 barrels of refined products, a grand total of 1,535,000,000 barrels. The latest official figures[17] give imports of crude as averaging 86,000 barrels daily and imports of refined oils as averaging 10,000 barrels daily. The latest weekly report of the American Petroleum Institute shows that for the week ended March 24, 1934, crude imports averaged 49,000 barrels and refined products 40,000 barrels, indicating a downward trend in these operations. In general, it can be said that imports of all oils constitute about 5 percent of our total new supply.

Exports

Except during the period 1920-22, exports of crude oil and refined products from the United States have exceeded the imports, as is illustrated by the fact that up to and including the year 1933 a grand total of about 3,000,000,000 barrels of crude oil and refined products has

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16/ Bureau of Foreign and Domestic Commerce.

17/ Bureau of Foreign and Domestic Commerce, data for February, 1934.

been exported from this country, as compared with total imports of 1,535,000,000 barrels. Of the total exports, about 83 percent has consisted of refined products, whereas crude oil has constituted 81 percent of the total imports. In recent years exports of refined oils have declined, owing largely to the growth of the refining industry in foreign countries. On the other hand, exports of crude oil have been stimulated by this growth in refinery capacity abroad, so that the total for 1933 of 36,703,000 barrels constituted the highest annual total ever recorded. The major portion of our crude oil exported is consigned to Canada, although Japan, France and Germany are also large purchasers.

Prior to 1923 kerosene and fuel oil were the principal products exported, but since that year gasoline exports have exceeded kerosene exports, and since 1929 they have been roughly equal to the combined exports of kerosene and fuel oil. In 1933 the exports of gasoline amounted to 29,186,000 barrels, which, though equivalent to only 45 percent of the highest record for such shipments, established in 1930, comprised 7 percent of our total demand for motor fuel.

The latest data available[18] indicate that at the present time average daily exports are as follows: Crude oil, 90,000 barrels; gasoline, 75,000 barrels; other refined products, 125,000 barrels; total, 290,000 barrels.

Summary of imports and exports

Present imports of all oils average about 96,000 barrels daily, or 4 percent of the total new supply. Exports of all oils average 290,000 barrels daily, or 11 percent of the total demand. The imports consist primarily of low-gravity crude of low gasoline content and fuel oil; the exports consist primarily of gasoline, kerosene, and lubricating oils, or oils of a comparatively high unit value. The tariff of 1932 curtailed imports roughly 50 percent, but the oil thus shut out has displaced a material portion of our exports.

Domestic demand

The total demand for all oils comprises the domestic demand for refined products, losses, crude used as fuel, and exports of crude oil and refined products. Although, as shown above, our exports are considerable, the domestic demand for refined products constitutes the

18/ Bureau of Foreign and Domestic Commerce, data for February, 1934.

major portion of the total demand. In 1933, the total domestic demand, excluding losses and crude used as fuel, amounted to 830,405,000 barrels, or 85 percent of the total demand.

In general, the consumption of oil in this country has shown a growth commensurate with the rapid rise in crude production already described. From the rise of the refining industry in the last half of the nineteenth century until about 1908, kerosene was the primary refined product; from 1908 until 1929, fuel oil led in quantity, though the lighter products had a higher total value. Gasoline assumed the lead in quantity in 1930, although it had long been the primary refined product. From a total of less than 5,000,000 barrels in 1900, the consumption of gasoline or motor fuel grew to 403,418,000 barrels by 1931, a gain of roughly 8,000 percent in a third of a century. The consumption of gasoline declined 7 percent in 1932, because of the decrease in car registrations resulting from the depression, but recovered slightly in 1933, when the continued decline in registrations was more than counterbalanced by an increase in the average unit consumption. The consumption of fuel oil increased rapidly from 1900 to 1930, but this growth had little influence on the production of crude oil, as fuel oil is essentially a by-product obtained incidentally to the refining of crude oil for kerosene in the earlier years and gasoline later. The production of crude oil has been adequate to keep pace with the increased demand for gasoline, mainly because the refiners have increased their average yield of gasoline from about 10 percent in 1900 to 44 percent in 1933; in other words, the refiners are now (1934) getting about five times as much gasoline out of a barrel of crude as they did in 1900.

Stocks

Stocks of crude oil and refined products have increased materially during the last 15 years, amounting at the present time to about 600,000,000 barrels, of which about 40 percent consists of refined products and 60 percent of crude. Although these data indicate that total stocks have almost trebled in the last 15 years, in terms of days' supply (ratio of stocks to demand) they are now practically on a par with stocks of January 1, 1918, when there was roughly 220 days' supply on hand.

Petroleum Products and Their Uses 19/

"The United States, with the largest production of petroleum and the greatest refinery capacity, consumes more oil than any country in the world. In no small part the relatively high consumption in this country has been due to the necessity of meeting the demand for gasoline for the motor car."

"Production of petroleum in America dates back to 1859, and from the earliest days the United States has supplied the bulk of the world's oil."

"The first important use to be discovered for petroleum was as a burning oil in lamps. Before the general introduction of electricity, kerosene or its predecessor, 'coal oil,' gave the world light; and the world had to come to the United States for a large part of its supply."

"The industrialization and mechanization of Europe created a vast market for lubricants."

"In the early days of the twentieth century automotive development in the United States began to make great forward strides, and by 1910 the automobile was creating a new demand for gasoline - a petroleum product. The obvious success of the petroleum industry's efforts to supply this hitherto unprecedented demand for gasoline, created by the phenomenal growth of the automobile, has resulted in the parallel growth of these two giant industries, whose prosperity is so vital to the economic welfare of the United States."

"The world was brought to a full realization of the essential importance of petroleum in every day life, in industry, and in safeguarding national security by the World War. The great development in the use of fuel oil in factories and in ships, the remarkable strides of aviation -- with its attendant demand for specialized fuels and lubricants - also had their inception during the war."

"The growth in the use of fuel oil for industrial and marine purposes has been only less sensational than the increase in the use of gasoline. The great powers began to convert battleships into oil burners just preceding the World War and the conversion became complete during and after the war. All the navies of the great powers are now on an oil-burning basis.

19/ All paragraphs within quotation marks are directly quoted from Petroleum facts and figures, 4th edition, American Petroleum Institute, Public Relations Department, copyrighted in 1931. Quotations used by permission.

Of even more significance * * * is a similar conversion to an oil burning basis of the merchant shipping of the world."

"Motor vehicles, with an enormous appetite for fuel and lubricants, increased rapidly in number. The World War stimulated the demand for fuel oil for industrial and marine uses. Aviation grew from a dream into an industry with a craving for more gasoline and more oil. The oil burner was transformed from a novelty into an accepted means of providing domestic and industrial heat. New uses were found for refined petroleum products. New markets were developed at home and abroad. The age of machinery definitely established its dependence upon the products of petroleum."

"It was perhaps only natural that an industry called upon under the urgency of sudden demand, and much of it a war-time demand that brooks no delay, should in expanding production of its raw material 400 percent in less than a score of years perform its task too well and create a condition of overproduction."

"Overproduction in the field was accompanied by overproduction in the refining branch of the industry. Capacity began to surpass demand. Highly efficient refining processes produced constantly increasing proportions of products in demand from given amounts of crude oil and intensified the overproduction problem. The flood of petroleum products spread to the market, necessitating dumping, unloading, and diversion to inferior uses of a valuable commodity, causing waste of a precious natural resource."

The growth of the petroleum industry is indicated by data collected by the Bureau of the Census, U. S. Department of Commerce. The petroleum-refining industry, according to the Census of Manufactures, ranked 24th in the value of products manufactured in 1909, 16th in 1914, and has varied from 7th to 2d during the period 1919 to 1931. The wholesale value of petroleum products in 1909 was $236,998,000; in 1914, $596,361,000; and from 1919 to 1931 it ranged from $1,500,000,000 to $2,600,000,000.

The parallel growth of the automobile industry is also shown by the reports of the Census of Manufactures. The motor-vehicles industry ranked 77th in 1909, 8th in 1914, 3d in 1919 and 1921, and either 1st or 2d in 1923 to 1931. The wholesale value of motor vehicles, including bodies and parts, was $193,823,000 in 1909. Since that time motor-vehicle bodies and parts have been computed separately, and the wholesale value of motor vehicles only was $503,230,000 in 1914 and ranged from $1,567,526,000 to $3,722,793,000 in 1919 to 1931.

The petroleum refineries in the United States have steadily increased in capacity from 1,186,155 barrels a day in 1918 to 4,023,388 barrels a day in 1931. 20/

20/ Statistics from official records, U. S. Bureau of Mines.

the overexpansion in the refining capacity is indicated by the crude oil runs to refinery stills, which amounted to 893,219 barrels a day in 1918 and increased to a peak of 2,706,049 barrels a day in 1929. In 1931 the run to stills amounted to 2,450,981 barrels a day.

"In response to changing demands for different petroleum products, refining operations have had to be adjusted so that the products in greatest demand could be supplied in sufficient quantity. The most striking and revolutionary adjustment came with the tremendously increasing requirements for gasoline, previously a waste product."

Gasoline, kerosene, gas and fuel oil, and lubricating oil represent the major petroleum products of refining operations. Gasoline produced in 1904 amounted to 6,920,000 barrels; in 1914, 34,915,000 barrels, and by 1929 it had increased to a peak of 435,078,000 barrels. In 1931, 431,510,000 barrels of gasoline was produced. In the same years the production of kerosene amounted to 32,304,000, 46,078,000, 55,940,000 and 42,446,000 barrels respectively. The peak production of kerosene occurred in 1926, amounting to 61,768,000 barrels. Gas and fuel oil had a remarkable increase in production similar to that of gasoline and amounted to 8,583,000, 88,193,000, 448,948,000 and 336,967,000 barrels in 1904, 1919, 1929 and 1931 respectively. The production of lubricating oil during these same years was 7,498,000, 12,329,000, 34,359,000 and 26,704,000 barrels respectively.

"By improvements and new processes - among the latter the 'cracking' of gas oil and fuel oil to make gasoline - the industry has been able to greatly increase the yield of gasoline. The yield of gas oil and fuel oil [was until 1930 the largest of any of the petroleum products], and a market has had to be found for it, largely in competition with coal."

In 1899 only 5.4 gallons (12.9 percent) of gasoline was derived from a 42-gallon barrel of crude oil run through American refineries. 21/ How the petroleum industry has squeezed more gasoline out of a barrel of crude is indicated by the increase in yield, amounting to 7.6 gallons, or 18.2 percent, in 1914; 11.0 gallons, or 26.1 percent, in 1920; 14.7 gallons, or 34.9 percent in 1926; and 18.6 gallons, or 44.3 percent, in 1931. On the other hand, the yield of kerosene per barrel of crude decreased from 24.2 gallons, or 57.6 percent, in 1899 to 2.0 gallons, or 4.8 percent, in 1931. The yield of gas and fuel oil from a barrel of crude oil increased from 5.9 gallons, or 14.0 percent, in 1899, to a high of 22.5 gallons, or 53.5 percent, 1918. After 1918 it decreased to 14.8 gallons, or 37.7 percent, in 1930, although it has constantly increased in total volume except during 1930 and 1931.

Motor fuel is produced at refineries by three methods - (1) straight-run distillation of crude oil, (2) cracking, and (3) blending natural gasoline.21/

21/ Statistics from Petroleum facts and figures, 4th edition, American Petroleum Institute, 1931, based on official records of the U. S. Bureau of Mines.

Since "cracking" was first applied some 18 years ago, it has been widely adopted and has become one of the guarantees of adequate future supplies of motor fuel. The average gasoline yield on straight refining is about 25 percent. The result of cracking operations is clearly shown by the steady increase above that figure - from a total gasoline yield of 25.3 percent in 1918 to 44.3 per cent in 1931. In 1918 "cracked" gasoline produced by refineries in the United States amounted to an estimated 8,500,000 barrels, or 10.0 percent of the total gasoline yield. By 1931 "cracked" gasoline had increased to 176,000,000 barrels, or 40.9 percent of the total gasoline yield. 20/

The United States Bureau of Mines states that cracking plants in the United States had a rated daily charging capacity of 2,031,395 barrels 22/ January 1, 1933. This total was made up of operating plants with a combined daily charging capacity of 1,580,051 barrels, shut-down plants with a capacity of 417,694 barrels, and plants being built with combined capacity of 33,650 barrels. Although many of the shut-down plants are technologically obsolescent, they can nevertheless convert heavy oil into gasoline and under war-time conditions would be available almost immediately and would be extremely useful to supply increased demand for motor fuel.

Statistics of the United States Bureau of Mines indicate that crude oil runs to stills in United States refineries in 1933 averaged 2,359,600 barrels a day. If this quantity of crude oil had been treated by modern cracking equipment, it could probably have yielded 70 percent of gasoline, or 1,651,700 barrels a day. This would be 619,900 barrels of gasoline more than the daily average production in 1933 of 1,031,800 barrels, an increase of 60 percent. Cracking plants are a much more promising source of additional motor fuel than oil shale, coal, alcohol, or other materials, provided that intelligent conservation of petroleum is practiced to insure the supply of raw material. The technique for the process has been developed and is in daily use, many such plants are already in existence, and additional facilities can be provided readily by adding to or duplicating plants. An additional advantage of petroleum motor fuel is that users are familiar with it and operating difficulties need not be anticipated. It would be exceedingly optimistic to assume that operating difficulties would not be encountered with new and unfamiliar fuels such as shale gasoline or alcohol blends.

Another important factor in increasing the efficiency of utilization of petroleum is the use of tetraethyl lead and bromine in gasoline, to reduce the

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22/ Hopkins, G. R., and Cochrane, E. W., Petroleum refineries including cracking plants in the United States, January 1, 1933: U. S. Bur. Mines Information Circ. 6728.

tendency of gasoline to detonate when it is burned in the automobile engine cylinder. The power output of a spark-ignition motor is proportional to the compression ratio. An engine with a low compression ratio has a lower power output than one requiring the same amount of fuel but having a higher compression ratio. However, a gasoline that will operate satisfactorily in an engine of low compression ratio will detonate in a similar engine of higher compression ratio. One method of eliminating this tendency of a gasoline to detonate is to "re-form" the gasoline - that is, crack it so as to change its chemical structure and render it nondetonating at usual compression ratios. However, the re-forming process is destructive of material. For example, in re-forming gasoline, about 3 gallons of re-formed gasoline is produced for each 4 gallons of straight-run gasoline charged to the re-forming equipment. The fourth gallon in converted almost entirely to gas and coke, which are of little value. By the addition of a small amount of certain chemical correctives the tendency of ordinary gasoline to detonate can be so modified that it is equal to the best cracked gasoline. This effect is achieved without loss of material by destructive cracking.

Although lead and bromine, the important elements in the correctives now in use, are essential war materials, the quantities required would be relatively minor, and such use would properly be regarded as preferential.

The American Petroleum Institute (Petroleum facts and figures, 4th edition, page 136, 1931) states that "An increasingly important source of gasoline is natural gas, which is supplementing the supply derived from crude petroleum." In 1931 the production of natural gasoline, according to the U. S. Bureau of Mines, amounted to 43,617,000 barrels, as compared with 9,161,000 barrels produced as recently as 1920.

"The development of this source of supply ranks only second to 'cracked' gasoline, derived from fuel oil and gas oil, in its importance in supplying the tremendous demands of the motorist. Commercial natural gasoline production dates from 1911. The gas from petroleum and natural gas wells is treated by two principal methods - absorption and compression. The raw gasoline derived is a very volatile product. New methods of rectification have been developed which now make it possible to produce natural gasoline suitable for use in high-compression airplane motors, but the major portion of the natural gasoline produced is used for blending with petroleum gasoline of low volatility, thus making available for motor use a quantity of motor fuel in excess of natural production."

In 1919, 2,957,000 barrels of natural gasoline was run to stills or blended at refineries. 21/ This volume increased to a peak of 46,457,000 barrels in 1929 and then decreased to 35,265,000 barrels in 1931. In 1919, 3 percent of the total gasoline produced was obtained from natural gasoline. This percentage increased to a peak of 10.7 percent in 1929 and decreased to 8.1 percent in 1931.

"The utilization of natural gas for making gasoline constitutes one of the most important achievements of the industry toward conservation. Formerly most of the gas coming out of oil wells was permitted to escape into the air. In recent years the building of natural-gasoline plants to take care of this gas has become an integral part of lease operations throughout the country."

"Making gasoline from natural gas is an industry apart from the manufacture of gasoline from petroleum, although closely related."

The enormous growth in use of gasoline began with the advent of the automobile. 23/ Beginning in 1895 with 4 motor vehicles, the number of motor-vehicle (passenger car and motor truck) registrations increased to 32,920, in 1903, 1,711,339 in 1914, a peak of 26,545,281 in 1930, and decreased to 24,136,879 in 1932. 24/ Of the motor vehicles registered in 1932, 20,903,422, or 86.6 percent, were passenger cars and 3,233,457, or 13.4 percent, were trucks. There were also 180,141 tax-exempt United States, State, and local official cars in 1932, which are not included in the motor vehicles registered for that year.

On the basis of net gallons of gasoline taxed and used divided by the average of motor-vehicle registrations for the first and last of each year, the U. S. Bureau ofMines estimates that the average consumption of gasoline per motor vehicle increased from 538.5 gallons in 1927 to 596.9 gallons in 1931.

The extent to which agriculture and the farmer are now dependent upon petroleum products is indicated by the number of motor vehicles on farms determined by the United States Census of Agriculture. Of the motor vehicles registered in 1930, a total of 5,035,060, or 19.2 percent, were on farms. The farmers had 900,385 trucks, or 25.8 percent of all registered.

The rapid increase in the consumption of gasoline by civil aeronautics in the United States is shown by data compiled by the Aeronautics Branch, U. S. Department of Commerce. Gasoline consumed in scheduled air transportation and miscellaneous flying operations in 1926 amounted to 78,324 barrels. By 1932 the consumption had increased to 809,061 barrels, an increase of 933 percent in a period of 7 years.

23/ Statistics from official records, U. S. Bureau of Public Roads, Department of Agriculture.

24/ Facts and figures of the automobile industry, 1933 edition, National Automobile Chamber of Commerce.

"The principal consuming agencies for fuel oil and gas oil are the merchant marine, the railroads, the oil producing and refining industry gas and electric power plants, the iron and steel industry; and homes, apartments, etc., using oil for domestic and commercial heating. The U. S. Navy, now on an oil-burning basis, is a large consumer of fuel oil; while the use of fuel oil in industry embraces almost every field employing heat and power.*** Food industries, ceramic industries, cement and lime plants, logging and lumbering, paper and wood pulp manufacturers; the textile, chemical, and automotive industries are some of these employing oil fuel for which statistics of consumption are available."

According to the U. S. Bureau of Mines, the total domestic deliveries of gas oil and fuel oil amounted to 327,306,000 barrels in 1931, and the principal uses were as follows: Steamships (including tankers) 25.5 percent; railroads, 17.8 percent; oil companies for fuel, 15.6 percent; domestic heating, 7.5 percent; gas and electric power plants, 7.5 percent; commercial heating, 4.8 percent; iron and steel products, 3.9 percent; and United States Navy, Army transports, etc., 2.8 percent.

"Before the war (1914), of the world's total gross tonnage of ships (steam and gas) amounting to 45,404,000 tons, less than 4 percent burned oil. In 1920 the world's tonnage had increased to 53,905,000 tons, of which oil burners represented about 17 percent. In 1930 the total tonnage was 68,023,804, of which 26,259,208 tons, or 38 percent, was listed as oil burning."

"The American merchant marine has an oil-burning tonnage of 8,774,043 gross tons, the largest of any country."

"The Diesel is an internal-combustion engine, in general similar to the automobile engine in construction, but so designed as to operate under high pressures and to burn nonvolatile fuels without pre-mixing them with air. In other words, it burns fuel oil, or Diesel fuel oil, instead of gasoline.** The Diesel ship has been called the automobile of the seas.** Diesel power for marine service, like aviation, received a great impetus during the World War, when various navies demonstrated the success of the Diesel engine.** About half the ships being constructed in the world are Diesels."

The rapid growth of the motor or oil engine ship is revealed by data complied by the Bureau of Navigation, U. S. Department of Commerce, which show that the gross world tonnage of such ships increased from 693,334 tons, or 7.7 percent, in 1920 to 7,002,201 tons, or 26.7 percent, in 1930.

Sidney A. Swensrud, assistant to the president, Standard Oil Co. of Ohio, in an article entitled "Factors affecting the demand for gasoline and crude oil over the next few years - a study of automobiles in use," presented at the New York meeting of the American Institute of Mining and Metallurgical Engineers in February, 1933, stated that he has been interested for some time in trying to appraise the petroleum industry's prospects for gasoline consumption over the next half dozen years or so and that anyone who has even approached the problem knows the intimate relation to it of the number of automobiles (passenger cars and trucks).

Swensrud after studying the annual sales of new car registrations and estimated number of cars scrapped each year, estimated that there were 23,150,000 cars (passenger cars and trucks) "available for use" at the beginning of 1932 and 21,200,000 at the end of 1932. The total registrations during 1932 were 24,136,879 cars.

The average life of a car today appears to be about 7 years. Swensrud estimated that 9,364,000 units were scrapped during the years 1930 to 1932, which figure is 46.3 percent in excess of the estimated number of new units produced during the same years. By reason of the "death" rate exceeding the "birth" rate and on the basis of a formula of "cars scrapped and in use according to life of car," worked out by C. E. Griffin, of the University of Michigan, in 1926, Swensrud further estimated that even on a very liberal assumption of new-car production during the period 1933 to 1938, the number of cars in use would continue to decrease during 1933 and 1934 and that the 1930 level of cars in use cannot be reached until at least 1938.

The intimate relations between the automobile and the petroleum industry may be further indicated by the following facts relative to the consumption of crude oil and gasoline by automobiles in 1931. According to the U. S. Bureau of Mines, 95 percent of the crude oil produced was consumed at refineries; 44.3 percent of the crude oil used by refineries was converted into gasoline; 90 percent of the gasoline produced was used in automotive vehicles (passenger cars and trucks). Multiplying these percentages indicates that about 37.9 percent of each barrel of crude oil produced in 1931 was used by automotive vehicles.

Waste of Petroleum and its Products

(Past and Present Conservation Practices in the Petroleum Industry)

Various Definitions of Waste

Waste in the petroleum and natural-gas industries is subject to wide definition and interpretation. In the general sense, the verb waste is defined: "to diminish by consistent loss; to suspend or expend unnecessarily, carelessly, or without valuable result; to apply to useless end; to squander." 25/ The Websterian definition, however, is not specific nor inclusive enough to be completely applicable in matters concerning oil and gas conservation.

Many varying definitions of waste have been written into the oil and gas statutes of the several States 26/ and have been the basis of extensive litigation and court proceedings. 27/

The Oklahoma conservation law has been sustained by the Supreme Court of Oklahoma, by several Federal district courts, and by the Supreme Court of the United States. 28/ Because the Oklahoma law specifically includes items that pertain to engineering and economic conditions which do not appear in the statutes of other States, the following sections defining waste are excerpted. 29/

> "Section 2. The term 'waste' as used in this act, as applied to the production of oil, in addition to its ordinary meaning and in addition to the meaning given thereto by any other provision of this act, shall include economic waste, underground waste, including water encroachment in the oil and/or gas bearing strata, surface waste, and waste incident to the production of oil in excess of transportation or marketing facilities, or reasonable market demands.***

25/ Webster's New International Dictionary.

26/ The oil and gas conservation statutes (annotated), 432 pp., Federal Oil Conservation Board, 1933.
(Note: The following States specifically define waste in their statutes or set forth conditions under which oil and/or gas shall not be wastefully used: Arkansas, p. 33; California, pp. 59 and 80; Colorado, p. 85; Indiana, p. 116; Kansas, p. 121; Louisiana, pp. 150, 161, 168; Michigan, pp. 200, 202, 214; Mississippi, p. 268; Oklahoma, pp. 279, 288, 289; South Dakota, p. 317; Texas, pp. 331-335; West Virginia, pp. 401-402; Wyoming, p. 412.)

27/ For citations see notes in Oil and gas conservation statutes (annotated), Federal Oil Conservation Board, 1933--California, p. 59; Colorado, p. 85; Indiana, p. 116; Oklahoma, pp. 288, 289; Texas, pp. 332-335, 358-359.

28/ See footnote 27, Oklahoma, pp. 288, 289.

29/ See House Bill 481, Oklahoma, approved April 10, 1933.

"Section 3. The term 'waste' as applied to gas contained in or produced from a common source of supply of oil shall, in addition to its ordinary meaning, include the unreasonable production and/or the inefficient or wasteful utilization of gas in the operation of oil wells drilled therein, the escape, directly or indirectly, of gas from oil wells drilled therein into the open air in excess of the amount necessary in the efficient drilling, completion, or operation thereof; the escape, blowing, or releasing, directly or indirectly, into the open air of gas produced from wells productive of gas only, or of gas and gasoline only, drilled into any such common source of supply, save only such as is necessary in the efficient drilling and completion thereof; and the unnecessary depletion or inefficient utilization of the gas energy contained in such common source of supply. In order to prevent the waste or to reduce the dissipation of the gas energy contained in any such common source of supply, the Commission, in addition to its other powers in respect thereof, shall have authority to limit the production of gas from wells producing gas only or gas and gasoline only to a percentage of the daily open-flow capacity of such wells that is less than the percentage of oil production allowed to oil wells drilled therein.

"Section 4. Whenever the full production of any common source of supply of oil in this State can only be obtained under conditions constituting waste, then any person having the right to drill into and produce oil from any such common source of supply may, except as otherwise authorized and/or in this act provided, take therefrom only such proportion of all oil that may be produced therefrom without waste as the production of the well or wells of any such person bears to the total production of such common source of supply."

The Texas law,30/ although reciting a number of items that shall be included as waste, states specifically that the term

"shall not be construed to mean economic waste, and the Commission shall not have the power to attempt by order or otherwise, directly or indirectly, to limit the production of oil to equal the existing market demand for oil."

In California the act of June 4, 1931, to prohibit the waste of crude petroleum and defining such waste and to limit production to current requirements, never became effective and was rejected by referendum May 3, 1932.31/ The State has, however, a statute known as the Lyon

30/ Act of Aug. 12, 1931 (Act, 1931, 42d Leg., 1st C. S., chapt. 26, sec. 1, art. 6014).

31/ The oil and gas conservation statutes, p. 80, Federal Oil Conservation Board, 1933.

act, enjoining unreasonable waste of gas.32/ The so-called California plan is complicated by the use of the word "reasonable" waste as applied to gas.33/

Although the definitions given in the Oklahoma statute, cited above, include several items, particularly waste of gas energy and economic waste, that will be discussed later, it is important to note here that the essence of this law is not new. In 1915 concerted thought was given to the subject of preventing waste with the aid of adequate legislation in the Mid-Continent field, and after meetings were held with various State agencies, the Bureau of Mines 34/ made the following statement regarding the essential requirement of a wise oil and gas conservation measure:

> "The laws not only protect against waste but also insure a market for natural gas and thus induce producers to conserve gas instead of allowing it to escape, a rateable marketing of all oil and natural gas offered for sale being provided for. In case production becomes too large for the available transportation and marketing facilities, the transportation facilities must be increased or the oil and gas must be confined until they can be utilized. This provision will prevent large quantities of oil and natural gas from being brought to the surface and stored with a resulting waste of gas and a lowering of oil prices."

Interrelated Factors Of Waste

Regardless of the varying definitions for waste, the subject may be treated under the following general divisions:

1. Physical waste
   - a. Surface losses (visible)
   - b. Underground losses (invisible)

2. Waste of energy (required to propel oil through the containing rocks to the wells and thence to the surface).

3. Economic waste

The three subjects are so interrelated and interdependent that each one involves and influences the others. For similar reasons, waste of liquid petroleum, because of the very nature of the hydro-

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32/ Idem, p. 70.

33/ Lombardi, M. E., Present economic situation of the oil industry; Mining and Metallurgy, Vol. 12, p. 232, May, 1931.

34/ Fifth Annual Report of the Director of the Bureau of Mines to the Secretary of the Interior, for the fiscal year ended June 30, 1915, p. 80.

carbon compounds found in the earth, must be considered in connection with waste of those fractions occurring in the gaseous state. 35/ Certain wastes of natural gas not associated with oil are set forth in subsequent sections of this paper.

Physical Waste

In presenting facts concerning past and present waste in the petroleum industry no definite date line can be drawn that marks a radical change in thought and practice. The evolution has been gradual, but it would be erroneous to state that dumping oil on the ground or into creeks or otherwise "carelessly applying it to useless ends" is at present a serious problem. "The actual physical losses of oil at the surface are relatively small compared with the total production of oil." 36/

The fluid and mobile characteristics of petroleum, the lack of knowledge regarding its behavior, the early court rulings pertaining to it, and in fact the whole spirit of the period shortly after the Civil War combined to create a condition that not only condoned but accentuated the profligate physical waste of petroleum.

The wasteful conditions attending the exploitation of oil in Pennsylvania along Oil Creek, at Pithole; the great oil fire at Titusville in June, 1880; and other examples of destruction by fire, spillage, and other careless practices are an important part of the history of that time.

As to gas wastage, Arnold and Clapp 37/ state: "The history of the natural-gas industry of the United States is an appalling record of incredible waste." They cite the example of a well at Murrayville, Pa., in 1878, having great volume and pressure, which was allowed to blow to the air for 3 years without any effort being made to check it.

In an effort toward reduction of the unnecessary wastes of oil and gas, the Bureau of Mines in 1913 began to write extensively on this subject. 37/38/

35/ For a discussion of the interrelation of oil and gas production, see Minerals Year Book, 1932-33, pp. 497-498, Bureau of Mines; also Report V of the Federal Oil Conservation Board to the President of the United States, Appendix VI, pp. 52-53, 1932.

36/ Minerals Year Book, 1932-33, p. 498, Bureau of Mines.

37/ Arnold, Ralph, and Clapp, F. G., Wastes in the production and utilization of natural gas and methods for their prevention; Bur. Mines Tech. Paper 38, p. 6, 1913.

38/ Arnold, Ralph, and Garfias, V. R., The prevention of waste of oil and gas from flowing wells in California; Bur. Mines Tech. Paper 42, 1914. See also Tech. Papers 45, 51, 68, 70 and 130.

These initial reports were followed by many others dealing with the engineering phases of oil and gas conservation. 39/

Although the industry has been aware of wasteful conditions and of its own volition has reduced the actual waste of oil, 40/ unfortunately, methods and practices to control and save gas in the ground for future energy and fuel requirements have not improved in like proportion. The Federal Oil Conservation Board, in its first report, 41/ cited the Cushing field, Oklahoma, as an example of wasteful development practices where at one period the average daily waste of gas was 300,000,000 cubic feet, or about 100,000,000,000 cubic feet in one year. Heggem and Pollard 42/ cite specific examples of waste from wells in the Cushing field. Other fields where vast wastes of natural gas occurred in the production of oil are Cromwell, Oklahoma; Burkburnett, Tex.; and El Dorado and Smackover, Ark. Wastes of gas in the production of oil were equally evident in several fields in the Los Angeles Basin 43/ and in the early development of the Kettleman Hills, California. 44/

The Cotton Valley oil field, in Webster Parish, La., which is a typical example of a textbook structure, is cited as typifying wasteful practices in the production of oil. Ross 45/ summarizes the condition as follows:

> "In the early development of the Blossom sand during 1924 the importance of pressure conservation in the main gas reservoir and of its effect upon oil recovery and water encroachment was not fully recognized. Consequently, billions of cubic feet of gas were blown to the air in an effort to bring oil into the wells. The beneficial results normally anticipated from a gas reserve, both as a commodity and as a propulsive agent, were lost, largely on account of the competitive methods, and the financial returns from this zone were disappointing."

39/ Selected list of Bureau of Mines publications dealing with petroleum, natural gas, oil shale, and their products, pp. 1-13, 1932.
40/ Memorandum regarding physical and economic waste in the oil industry (prepared for use of the Committee on Interstate and Foreign Commerce, requested in letter of October 11, 1932, from Hon. Sam Rayburn, chairman), transmitted by the Director of the Bureau of Mines in a letter dated Nov. 1, 1932.
41/ Report of the Federal Oil Conservation Board to the President of the United States, Sept., 1926, Part I, p. 7.
42/ Heggem, A. C., and Pollard, J. A., Drilling wells in Oklahoma by the mud-laden-fluid method: Bur. Mines Tech. Paper 68, pp. 13-15, 1914.
43/ Idem, p. 7.
44/ Report IV of the Federal Oil Conservation Board to the President of the United States, p. 16, May 28, 1930.
45/ Ross, J. S., Engineering report on Cotton Valley Field, Webster Parish, La.: Bur. Mines Tech. Paper 504, p. 1, 1931.

Crater wells

Tremendous volumes of gas and oil have been lost from "wild" and burning wells. It is true that many of these wells have gotten out of control through no fault of the operators, but the fact remains that each has been a very evident and spectacular source of diminishing the country's oil and gas resources.

Typical of the areas that are subject to extreme cratering conditions are the high-pressure fields of Louisiana. In 1921 the Bureau of Mines reported on the Monroe gas field. Bell and Cattell 46/ state: "Gas is wasted in the Monroe field in drilling, in producing, in transmission, and in utilization. There is underground waste, which is invisible, and surface waste, much of which is visible." The visible waste from four craters on April 1, 1921, was 3,000,000 cubic feet a day. Another well blowing wild and forming a crater was wasting 10,000,000 cubic feet a day. There was no way to estimate the underground waste or damage from water infiltration, but it was known that one well which was wasting no gas at the surface was wasting about 10,000,000 cubic feet a day into a water-bearing stratum. So acute became the crater problem in the Richland gas field, Richland Parish, La., that the Bureau of Mines made a special study of that area and reported the condition of wells and methods used in attempting to control them. 47/

Present waste of natural gas

It has been estimated that between 60 and 70 percent of the natural gas actually utilized is produced in conjunction with crude oil operations. 48/ Therefore, as previously stated, the waste of these two hydrocarbon companions cannot be treated separately. However, there are certain phases of the conservation problem that pertain especially to natural gas.

The natural-gas industry has been cognizant of the existing conditions, and in 1930 a resolution on conservation was adopted at the convention of the Natural Gas Department of the American Gas Association. 49/ Since that time the work on the project by the natural-gas

46/ Bell, H. W., and Cattell, R. A., The Monroe gas field: Louisiana Dep. Conservation, Bull. 9, 99 pp., 1921, especially pp. 43-50, 72-76.
47/ Hill, H. B., Crater wells, Richland gas field, La.; Bur. Mines Tech. Paper 535, 37 pp., 1932.
48/ Turner, Scott, Conservation of natural gas in relation to some recent developments; Bur. Mines Information Cir. 6392, 1930
49/ Resolution on conservation, adopted at convention of Natural Gas Department of the American Gas Association, New Orleans, La., May 5-8, 1930.

industry, as represented by the Association, has been conducted in general accord with the report of the chairman of the committee to which this natural-gas conservation project was referred. 50/

In the deliberations and written record pertaining to the foregoing natural-gas conservation project, reference was made to the need for data that would show the total annual wastage of natural gas.

Satisfactory data have not yet been gathered from which an approximation of the amount of natural gas wasted in the United States annually can be made. The State of California has kept the best records, and even these figures begin only in 1920. A summary of the net production, gas utilized, and wastage, in California from 1920 to 1932 is given in a report of the Federal Oil Conservation Board. 51/ Subsequent figures have been compiled by the Gas Administrator, Railroad Commission, State of California. 52/

Appendix VI of the report of the Federal Oil Conservation Board just cited also gives factual information in some detail regarding gas losses under the following headings:

1. Losses in production (a) associated with oil; (b) not associated with oil.
2. Losses of residue gas (blown to the air at natural gasoline plants).
3. Losses in transportation (leakage from high-pressure natural-gas transmission lines.)
4. Losses in distribution and utilization.

Texas Panhandle

Report V of the Federal Oil Conservation Board states that the Texas Panhandle is probably the source of the greatest loss of gas in that State. The condition in that area has grown continually worse as

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50/ Report of the Technical and Research Committee, Natural Gas Department, American Gas Association, addressed to the Advisory Committee and Managing Committee, Natural Gas Department, American Gas Association; published in Natural Gas, vol. xi, no. 11, November 1930, p. 14.
51/ Report V of the Federal Oil Conservation Board to the President of the United States, pp. 47-57, 1932.
52/ Waste gas in California for 1932 has been reported as about 17,500,000,000 cubic feet, compared with over 68,000,000,000 cubic feet in 1931; see Pipe Line News, June, 1933, p. 20. (Note·Reference to published figures for 1933 not available at this writing but can be obtained, if needed, from State Gas Administrator.)

regards gas wastage, and supporting evidence of the condition is no longer lacking.

Of the original recoverable gas in the reservoir, estimated by reliable geologists 53/ to be of the order of 13,000,000,000,000 cubic feet, about 4,000,000,000,000 cubic feet has been produced. Of this amount Bredberg 54/ states that more than 60 percent, or about 2,400,000,000,000 cubic feet, "has been wasted and dissipated into the air after being stripped of a small gasoline content constituting less than 3 percent of the heat-producing value of such gas."

Bignell 55/ presents tabular data and graphs showing facts pertaining to the conditions in the gas fields of the Texas Panhandle. Throughout 1932 and 1933 the amount of gas blown to the air daily was never below 276,000,000 cubic feet and in November, 1933, was 593,600,000 cubic feet.

The original rock pressure was about 430 pounds to the square inch. A pressure contour map has been prepared 56/ showing the excessive drop in pressure in a large area surrounding the 37 or more natural-gasoline plants. Despite the evidently wasteful condition, additional plants are being built.

Struth and others 57/ have given additional pertinent information on this enormous dissipation of natural gas and its contained energy in the State of Texas.

53/ Cotner, Victor, and Crum, H. E., The Texas Panhandle: American Assoc. Petroleum Geologists Bull., vol. 17, no. 8, pp. 877-906, August, 1933.

54/ Bredberg, L. E., Oil men and landowners form association to curb production rate of Panhandle gas: Oil and Gas Jour., Feb. 8, 1934, p. 20.

55/ Bignell, L. G. E., Industry alert to adverse conditions created in Texas Panhandle due to huge gas waste : Oil and Gas Jour., Feb. 8, 1934, p. 21.

56/ Suggestions for settling Panhandle problem come from many sources; Oil and Gas Jour., Feb. 22, 1934, p. 38. (Pressure-contour map of the Texas Panhandle oil and gas field.)

57/ Struth, H.J., Petroleum economic service, Houston, Texas, Feb. 14, 1934. Texas Panhandle producers, landowners, alarmed over gas waste; Oil Weekly, Feb. 5, 1934, p. 8.

Oklahoma City

In the Oklahoma City field the quantity of gas produced with oil and wasted without thought of future needs has been tremendous, in spite of provisions of the Oklahoma statute. 58/ The chairman of the Corporation Commission of the State of Oklahoma estimated that for a period of at least 2 years the average daily loss was 300,000,000 cubic feet. 59/

Many of the wells have ceased to flow naturally, and water is present in parts of the field. 60/ Problems of mechanical lifting now confront the operators 61/ because of rapidly declining gas pressures. These are evidences that a producing agency of great value has been lost through the dissipation of gas energy.

After studying the gas reserves of the Oklahoma City pool, the Bureau of Mines 62/ concluded that "the gas reserves of the Pennsylvanian (upper or dry-gas) formation should be regarded merely as an auxiliary supply to augment the formation gas in the pre-Pennsylvanian (lower or oil-producing) zones when the oil wells stop flowing naturally."

Evaporation losses

Although evaporation of crude petroleum and gasoline is unseen, it is a physical surface loss and should be considered among the important preventable wastes of the oil industry. Studies made by the Bureau of Mines prior to 1928 63/ showed that the average loss per year from well to refinery was 6.2 percent of the gross production. The evaporation loss at refineries was 2.1 percent, making a total

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58/ See footnote 30/.
59/ Report V of the Federal Oil Conservation Board to the President of the United States, 1932, p. 50.
60/ Bignell, L. G. E., Changed conditions in the Oklahoma City field create new problems for production men; Oil and Gas Jour., July 27, 1933.
61/ Beardmore, H. F., and Harder, H. D., Possible future production methods, Oklahoma City field; Oil Weekly, Feb. 19, 1934, p. 15. (Paper presented before American Petroleum Institute, Division of Production, Oklahoma City, Feb. 15-16, 1934.)
62/ Hill, H. B., and Rawlins, E. L., Estimate of the gas reserves of the Oklahoma City oil field, Oklahoma County, Okla.; Bur. Mines Rept. Investigations 3217, 1933.
63/ Wiggins, J. H., Evaporation losses of petroleum in the Mid-Continent field: Bur. Mines Bull. 200, 115 pp., 1921; Methods of decreasing evaporation losses of petroleum: Tech. Paper 319, 57 pp., 1923.

loss of 8.3 percent. A recent survey of the Bureau of Mines 64/ shows that evaporation losses are still a source of waste in the petroleum industry. Although improved equipment and methods have reduced the 8.3 percent total loss by evaporation, as determined in the earlier survey, to 2.7 percent, and although the average evaporation loss of crude oil from wells to refineries is now approximately 2 percent, in contrast with the 6.2 percent of the earlier survey, nevertheless the oil produced in the United States in one year, having a gravity of 24 degrees A.P.I. or lighter, is still subject to an evaporation loss of about 14,000,000 barrels by the time it reaches the refineries. If the gasoline and other finished oils were considered, a much greater loss would be reflected. However, the figure of 14,000,000 barrels indicates that the evaporation of crude petroleum is a continuing important economic factor, and these losses can be reduced.

Underground wastes

The industry is definitely aware of the underground wastes that attend the production of oil and gas. The deleterious effects of migration of oil and gas and of premature water flooding causing underground waste have been studied and reported upon by Federal and State agencies, by all groups of the industry concerned with its engineering development, and by many individuals. It cannot be said that the industry has been remiss in this matter, because the companies, individually and as a whole, realize better than anybody else that marginal profit, permitting them to continue in business, depends upon protection against these unseen wastes, which are of great magnitude.

The Bureau of Mines was among the first to point out the need for adequate safety measures against underground waste. 65/ As an

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64/ Schmidt, Ludwig, Applied methods and equipment for reducing evaporation losses of petroleum and gasoline: Bur. Mines Bull. (in press, 1934).

65/ Ambrose, A.W., Underground conditions in oil fields; Bur. Mines Bull. 195, 1921.

Swigart, T. E., and Beecher, C.E., Manual for oil and gas operations; Bur. Mines Bull. 232, 1923.

Swigart, T. E., and Schwarzenbek, F.X., Petroleum engineering in the Hewitt oil field, Carter County, Okla., Bureau of Mines in cooperation with Ardmore, Okla., Chamber of Commerce, 1921.

Kirwan, M. J., Rison, C. O., and Wardwell, D. P., Report on the Quinn dome, in the Lyons-Quinn oil and gas field, Okfuskee and Okmulgee Counties, Okla., with special reference to the migration of gas found below the Lyons oil sand and the resulting effect on the oil and casing-head gas production of this sand. Bureau of Mines in cooperation with the Office of Indian Affairs, 1924.

example, the judicious use of cement combined with proper casing programs was definitely recommended. 66/ The history of the Powell field, Texas, 67/ shows clearly that the operators in that field were able to cope with their serious water problems and retard the encroaching water, which would have resulted in a much greater underground waste if they had failed to adopt the recommended corrective measures.

Many similar examples might be cited, but it is a well-known fact that underground waste of oil through invasion or premature encroachment of water into producing strata is now only a small portion of what it was in former years.

The following general statement summarizes the condition regarding physical waste, both visible and invisible: The history of the industry, as reflected in its technical literature, shows that during a period beginning about 1921-22 and extending to the beginning of the so-called "proration period" (later part of 1926) the fear of an impending shortage of oil and the rapidly increasing engineering knowledge and better operating technique combined

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65/ cont'd Kirwan, M. J., Effects of extraneous gas on the production of oil wells in the Lyons-Quinn field of Oklahoma; Bur. Mines Rept. Investigations 2612, 1924.

Wardwell, D. P., and others, Water problems in the north part of the Cushing oil field, Creek County, Okla., Bur. Mines, 1927.

66/ Tough, F.B., Method of shutting off water in oil and gas wells; Bur. Mines Bull. 163, 1918.

67/ Hill, H. B., and Sutton, C. E., Production and development problems in Powell oil field, Navarro County, Tex.; Bur. Mines Bull. 284, 1928.

to reduce by an appreciable degree the actual physical wastes of oil. 68/ As stated in another section, the wastes of gas were not decreased in like proportion.

Growing realization of function of natural gas and Relations of fluid energy

Engineers have realized for many years that "in the expansion of the gases, as the pressure is reduced[in the oil-bearing formations] an enormous amount of energy is released which is the principal force in driving the oil from the sand into the wells." 69/

It was before the "proration period," referred to above, that accurate knowledge based upon scientific research began to reveal the true nature and some of the properties and characteristics of petroleum and its associated gases as they occur underground. 70/

68/ Further discussion of physical wastes above and below ground and the industry's part in preventing them is given in Memorandum regarding physical and economic waste in the oil industry (prepared for use of the Committee on Interstate and Foreign Commerce, requested in letter of October 11, 1932, from Hon. Sam Rayburn, chairman), transmitted by the Director of the Bureau of Mines in a letter dated Nov. 1, 1932.

69/ Lewis, J. O., Methods for increasing the recovery from oil sands; Bur. Mines Bull. 148, p. 13, 1917.

70/ Dow, D.B., and Reistle, C.E., Jr., Absorption of natural gas and air in crude petroleum; Mining and Metallurgy, vol. 5, pp. 336-337, July, 1924.

Dow, D.B., and Calkin, L. P., Solubility and effects of natural gas and air in crude oils; Bur. Mines Rept. of Investigations 2773, February 1926.

Beecher, C. E., and Parkhurst, I. P., Effect of dissolved gas upon the viscosity and surface tension of crude oil; Am. Inst. Min. Met. Eng. Trans., Petroleum Development and Technology in 1926, pp. 51-69.

Complete record of public hearings, Federal Oil Conservation Board, Feb. 10 and 11, 1926, Washington, D. C.

Report of Gas Conservation Committee of the American Petroleum Institute, E. W. Marland, chairman, meeting held at Ponca City, Okla., Oct. 17, 1927.

As this knowledge developed and was applied, there was a growing realization of the function of natural gas in oil production.

So complete a summing up of the knowledge on this subject, as of 1929, is given in a report published by the Bureau of Mines in cooperation with the American Petroleum Institute, that reference must be given to the volume in its entirety. 71/

Stimulated by this and subsequent writings, 72/ all concerned now recognize that the loss of energy needed to produce oil, through the blowing of gas to the air or otherwise dissipating it, is of equal and perhaps greater importance than the actual physical waste of gas available for fuel and other purposes at the surface.

71/ Miller, H. E., Function of natural gas in the production of oil, a report of the Bureau of Mines in cooperation with the Division of Development and Production Engineering of the American Petroleum Institute, 267 pp., 1929.

72/ The following references are a few typical examples of work on the subject performed since 1929;

Lacey, W. N., and associates, reported work on A. P. I. Research Project 37, conducted at California Institute of Technology.

Reistle, C. E., and Hayes, E. P., A study of subsurface pressures and temperatures in flowing wells in the East Texas field and the application of these data to reservoir and vertical flow problems; Bur. Mines Rept. Investigations 3211, 1933.

Lindsly, B. E., A study of "bottom-hole" samples of East Texas crude petroleum; Bur. Mines Rept. Investigations 3212, 1933.

The fluid-energy attributes of oil, gas, and water 73/ as they occur in underground structures and the responsibility for avoiding inefficient and wasteful application of that energy, which would prevent the recovery of maximum quantities of the hydrocarbon contents, constitute the present major problem of conserving the Nation's oil reserves. 74/

A striking and typical example of the recognition by executives as well as engineers of the demoralizing effects upon the industry and the Nation of unrestricted dissipation of energy in the reservoir, attributable in the main to existing "pirate" methods of operation, is given in an address by W. S. Farish before the American Institute of Mining and Metallurgical Engineers, at Ponca City, Okla., in October, 1932. 75/

Well Spacing and Allocation of Production

Conserving the energy in the reservoir and preventing its unwarranted dissipation is inextricably involved with well spacing and the capacity of wells to produce oil and/or gas. 76/

73/ Moore, T. V., Application of the principle of volumetric withdrawal to the allocation of production; American Petroleum Institute, section IV, Proceedings Fourteenth Annual Meeting; Production Bull. 212, pp. 11-14, (reprint), November, 1933.

74/ Umpleby, J. B., Changing concepts in the petroleum industry; Am. Inst. Min. Met. Eng. Trans., Petroleum Development and Technology in 1932, pp. 38 to 50 (with discussion).

Umpleby, J. B., Efficient utilization of reservoir energy (read before Petroleum Division, A. I. M. M. E., New York, February, 1934); Oil Weekly, vol. 72, no. 12, pp. 22-24, March 5, 1934.

75/ Farish, W. S., A rational program for the oil industry; Oil and Gas Jour., Oct. 6, 1932.

76/ Minerals Year-Book, 1932-33, pp. 503-504, Bureau of Mines.

The problem of efficient well spacing is not new[77] nor is it subject to exact mathematical solution. The varying characteristics of the formations constitute the first difficulty. Of even greater complicating effects are the economic considerations that cannot be separated from the physical phases of the problem of the greatest ultimate recovery of oil.

Not infrequently citations to Bureau of Mines publications [77] have been made at hearings and court proceedings to support the claims of those who desire a close spacing of wells. Although recognizing the permanent importance of the earlier and epochal work, the Bureau of Mines has been careful for some time to point out the fact that the method of estimating ultimate recovery by the curve of decline in production, which, as stated, is directly related to well spacing, is not generally applicable without modification in fields under proration or other production control. Engineers must study the subject far more intensively and extensively than has yet been possible, in connection with operating conditions that are quite different from those existing prior to 1924 and 1925, before definite criteria for well spacing can be determined. That many more wells than were necessary have been drilled is indicated in many writings, typical of which is the following:

> "Unfortunately, even when engineering facts regarding the reservoir have been known, it frequently has been impossible to work out rational spacing programs due to conditions of competitive drilling calling for a multiplicity of 'offset' wells in place of a few carefully selected wells which would have prevented attendant physical losses." [78]

For some years the Bureau of Mines and representatives of the natural-gas industry have cooperated to develop a sound method for gaging gas-well capacities in order that wells may be drilled and produced with maximum efficiency, from the point of view both of proper spacing and of prevention of waste at the surface and underground. Such a method has been perfected to a point where it is applicable in nearly all fields. [79]

77/ Beal, C.H., The decline and ultimate production of oil wells, with notes on the valuation of oil properties: Bur. Mines Bull. 177, 1919.

Beal, C.H., and Lewis, J.O., Some principles governing the production of oil wells: Bur. Mines Bull. 194, p. 18, 1921.

Cutler, W.W., Jr., Estimation of underground oil reserves by oil-well production curves: Bur. Mines Bull. 228, pp. 85-90. 105-107, 1924.

78/ Minerals Year Book, 1932-33, p.504, Bur. Mines.

79/ Pierce, H.R., and Rawlins, E.L., The study of a fundamental basis for controlling and gaging natural-gas wells: Bur. Mines Reports of Investigations 2929,2930, 1929.

Rawlins, E.L., and Schellhart, M.A., Back-pressure data on natural-gas wells and their application to production practices (manuscript Technical Paper of the Bureau of Mines).

Many of the fundamental principles established in the natural-gas work have been used recently and found applicable in the production of oil, which is a more difficult problem because the substances dealt with are in both gaseous and liquid states.

The essential engineering factors in the allocation of production, in contrast with the many inaccurate and waste-provoking attempts to establish "potentials," have been presented comprehensively in a progress report and special papers by the Topical Committee on Allocation of Production of the Central Committee on Drilling and Production Practice, American Petroleum Institute. 80/

The "proration period" has witnessed much paradoxical thinking and has given rise to many anomalous conditions pertaining to conservation measures in the oil and gas industries. In brief, knowledge has increased rapidly as to effectual methods of preventing physical wastes of oil and gas and conserving the energy necessary for the economic recovery of these substances. On the economic side the pattern is more complicated, but some forms of economic waste are easily recognized, together with their known remedies. The reasons and remedies for others are more obscure. Although the concomitant condition should be one of definitely decreasing waste throughout the industry, the period has been marked by wasteful competitive development and premature extraction of the Nation's underground petroleum reserves. The East Texas field offers an outstanding example.

The conclusion is that engineering and scientific knowledge regarding waste in all its phases cannot be applied correctively to conserve the diminishing reserves of oil and gas as long as the theory of "capture and reduction to possession" is recognized as controlling.

80/ American Petroleum Institute, section IV, Proceedings Fourteenth Annual Meeting (Production); Production Bull. 212, pp. 2-21, November, 1933 (reprint).

Substitutes for motor fuel

Gasoline substitutes from coal

The processes for obtaining motor fuel from coal may be grouped in four classes:

(1) The high-temperature carbonization of coal, including the gas- and coke-manufacturing industry.

(2) The low-temperature carbonization of coal.

(3) The hydrogenation and liquefaction of coal by the Bergius process.

(4) The complete gasification of coal and conversion of the resulting gases by pressure synthesis into methanol, synthol, and other liquid combustibles.

Supplementary sources of motor fuel

1. In coke and gas works about 2.5 gallons of refined motor benzol is obtained by the high-temperature carbonization of 1 ton of coal. The total coal coked in the United States in 1926 yielded 112 million gallons of motor benzol, or 1.02 percent as much as the 11 billion gallons of gasoline produced in 1925. If the entire output of about 500 million tons of bituminous coal in 1926 had been put through byproduct ovens the yield of motor benzol would have been only 1-1/4 billion gallons, or 12 percent as much as the gasoline produced in 1925. Today the motor fuel derived from this source is much less, owing to the decreased demand for coke and coal gas. Obviously coke-oven light oil can never supply more than small portions of future motor-fuel requirements.

2. Low-temperature carbonization is often cited as the process that will solve the problem of future motor-fuel supply. In this process coal is heated to 450° to 700°C. instead of 1000° to 1300°. The tar yields are from 20 to 35 gallons a ton, or two to three times that obtained by high-temperature carbonization. Also, the tar resembles petroleum in some respects. From 1 to 2 gallons of light oil can be scrubbed from the gas, and another gallon or two distilled from the tar, the total yield being from 2 to 4 gallons.

Refining losses would bring the net yield of motor fuel from gas-scrubbing and straight distillation of the tar to about 2.5 gallons a ton, or about the same as is obtained in high-temperature carbonization. However, this low-temperature tar may be subjected to the same pressure-cracking processes that are used for petroleum and thus yield 20 to 30 percent of motor fuel. It is therefore reasonable to assume a possible yield of 7 to 12 gallons per ton of coal carbonized at temperatures of 450° to 700°C.

If 136 million tons of bituminous coal, about one fourth of the output in 1923, had been carbonized at low temperature, the motor-fuel yield on the basis of 10 gallons to the ton would have been 1360 million gallons, or but 12 percent as much as the gasoline production in 1925. It is evident that the maximum probable development of low-temperature carbonization, while furnishing a material quantity of motor fuel, cannot satisfy the entire demand. We must turn to processes in which motor fuel is the principal product rather than a by-product.

Primary sources of motor fuel from coal

Of these the Bergius process of liquefying coal is the most promising, as it converts from 30 to 60 percent of the coal into tar and oils, the yield varying with the type of coal and the conditions of hydrogenation. In this process pulverized coal mixed with oil or tar to form a thick paste is heated at 400° to 500°C. in an atmosphere of hydrogen under a pressure of 200 to 250 atmospheres. A catalytic material is added to speed up the reaction. Under these conditions the coal is converted into a black tarry liquid, which on separation from the ash and undecomposed residue yields from 35 to 60 percent of crude oil, or 90 to 140 gallons to the short ton of coal.

Synthesis of motor fuel from gases produced from coal or coke

The synthesis of ammonia from nitrogen and hydrogen became possible when chemists discovered that certain substances called "catalysts" greatly speeded up chemical reactions, and the commercial production of synthetic ammonia became a reality when engineers devised gas-tight equipment in which the process could be conducted under pressures of hundreds of atmospheres and at temperatures approaching red heat. This accomplishment marked the beginning of a new epoch in chemical engineering. Useful chemical compounds formerly obtained by roundabout methods from plants or animals could now be synthesized directly from the elements carbon, hydrogen, and oxygen, or from simple compounds of these elements, such as carbon monoxide, water, acetylene, and ethylene. European chemists were quick to see the possibilities of making alcohols and hydrocarbon motor fuels from water gas or coke-oven gas.

Fischer and Tropsch 81/ reported the production of a mixture of hydrocarbons, alcohols, aldehydes, ketones, and organic acids by pressure synthesis from water gas, using an alkalized iron catalyst. Although the mixture, which they called "synthol", was usuable for motor fuel it was obviously inferior to a straight hydrocarbon gasoline, and the pressure process was dropped in favor of the subsequently discovered atmospheric-pressure synthesis, which yielded hydrocarbons only.

81/ Fischer, Franz, and Tropsch, Hans, Uber die Reduction des Kohlenoxyde zu Methane am Eisenkontakt unter Druck: Brennstoff-Chem., vol. 4, p. 193, 1923; vol. 5, pp. 201, 217, 1924. See also Fischer, Franz, The synthesis of petroleum: 1st Internat. Conf. Bituminous Coal, Carnegie Inst. Technology, 1926, Proc., pp. 234-246.

Patart 82/ and Audibert 83/ in France and the Badische Anilin und Soda Fabrik (now the I.G. Farbenindustrie) in Germany developed methods independently for producing methanol from carbon monoxide and hydrogen.

Road tests in Germany with a 4-cylinder truck reported by Fischer and Tropsch 84/ and in France by Dumanois 85/ showed that the mileage per gallon of methanol was approximately half that obtained with gasoline. The manufacturing cost of methanol--12 to 20 cents a gallon--and its low thermal value make it much more expensive than gasoline.

The production of synthetic gasoline from water gas at atmospheric pressure, reported by Fischer and Tropsch 86/ in 1926, has not reached commercial realization, although a semicommercial plant at the Mulheim Coal Research Institute has been operating experimentally during the last few years. The principal difficulties in large-scale commercial operation of the process are to dissipate the high heat of reaction and keep the catalyst at the proper temperature; also, the gases must be purified carefully to remove sulphur. It is believed that these problems may be near solution. The cost, however, promises to be considerably above that of petroleum gasoline.

82/ Patart, Georges, The industrial transformation of bituminous coal into organic technical products: 1st Internat. Conf. Bituminous Coal, Carnegie Inst. Technolgy, 1926, Proc., pp. 132-160; Une vouvelle conquete de la catalyse sous pression: la production industrielle de l'alcool methylique de synthese: Chimie et industrie, vol. 13, pp. 179-185, 1925.

83/ Audibert, E., La fabrication des carburants synthetiques aux depends des melanges de carbone et d'hydrogene: Chimie et Industrie, vol. 13, pp. 186-194, 1925; trans. in Fuel, vol. 5, p. 170, 1926; also A contribution to the study of the synthesis of methyl alcohol: 2nd Internat. Conf. Bituminous Coal. Carnegie Inst. Technology, 1928, Proc., vol. 2, pp. 503-522.

84/ Brennstoff-Chem., vol 6, p. 233, 1925.

85/ Compt. Rend., vol 181, p. 26, 1925.

86/ Fischer, Franz, and Tropsch, Hans, Die Erdolsynthese bei gewohnlichem Druck aus den Vergasungsproducкten der Kohlen: Brennstoff-Chem., vol. 7, p. 97, 1926; see also The synthesis of petroleum; 1st Internat. Conf. Bituminous Coal, Carnegie Inst. Technology, 1926, Proc., pp. 234-246.

Appraisal of the four types of processes for obtaining gasoline from coal

A careful appraisal of the present technical and economic status of the four types of processes for obtaining gasoline from coal, described above, leads to the conclusion that the hydrogenation and liquefaction of coal is the only one that as yet appears to be available for use in large-scale production of gasoline if our petroleum resources should fall off rapidly in the near future. Neither high- nor low-temperature carbonization of coal can be economically operated for the production of the relatively small portion of byproduct motor fuel obtained.

At the present time the synthesis of motor fuels from water gas appears considerably more expensive than the hydrogenation of coal; furthermore, the synthetic hydrocarbon processes have not yet attained commercial development. However, even in the hydrogenation process the cost of manufacture at the plant, estimated at 12 cents a gallon, is far above the present cost of petroleum gasoline at the refinery.

So far as a national conservation of fuel is concerned, it is highly wasteful to consume a large portion of our present supply of petroleum for ordinary heating and stationary power generation, when coal would answer as well, and then find it necessary in the future to make our needed gasoline in a roundabout and expensive manner from coal. The waste lies not only in the extra labor and equipment involved, but, what is more important, in the energy consumed in the process of conversion. In round numbers 4 tons of coal is consumed in making 1 ton of gasoline. Only 40 to 45 percent of the original heat units in the coal used is found in the resulting gasoline.

It is true that the United States has large resources of coal. It has been estimated that the reserves of coal, exclusive of anthracite, are 3-1/2 trillion tons, but much of this is of low rank and may not be suitable for hydrogenation. It is estimated that somewhat more than our present annual production of coal would be required to yield our present annual requirement of gasoline. Such doubling of our coal consumption would no doubt solve the immediate problem of the coal industry, but at a tremendous cost 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 fuels of natural gas and petroleum for those uses that can not be so efficiently met by the direct combustion of coal.

Time required to put hydrogenation on a commercial basis

It must be emphasized that the commercial plants obtaining gasoline from coal in England and Germany are not, in a strict sense, on a commercial basis. Large subsidies in the form of tariffs or excise taxes on petroleum or gasoline from petroleum are required to make their operation commercially possible. Neither of these countries has any important home sources of petroleum, but they do have extensive coal deposits. In case of war and blockade, the production of motor fuel from coal would be of the greatest importance to these countries. The large internal petroleum resources of the United States, if properly conserved, will defer this war need of converting coal, certainly for one and possibly for three or more decades.

Although England is now constructing its first commercial coal hydrogenation plant, it cannot be said that it has solved all technical commercial problems. Considerable development work will be required to put this plant into smooth operation, and several years may elapse before the plant solves all of its development problems.

Although the German plant at Leuna has been operating for several years, it has been working largely on tars and brown coal. The British plant now being built will be the first large-scale operation to use ordinary high-volatile bituminous coal such as we have in abundance in the United States.

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

In conclusion, it is now proved that technical processes for making gasoline or motor-fuel substitutes from coal are available if and when a failing supply of petroleum requires this step. But the product will be made with the sacrifice of much more of the original fuel energy than is lost in making gasoline from petroleum. Furthermore, the cost of the gasoline to the consumer will be materially higher. The fact that gasoline can be made from coal is no reason for continuing our present wasteful exploitation of petroleum reserves.

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Report II of the Federal Oil Conservation Board, pp. 5-9, 13-14, January 1928.

Fieldner, A. C., Recent developments in the production of motor fuels from coal: Bur. Mines Information Circ. 6075, 18 pp., July, 1928.

Fieldner, A. C., Recent developments in coal utilization; Minerals Yearbook, 1932-33, pt. 2, pp. 433-450, Bur. Mines.

Gasoline substitutes from oil shale

The enormous deposits of oil shale in various sections of the United States are often mentioned as possible future sources of motor fuel and fuel oil. The oil shale fields of the United States have been divided into three general classes - oil shale of the Rocky Mountain region, Devonian black shale of the Eastern States, and cannel shale of the Eastern States.

These oil-shale deposits can be made to yield large amounts of crude shale-oil 87/ and this oil can be used directly as boiler fuel 88/ and can be converted into motor fuel by known processes. 89/

According to Gavin 90/.

"The production of oil from shale requires one more operation than does the production of petroleum. In the latter case, once the mine (well) is driven into the oil sand, the crude product is recovered with but relatively little cost. In the case of oil shale, the rock itself must be mined and afterward treated to produce the crude oil. The character of petroleum is what it happens to be when the driller strikes the sand; the character of shale oil is largely dependent upon the process and conditions used in its manufacture. Once the crude shale oil has been produced, its refining is more complex and more costly than the equivalent refining of petroleum.

"The oil-shale industry will ultimately be developed on as safe and sane a basis as other great manufacturing and mining industries.

87/ Gavin, M. J., and Desmond, J. S., Construction and operation of the Bureau of Mines experimental oil-shale plant,1930, and unpublished data in files of the Bureau of Mines.

88/ Tests of shale oil produced by Bureau of Mines at Rulison, Colo.--Evaporative efficiency runs with 5 types of fuel-oil burners: U.S. Naval Boiler Laboratory, Philadelphia Navy Yard, Report 1075, Sept. 2, 1932.

89/ Unpublished data in files of Bureau of Mines.

90/ Gavin, M. J., Oil shale, a historical, technical, and economic study: Bur. Mines Bull. 210, 1924.

It is clear, however, from experience in other countries and from the very nature of the mineral and its crude products that the industry can come to commercial importance only as a type of large-scale, low-grade raw materials mining and manufacturing industry, and the profits derived from it will be of the order of those derived from other industries of the same general nature.

"It is hardly believed that shale oil, considered in a large way, will be a competitor of petroleum; it is more likely to be a slowly developed successor of petroleum. A general impression has arisen that the larger oil companies are seeking to retard development of the oil-shale industry, because they fear the possible competition of shale oil. There can be little truth in this belief. The writer believes that the petroleum industry as a whole welcomes the advent of shale oil, as its leaders are fully aware of the serious situation the American petroleum industry is facing. * * * Competition of shale oil with petroleum cannot be regarded seriously, since, because of the many technical problems which must be solved in connection with the former and the large amount of capital which will be required before the industry can hope to compare in production with the present petroleum industry, shale oil will probably be sorely needed long before it is produced in quantities sufficient appreciably to relieve the impending shortage of petroleum. It will be much longer, as before noted, before it can go far in supplying the present demand for petroleum, which normally will grow at a much greater rate than domestic petroleum supplies can support. M. L. Requa, former director of the Oil Division of the United States Fuel Administration, at the November, 1920, meeting of the American Petroleum Institute, in an address, made a statement which is worth quoting in this regard: 'The oil-shale industry, the coal-refining industry, the power-alcohol industry, with their potentialities and their limitations, deserve our close consideration. While they may superficially appear as our competitors, they are fundamentally our allies. When the time is ripe, I believe these supplemental sources of supply can be developed by the petroleum industry more advantageously than by any other agency.'

"Shale oil appears to be the most natural and logical substitute for petroleum. The supplies of shale are so great as to dwarf by comparison the quantity of petroleum already produced and still available for production in the United States. The writer believes that the oil-shale industry will ultimately be an industry of great magnitude and commercial importance in this country, but many years and much money will be required before it reaches this status. In its last analysis, it is an industry comparable with the low-grade-ore mining industries of the Western States and, like them, will require the services of the highest types of business, executive, and technical skill, backed by large capital, and which can afford and be prepared to wait a considerable time for a conservative return on the investment."

It is a far cry from oil shale in the Green River formation in Colorado (Naval Fuel Oil Reserve No. 1) to gasoline in an airplane or automobile. Shale oil has not been produced in the United States under commercial conditions. The plants that have been built have been on an experimental basis. Gavin 91/ says: "------- Up to the time of writing [April, 1923] the only operations approaching a commercial scale are those being conducted by the Catlin Shale Products Co. at Elko, Nev. An oil-shale industry can hardly be said to exist in the United States, except in the literature of promotion concerns." Furthermore, experience with these experimental plants does not form a basis for definite conclusions regarding costs of commercial operations. The Bureau of Mines has conducted probably the most consistent series of investigations of oil shale utilization that have been made in the United States and has published many of the results of its work.92/ Detailed results of work done by the Bureau of Mines during 1928 and 1929 have not been published, owing to lack of funds. However, the original data and manuscript reports are available in the files of the Bureau.

On the basis of these data and an unpublished report by E. D. Gardner and C. N. Bell, entitled "Proposed methods and estimated costs of mining oil shale at Rulison, Colo.," engineers of the Bureau of Mines estimate that 12 to 18 months would be required to build a plant with a retorting capacity of 10,000 tons of oil shale a day, taking its supply of oil shale from Naval Oil Shale Reserve No. 1, and to develop the mine to the point that that amount of oil shale could be delivered daily to the retorts. The cost of such a mine and retorting plant, prior to the time that the first ton of shale is delivered to the retorts, is estimated at $7,000,000. If this amount could be amortized over a period of years, the cost per barrel of oil produced might be a fairly reasonable figure, but if the plant were erected under war-time conditions and closed after 3 years' operation, the capital cost alone of shale oil might easily be $1.05 a barrel, to which would have to be added labor and operating costs.

Engineers of the Bureau of Mines estimate that during the development period of 12 to 18 months required to bring the mine and retorting plant to the point of beginning retorting operations an average of 400 men would be employed. To operate the mine at capacity would require 500 men, and for the retorting plant with 275 retorts 150 men. Each retort would cost about $20,000. A plant of this size would produce about 5,400 barrels of oil a day. Lieut. J. E. Hamilton, Bureau of

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91/ Gavin, M. J., op. cit., p. 98.

92/ Karrick, L. C., Manual of testing methods for oil shale and shale oil; Bur. Mines Bull. 249,1926; Jakosky, J. J., Uses of water in the oil shale industry; Tech. Paper 324, 1923; Finley, W. L., and Bauer, A. D., Coking of oil shales; Tech. Paper 398, 1926; Bulls. 210, 315, already cited; and many short papers.

Engineering, U. S. Navy, has stated informally that a naval cruiser traveling at full speed requires 6,800 barrels of fuel oil in 24 hours.

From this recital it can be seen that oil shale is by no means the ready source of fuel in an emergency that it is often assumed to be.93/ A long period of time would be required to make the fuel available, much labor would be required, and costs would be extremely high.

Alcohol as motor fuel

The case of alcohol as a constituent of motor fuel has been argued extensively pro and con in the technical press and in the newspapers during the last 12 to 18 months and intermittently for many years prior to 1933.94/ Alcohol has been employed, either directly or as a constituent of a mixture, as a substitute for gasoline in various countries since the first introduction of the internal-combustion engine, at such times and in such areas as special conditions were conducive to its use. The use of alcohol as motor fuel under these conditions should be given consideration only to the extent that it indicates the possibilities of alcohol as a substitute for gasoline with regard to performance. Utilization of alcohol motor fuels to dispose of surplus agricultural products is a very different matter from the use during war time of alcohol made from agricultural products that will themselves be in great demand. In this connection it is important to remember that alcohol is itself a military necessity in time of war.

The use of corn and other grains or vegetables as sources of alcohol for motor fuel during war time may be dismissed from consideration. Such materials would be too urgently needed as food products.

A recent Senate document 95/ shows that the total production of corn in the United States has not been adequate to replace the motor-fuel requirements for gasoline during any year since 1923, assuming a yield of 2.36 gallons of alcohol from a bushel of corn.

Alcohol and other fuels can be made from straw, corn-cobs, corn-stalks, agricultural dusts, and other agricultural wastes.96/

93/ Bur. Mines Bull. 315, p. 3.

94/ Graf, D. W., Power alcohol, a partial list of references, U. S. Dept. Agr., 1933.

95/ Use of alcohol from farm products in motor fuel ; 73d Cong., 1st sess., S. Doc. 57, table 20, p. 55.

96/ The utilization of agricultural products for the production of motor fuels: Rept. II of the Federal Oil Conservation Board, Appendix IV (by Bur. Chemistry, U. S. Dept. of Agr.).

Work along this line has been mainly on an experimental basis, and a considerable time may elapse before plants for the production of fuels from such sources could be put on a production basis. However, in view of the fact that economic deterrents may not be effective during war time, these wastes may be more practicable sources of fuel than primary agricultural products that require essential manual labor for their production.

The following excerpts from Report II of the Federal Oil Conservation Board, Appendix IV, cited above, indicate the limitations of these sources of alcohol:

"Alcohol from cellular wastes

"(1) From waste sulphite liquor from paper pulp mills.—The yield from this material is low, and several technical difficulties have been encountered in developing the process. Only one distillery in the United States is reported to have produced alcohol from this source commercially. Several paper mills have investigated this possibility and have even gone so far as to erect experimental distilleries for this purpose.

"(2) From mill and forest-wood waste and trees.—Two kinds of alcohol may be obtained from these materials, methanol or methyl alcohol (wood alcohol) and ethyl alcohol.

"Methanol (methyl alcohol).—Several substances of commercial importance, including methanol, are obtained from the hardwoods, such as oak, beech, and maple, by destructive distillation. Sawdust has not been used successfully for this purpose because of the difficulty of securing good heat penetration in the closely packed material. Methanol is less efficient than ethyl alcohol as a motor fuel; this and its higher cost (80 cents per gallon in tanks) as compared with that of denaturated ethyl alcohol (27 to 33 cents per gallon in tanks) eliminate it from consideration as a motor fuel.

"Ethyl alcohol.—At least two distilleries in the United States have attempted to produce industrial alcohol profitably from sawdust and other mill waste by hydrolysis and fermentation. Yields of approximately 12 to 20 gallons of 95 percent (190-proof) alcohol per ton of dry raw material have been reported. In order to justify the initial investment and overhead expense involved in the erection and operation of a distillery of appropriate size, it is necessary that the plant be in the immediate vicinity of a mill of large capacity. It has been estimated that a quantity of mill waste at least equivalent to approximately 200 cords of wood per day would be required in order to justify the expense of constructing and operating such a plant for producing alcohol from this material. The fact that only a few mills in the United States produce enough waste to warrant the production of alcohol from this material has retarded the development of the industry."

Senate document 57, above cited (p. 22), states that during the year ended June 30, 1932, 84.76 percent of the industrial alcohol produced was made from molasses, 9.69 percent was made synthetically, and only 3.75 percent was made from grains. The remaining 1.8 percent was made from other materials and mixtures.

Consideration of the employment of alcohol as motor fuel during war time involves two major objections in addition to processing cost and raw material required. The first of these is that all existing equipment for producing alcohol would probably have to be operated at capacity to supply urgent demands for alcohol needed in the manufacture of munitions and other war materials. The second objection is that the labor and equipment required to fabricate and erect additional plants would be urgently needed to provide munitions and other military necessities. The following extract from Senate Document 57 (pp. 20-21) is enlightening on this question:

"Manufacturing plant capacity

"In considering any proposal for the utilization of additional quantities of farm products in the manufacture of alcohol for motor fuel, plant capacity and the rate at which additions could be made to the capacity must be taken into account. The industrial-alcohol industry of the United States has never produced more than 107,000,000 wine gallons in a year. At the present time the industry is operating much below capacity. In 1932 only 78,000,000 gallons of 95 percent alcohol were produced. The capacity of existing plants is probably about 250,000,000 to 275,000,000 gallons. The antifreeze and other industrial requirements for alcohol probably would continue to take about 75,000,000 gallons. A 2 percent blend with all gasoline used would require about 300,000,000 gallons. Consequently, the producing capacity of industrial-alcohol plants would have to be expanded to the extent of at least 100,000,000 gallons to provide the alcohol for such a blend.

"The present capacity of alcohol production centers is estimated to be about as follows:

	Gallons
Eastern seaboard	112,000,000
Southern districts	60,000,000
Middle Western districts	89,000,000
Pacific coast	6,000,000
Total	267,000,000

"If alcohol to the extent of 2 percent of the annual consumption of motor fuel were required or desired for use within a year, this could be obtained only by postponing the effective date of the requirement until stocks could be accumulated. * * * The production of a supply of alcohol equivalent to 2 percent of the annual motor-fuel consumption would require additional plant capacity to the extent of about 110,000,000 gallons, and the operation of these plants would require an additional 47,000,000 bushels of corn or its equivalent. Additional capacity to provide alcohol to the extent of 5 and 10 percent of the annual motor fuel requirements probably could be developed within 2 or 3 years.

"Supplies of raw materials for alcohols

"Anhydrous alcohol, for a 2 percent blend with 15,000,000,000 gallons of motor fuel, would require equivalents of about 112,000,000 bushels of corn and 23,000,000 bushels of barley. A 5 percent blend would require about 280,000,000 bushels of corn and 57,000,000 bushels of barley; and a 10 percent blend, 560,000,000 bushels of corn and 114,000,000 bushels of barley.

Recapitulation

The foregoing discussion points unmistakably to the conclusion that coal, oil shale, and alcohol are not yet practical sources of motor fuels. Construction of equipment to produce oil from coal or shale and to provide additional supplies of alcohol would require an enormous amount of labor and material, and production would not begin until at least a year after plant construction had started. In war time alcohol would be urgently needed for the production of explosives and other war materials and many additional plants would be required to provide for even as little as 10 percent of our normal requirements of gasoline.

On the other hand, the American petroleum industry has a large potential capacity to produce additional fuels and other products.

The United States Bureau of Mines reports the following quantities of petroleum and petroleum products in storage in the United States December 31, 1933;

	Barrels
Crude petroleum	355,394,000
Natural gasoline	3,186,000
Gasoline	52,240,000
Kerosene	6,495,000
Gas oil and fuel oil	122,287,000
Lubricants	6,896,000
Total, all oils	546,498,000

	Short Tons
Paraffin wax	34,400
Petroleum coke	727,400
Petroleum asphalt	254,500
Total	1,016,300

These materials are owned by individuals and corporations. They constitute our real reserves of fuels, lubricants, and other materials, immediately available in case of emergency. They constitute about 220 days' supply at the rate of demand during the year 1933, and if these stocks were to be conscripted for strictly military uses, they would probably be sufficient for a much greater number of days, pending the time that additional supplies were made available.

Oil refineries are widely distributed throughout the United States, their equipment and processes have had intensive development under the urge of competition, and therefore results can be predicated accurately. 97/

Petroleum refineries are potential emergency sources of alcohols and other chemicals required in the production of explosives and other war materials, and additional refinery operations to supply fuels and lubricants would furnish intermediate products for the manufacture of needed supplies of these essential war-time products. 97/

Summary

The preceding brief review of the petroleum situation in the United States and of the possibility of developing substitutes for petroleum as a source of a particular type of power that is so essential to our present national economic life lead to the inescapable conclusion that every effort of Government and industry should be directed to the conservation of petroleum. This effort should permeate all phases of the industry, from the development of the crude product, through every step in refining and manufacture, to final use.

The resource is limited, although that vital fact is obscured by present overproduction; satisfactory and economical substitutes are not yet commercially developed; the conditions that the Nation will face when existing supplies approach exhaustion cannot be foreseen; and that day must be deferred to the utmost possible limit by the exercise of every conceivable waste-preventing measure, from the drilling of a well to the final consumption of the finished product.

97/ Brooks, B. T., Alcohols and related products from petroleum: World Petroleum Cong. 1933, Proc., vol. 2, p. 840.