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PETROLEUM, PAST, PRESENT AND FUTURE[1]

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Synopsis: This paper reviews the recent remarkable progress in the petroleum field. Our growing dependence on the products of the oil industry has resulted in considerable concern regarding the ability to supply our future needs for liquid hydrocarbons. The proved reserves of crude oil correspond to some fifteen years' consumption at the prewar rate. However, the excessive wartime requirements for petroleum have led to such a high rate of withdrawal from these underground reservoirs that we may not be able to keep up with the demand for long. In addition to the proved reserves of petroleum known to be present in the earth, large but as yet undiscovered petroleum resources may be expected to exist in various parts of the world. How long we can continue to find this oil and bring it to the surface at the desired rate is a question, but it is certain that eventually a shortage in natural petroleum will occur. When that time comes, it should be possible to supply our needs for gasoline and other hydrocarbon products from such alternate sources as natural gas, shale oil and coal. It is concluded that there need be no sudden change as far as the supply and consumption of gasoline and other petroleum derivatives are concerned. Future developments in this field will probably be characterized by further technological progress, increased drilling for oil on a world-wide basis, necessary adjustments in supply and demand, and a gradual shift to synthetically produced hydrocarbons.

A GREAT deal of attention is currently being devoted to the petroleum situation. Until a short while ago we were primarily concerned with the transportation problem. The question of getting available petroleum

1 Presented before the general meeting at the 106th meeting of the American Chemical Society, Pittsburgh, Pa., and printed in the November issue of *Industrial and Engineering Chemistry*. Unless stated otherwise, the charts shown are based on data from the Bureau of Mines and other Government agencies, "Petroleum Facts and Figures" (1941 and previous editions), and on petroleum industry figures.

products to where they were needed seemed to overshadow all other considerations. Now that the transportation difficulties gradually are being overcome, our interest is turning to the question of the country's ability to produce crude oil to supply the present and future demands for petroleum products.

Our industrialized civilization is fundamentally based on the utilization of mineral resources. It is therefore not surprising that, in the forty-year period of industrial expansion in this country, the world's mineral production has been greater than in all preceding history.[2] In the United States petroleum and its by-products in terms of dollar value account for 40 per cent. of the total mineral production.[3] Half of the crude oil used to date in this country has been taken out of the ground in the last twelve years.

The importance of petroleum in relation to other available sources of energy is brought out by Fig. 1;

U. S. ENERGY SOURCES

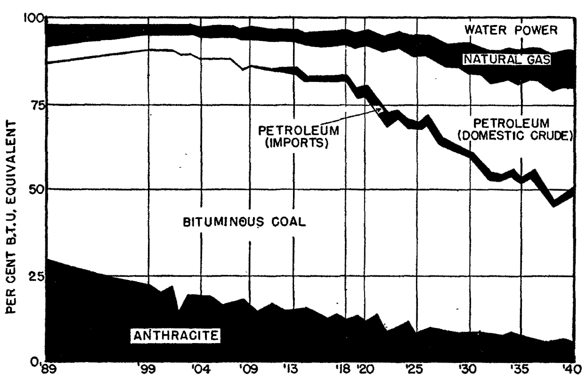

FIG. 1. Percentage of total B.T.U. equivalent contributed by the several sources of energy, counting water power at constant fuel equivalent, 1889–1940. If water power is counted at the prevailing fuel equivalent of central stations in each year, its proportion is 3.2 per cent. in 1899 and 3.5 in 1940, and the proportions of other sources of energy are affected accordingly (reproduced from Bureau of Mines Minerals Year Book Review of 1940, page 776).

it is seen that some 40 per cent. of our energy (B. t. u. equivalence basis) comes from crude oil and natural gas. A peak of 43.5 per cent. was actually reached in 1938. Some of the remarkable growth indicated for this energy source represents a shift from coal, but most of the gain in the recent twenty-year period is due to the development of new forms of transportation based on the use of liquid fuels.

This trend toward motorized transportation has not only been responsible for a greatly increased production of crude oil, but has also resulted in the conversion of a gradually increasing proportion of the crude into gasoline. According to Fig. 2, the yield of gasoline on crude increased from 25 per cent. in 1919 to some 45 per cent. in 1932. How the technological developments in cracking made this rise possible is so well known to chemists that it requires no further discussion.

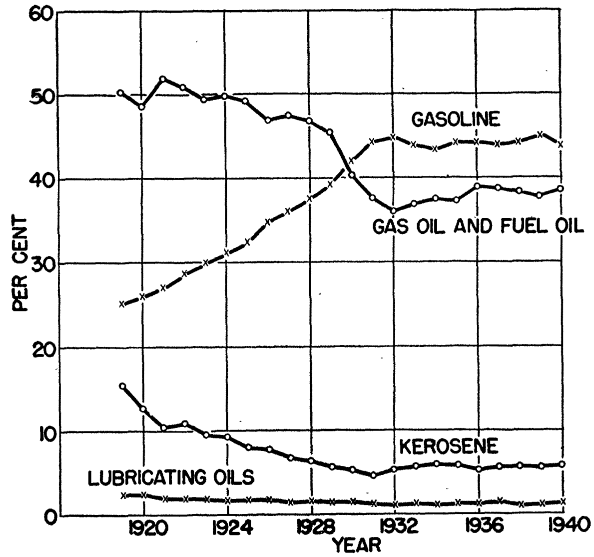

FIG. 2. Average yield of principal petroleum products per barrel of crude oil produced.

That the average gasoline yield has leveled off in the 43–45 per cent. region during recent years is purely a matter of relative demand for the various products from petroleum. From a technological standpoint there is nothing to prevent it from going higher. In-

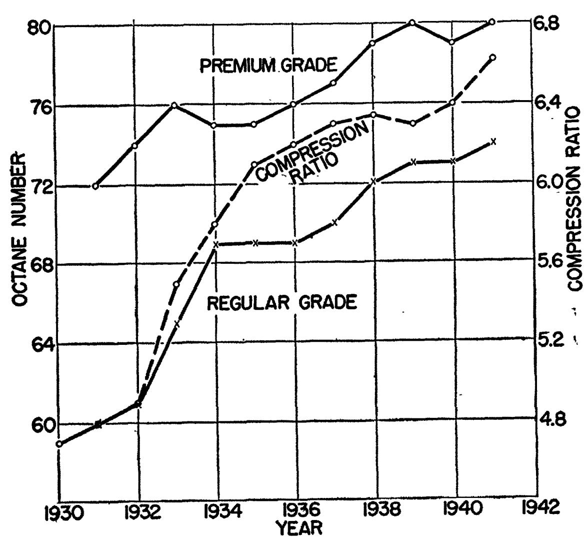

FIG. 3. Trends in octane ratings of gasolines and in compression ratios of automobile engines.

[2] C. K. Leith, J. W. Furness and C. Lewis, "World Minerals and World Peace," Washington, Brookings Institution, 1943.

[3] "Petroleum Facts and Figures," 7th ed., New York, American Petroleum Institute, 1941.

deed, it is entirely feasible by catalytic cracking under high pressure of hydrogen to convert crude oil to gasoline, volume for volume.

Along with the increase in yield of gasoline there has also been a marked improvement in quality. One of the important factors as far as quality of motor fuel is concerned is octane number. The progressive increase in octane rating shown in Fig. 3 may be taken as evidence of the petroleum industry's ability to control the chemical composition of its fuels; it can also be seen from this figure that the improvement in octane number, by and large, parallels the engine builder's increase of compression ratio, which in turn is a criterion of the power output that can be obtained per unit of fuel.

As a result of the progress made by both the petroleum and automotive industries, the American public has become increasingly dependent upon motorized transportation. Fig. 4 shows the growth in number of passenger cars registered, as well as in the average gasoline consumption per car. The depression of the thirties brought home to all of us how dependent modern society has become upon the automobile. It was frequently stated then that the last thing the average man was willing to give up was his private means of transportation. The family car stood out as ranking with shelter, food and clothing as a necessity of life. Many were the instances related in which the car seemed to head the list. This situation is brought out in Fig. 4, which shows an inconceivably small sacrifice in automobile use during the depression. It should be noted that these data concern passenger cars only. Had busses and trucks been included, the resulting curves for total car registration and average fuel consumption would have shown almost imperceptible dips. This record of the past leaves no doubt that the American public has a live interest in the future of petroleum.

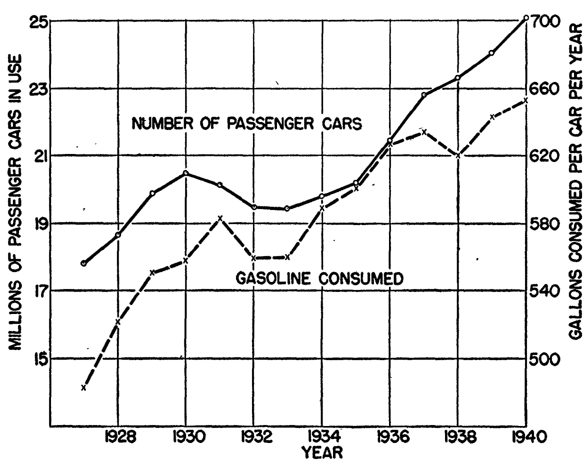

FIG. 4. Passenger cars in use in the United States and their consumption of gasoline.

It is not only motorized transportation, however, that is dependent upon an adequate supply of petroleum. During the recent period of expanded crude oil production, our entire mode of living has become geared to the use of petroleum products. Industry, agriculture and shipping alike are large consumers of a multitude of hydrocarbon materials derived from petroleum sources. The list includes such varied products as industrial and process oils, greases and extreme pressure lubricants, asphalts and road oils, solvents and insecticides, and an ever-increasing number of chemical raw materials and derivatives. The petroleum chemicals business, which already had contributed a considerable volume of various alcohols and related products, has recently been called upon to increase several fold the country's supply of toluene for explosives and to furnish two thirds of the butadiene for the synthetic rubber program. According to Ickes[4] the production of toluene from petroleum will, by the end of the current year, be nearly six times that obtained from all by-product operations.

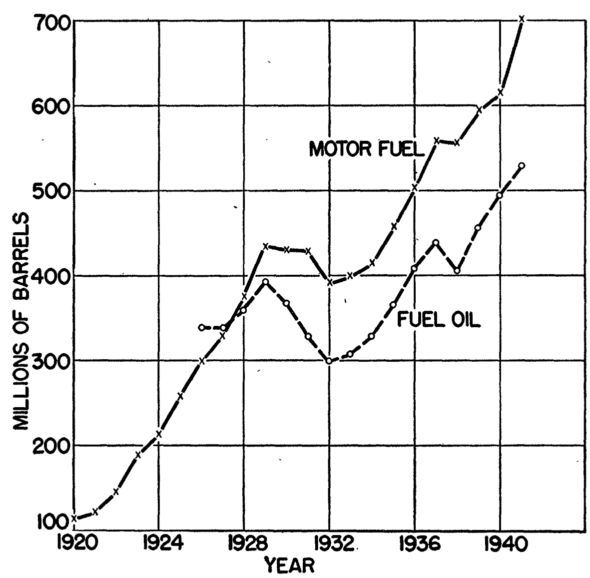

FIG. 5. Production of motor fuel and fuel oil (includes Diesel and other gas oil and distillates, and residual fuel oil, but not kerosene).

The four main classes of products shown in Fig. 2 add up to account for some 90 per cent. of the materials derived from crude oil. The group of products included in the classification "fuel oil" rank next to gasoline in volume. The growth in fuel oil production is illustrated in Fig. 5. Heating oil accounts for some 25 per cent. of the total fuel oil consumption;

[4] H. L. Ickes, "Fightin' Oil," New York, Alfred A. Knopf, 1943.

DOMESTIC OIL BURNER INSTALLATIONS

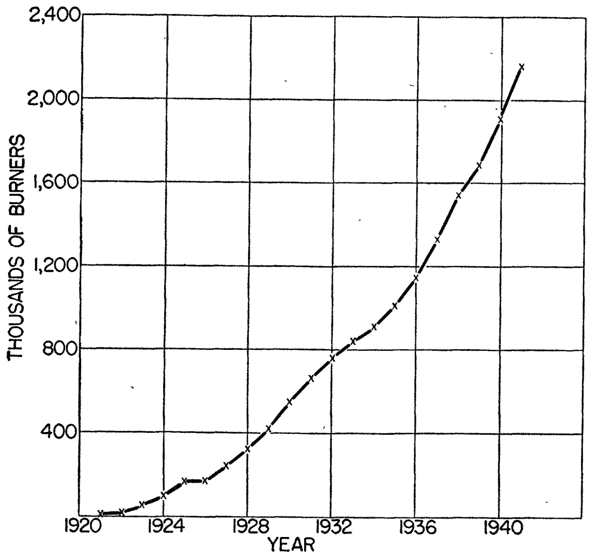

FIG. 6. Domestic oil burners installed at beginning of each year.

about two thirds of this is used for homes. How this outlet for petroleum has developed can best be seen from Fig. 6, which shows the growth in domestic oil burner installations. Although it may be easier to heat a house than to run an automobile with a substitute fuel, the millions of American families who are dependent upon petroleum for heating can also be counted on to have a genuine interest in the future of our oil supplies.

The position of the United States as a producer of crude oil is shown by Fig. 7. The data indicate that prior to the war we supplied some 63 per cent. of the world's petroleum requirements. At present the figure is higher. Although considerable crude from other sources is normally worked up in American-owned refineries located outside the United States, our actual import and export of crude are small in comparison with domestic production (Fig. 8). The volume of refined products imported has been about equal to that of the crude oil import, while the export of refined products has been running 20–40 per cent. higher than the figures for crude export during the period covered by Fig. 8. In other words, the United States production of crude oil has been in rather close balance with domestic requirements of petroleum products.

PRODUCTION OF CRUDE OIL IN 1940

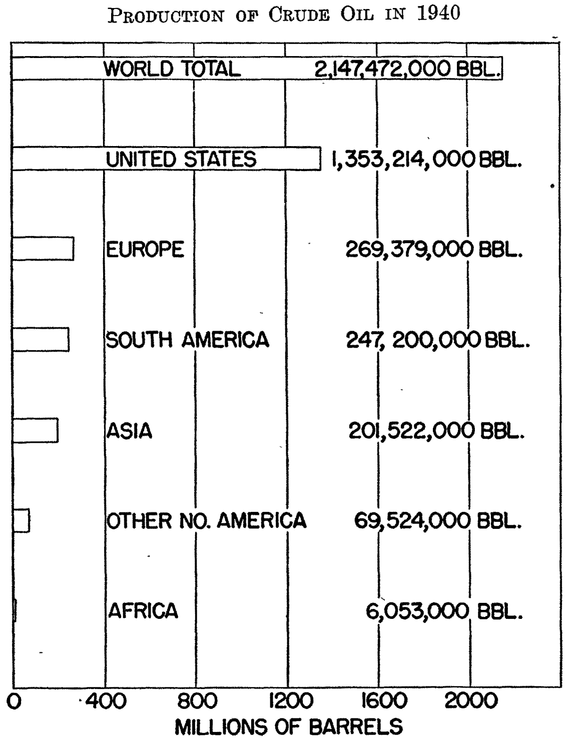

FIG. 7. Production of crude oil in 1940.

CRUDE OIL PRODUCTION, IMPORT AND EXPORT

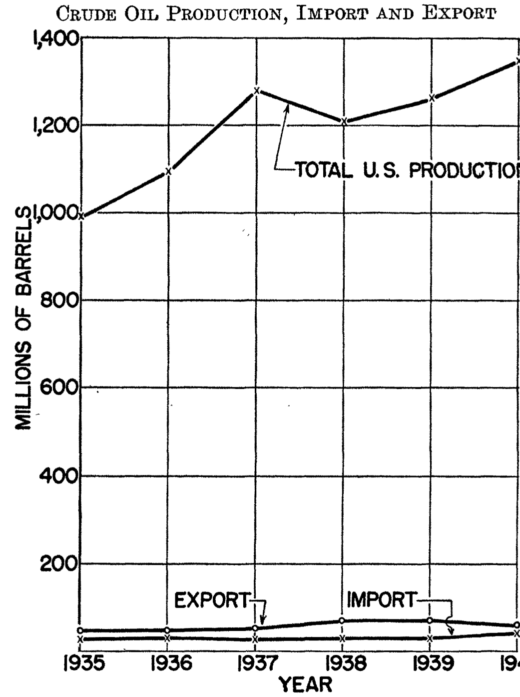

FIG. 8. United States crude oil production, import and export.

Fig. 9 gives the production and refining of petroleum by states. It is evident that there is considerable flexibility as far as the location of these two branches of the industry is concerned. Due to the ease with which crude oil can be transported by pipe line, tanker, barge and rail, the refining operations are not tied down to the place of production but can be carried out at points most suitable from the standpoint of distribution and/or consumption of the finished products.

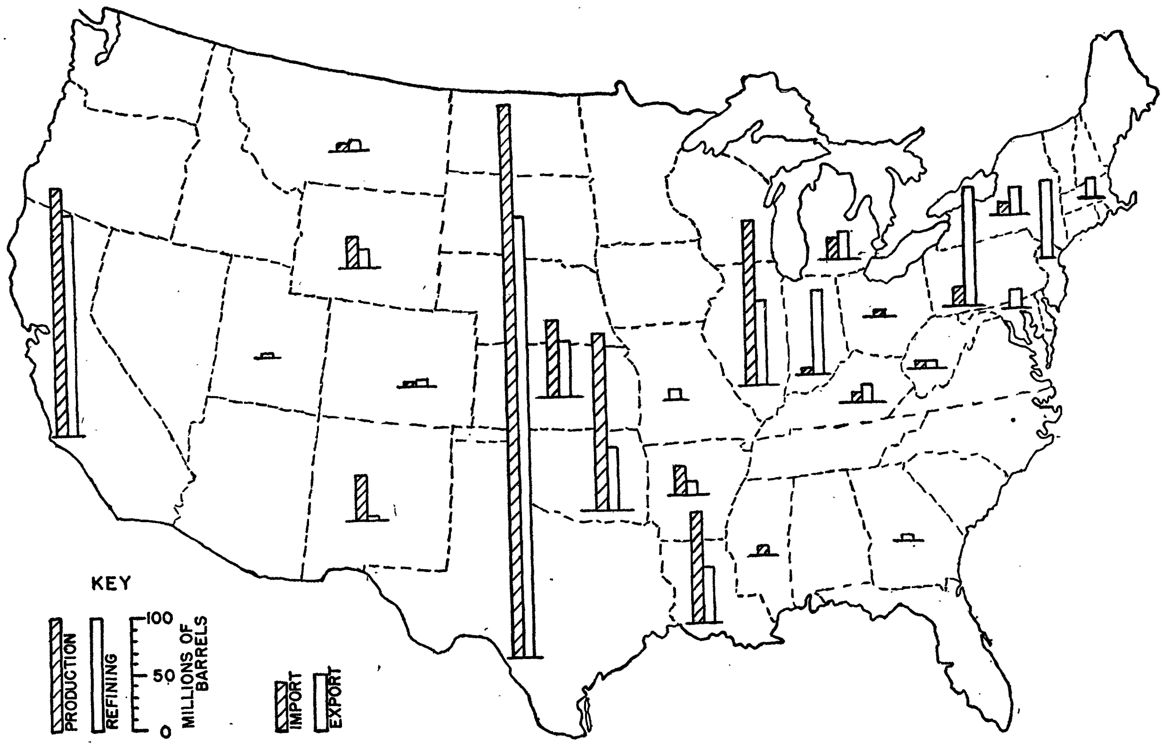

Fig. 9. Production and refining of petroleum by states.

The rate at which crude oil has been withdrawn from the ground is shown in Fig. 10 by the curve labeled "cumulative production." On the "cumulative, discovery" curve, the somewhat scattered points indicate the estimates made by various authorities at the time indicated. The vertical distance between the two curves represents the "proved reserves" at any one time. These are the oil reserves which, according to best estimates, are known to exist in the ground. As of July 1 of this year, the known and untapped reserves amounted to 20.4 billion barrels,[4a] or sufficient for perhaps fifteen years of our normal requirements. The proved reserves outside the United States are slightly greater, about 22 billion barrels. Of this oil located in other parts of the world, Britain controls about 50 per cent., America 25 to 30 per cent. and Russia around 20 per cent.[5]

The data in Fig. 10 show that, except for a period in the twenties when a shortage was seriously feared, the proved reserves have always kept ahead of production by a rather comfortable margin. However, only part of the growth in reserves shown is due to discovery of new fields; the remainder is made up of extensions to existing fields. As a new field is being developed by the drilling of additional wells, information is obtained which may lead to an upward revision of the originally estimated volume of oil present. This is what is meant by an extension to an existing field in

U. S. Crude Production and Reserves

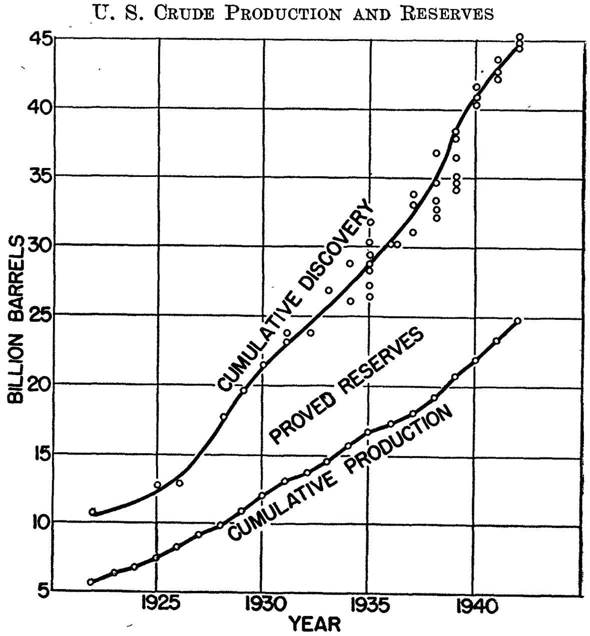

Fig. 10. Cumulative production and discovery of petroleum in the United States, adapted from Levorsen's data (*World Petroleum*, November, 37, 1942).

[4a] W. V. Howard, *Oil Gas Jour.*, July 28, 90, 1943.
[5] W. E. Pratt, "Oil in the Earth," Lawrence, Kans., University of Kansas Press, 1942.

contrast to the discovery of an entirely new field. The trend of actual discovery is brought out in Fig. 11, which shows the present estimates of the ultimate recoverable oil in the fields discovered each year since 1918. It is apparent that there has been a deficiency in new discoveries as compared with consumption of crude since 1939. It is this lag in the discovery of new petroleum reservoirs which now is the subject of so much discussion.

Normally the fifteen-year backlog of crude reserves would have given the petroleum industry the opportunity to work out its supply problem over an extended period. Except for the war, we would probably not have heard much about an impending crude shortage at this time. It is the necessity for providing the Allied forces with petroleum for a global war that has aggravated the situation.[6] Before attempting to

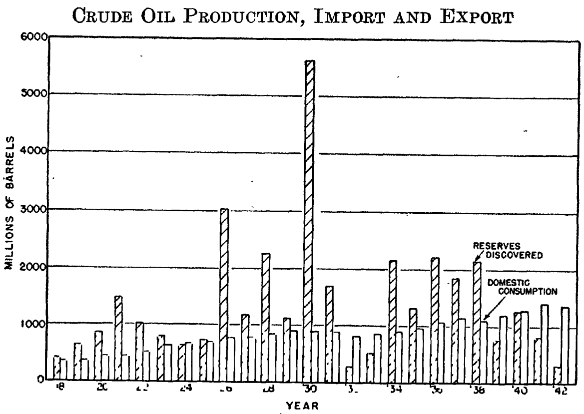

FIG. 11. Annual discoveries and consumption of petroleum, according to Heroy.[6]

explain why this is so, it may be well to see what is involved in the war requirements.

In a recent report by W. R. Boyd, Jr., chairman of the Petroleum Industry War Council, mention is made of "the tremendous military demands for petroleum, which because of censorship have not been revealed to the oil industry, and already, exclusive of huge amounts of aviation gasoline and lubricants, are equivalent to about 25 per cent. of the total current production of crude oil in the United States. This demand has an even greater effect because the manufacture of special war products, particularly aviation gasoline, requires a disproportionate amount of the capacity for the manufacture of motor gasoline."[7] According to Petroleum Administrator Ickes, 60 per cent. (or nearly two out of every three tons) of the supplies sent overseas to our expeditionary forces over distances varying from 3,000 to 10,000 miles are oil.[4] Using President Roosevelt's figure of 1,110 gallons of fuel per bomber, a thousand-plane raid in the European theater of war consumes more than a million gallons of aviation fuel, or the equivalent of about one third of the cargo carried by a modern tanker. The situation is aptly described in Premier Stalin's toast at the time of Prime Minister Churchill's visit to Russia: "This is a war of engines and octanes. I drink to the American auto industry and the American oil industry." Or as Ickes has expressed it, ". . . the side than can throw the most oil into the fray over the longest period of time will win."[4]

To meet these requirements, the United States is now producing crude oil at the rate of more than 4,200,000 barrels a day. To illustrate what this figure means, we may observe in passing that it represents well over four times the production during the height of the World War in 1918. Only four to five days' production at that rate is needed to equal the annual prewar consumption of petroleum and related products in the whole of the Italian Empire with its population of 45,000,000.[8,9] Less than ten days are required to equal the most recently estimated yearly production of crude in Rumania, which is the chief supplier of petroleum to the Axis powers.[10]

Large as current production is, it may at first sight appear strange that there is much of a drain on the reserves of some 20 billion barrels known to be in the ground. The explanation is that a "rate of withdrawal" factor is involved. To understand this problem fully, we must remember that crude oil occurs in the ground in porous rock, the permeability of which governs the physical rate at which the oil can be withdrawn. Also, oil contains no inherent energy, and it must therefore be displaced from the reservoir rock either by expanding gas associated with it or by water. In dealing with such a heterogeneous system, the efficiency with which the oil is displaced improves with reduced rate of withdrawal. Conversely, high rates of withdrawal result in inefficient flushing of the oil from the reservoir rock and consequent reduction in recovery. This imposes certain restrictions on the country's capacity for producing petroleum.

In other words, there is no immediate shortage of oil known to be in the ground. The problem confronting us is rather one of being able to withdraw this oil at the desired rate. In some fields, which are being operated on the best engineering principles, the natural gas is pumped back into the ground to aid in

[6] W. B. Heroy, "Supply of Crude Petroleum within U. S.," statement in connection with Bill S. 1243, July 29, 1943.

[7] H. D. Ralph, *Oil and Gas Jour.*, July 22, 10, 1943.

[8] *Oil and Gas Jour.*, July 28, 86, 1943.

[9] *Oil and Gas Journal* (*l. c.*) gives the prewar petroleum requirements of Italy as less than 40,000 barrels daily; "Petroleum Facts and Figures" (13, page 18) mentions a somewhat higher figure of 21 million barrels a year as the Italian consumption in 1938 of petroleum and related products (motor benzol, alcohol, and synthetic fuels).

[10] *Ibid.*, August 5, 14, 1943.

bringing still more oil to the surface; but in many older fields all or most of the gas has been withdrawn, leaving an inordinately high percentage of the original oil to be taken out of the ground by secondary recovery methods.

Next comes the question of oil not yet discovered. It is difficult for any one to make a reliable estimate of the possible hidden reserves of crude. The viewpoint of the petroleum geologist is presented by Pratt,[5] who discusses the prospects of finding oil in terms of the subterranean structures and the efforts to explore these structures for their oil deposits. Of the crude so far discovered and developed world-wide, some 54 per cent. is accounted for by the search within the United States (Alaska not included). While this country constitutes only 5 per cent. of the land area of the earth, it contains 15 per cent. of the structural area most favorable for the occurrence of oil fields. If exploration by drilling is extended over this total area and if per acre yields equal to the average of the already proved areas are assumed, it would appear that the United States ultimately should give up at least 100 billion barrels of oil, including the 46 billion barrels which represent the total discovery (production plus reserves) to date. On the same basis, the rest of the world would ultimately produce some 600 billion barrels of oil, including the 38 billion barrels already found. Such considerations lead to the conclusion that "at the present rate of consumption the probable ultimate oil resources of the earth, made available and freely distributed, should meet humanity's needs for 300 years to come."

How to locate these potential oil reserves is a problem with so many technical and emonomic aspects that an adequate discussion can not be undertaken as part of this brief review. Not even those best qualified to have an opinion of this subject can predict how long new oil will continue to be brought in at the rate it is needed. This is the situation which has aroused so much recent comment and which logically leads to the question of where we stand with respect to alternate sources for the products now being obtained from petroleum.

(To be concluded)

OBITUARY

BARBARA STODDARD BURKS

THE death on May 24, 1943, of Dr. Barbara Stoddard Burks brought to a close the short career of a clear-visioned investigator who did much to emphasize the close relationship between the fields of psychology and genetics. Born in New York City in 1902, Dr. Burks received the A.B. and Ph.D. at Stanford University and was early identified with the psychological research in progress in California. In collaboration with Dr. Lewis M. Terman, she made a study of school children of outstanding intelligence, following their development through adolescence and finding them still superior in intelligence and achievement in later years. During her years in California, she began an extensive study of the children of parents with readily recognizable traits, such as alcoholism, comparing the development of those children reared by their own parents with those placed with foster parents. The results of this study helped to clarify the role of heredity in psychological development, while revealing the complexities of the situation. She made also a thorough and painstaking analysis of the intelligence, temperament and social adjustment of identical twins reared apart, following a number of such twins through many years of development, and concluding that heredity is of fundamental importance in determining the mental ability and temperament of the individual, while environmental differences play an important role in social adjustment. A well-trained and capable mathematician, Dr. Burks applied precise statistical criteria to her analyses.

In 1934, after the death of her husband, Dr. Burks went to Europe as a fellow of the General Education Board, and upon her return in 1936, she became a research associate at the Eugenics Record Office of the Carnegie Institution of Washington at Cold Spring Harbor, New York. Here she pursued for four years her interest in genetics in relation to physical and mental traits. She studied the inheritance and linkage of several mutations in man (ovoid red blood corpuscles, mid-digital hair and missing lateral incisors) and sought to establish a case of autosomal linkage. She also continued her studies of identical twins reared apart, making frequent trips across the continent to interview and test her cases. The high regard in which she was held by geneticists was evidenced by her appointment as chairman of a section meeting, that on abnormal human characters, at the Seventh International Congress of Genetics at Edinburgh in 1939, only one other woman, Dr. Kristine Bonnevie, being so honored.

In 1940, Dr. Burks became a research associate at Columbia University, collaborating with the State Charities Aid Association and the Social Science Research Council in a continuation of her foster-child studies. This work, left unfinished at her death, is being carried forward by Dr. Anne Roe. Dr. Burks was awarded a Guggenheim fellowship for the year 1943–44 for an extension of her study of identical twins, but her death occurred before the tenure of the fellowship began.

Dr. Burks was keenly interested in social problems