

Petroleum—Today and Tomorrow

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FROM ALMOST EVERY POINT OF VIEW, petroleum was "strategic mineral number one" during the World War that ended in 1945. Even the spectacular advent of the atomic bomb in the final days of the conflict did not displace it from its position of prime importance, although within a few years uranium will almost certainly be the "number one" material in the minds of military strategists, if it is not even now in that position.

It was the ceaseless flow of petroleum from the oil fields of the United States, Venezuela, the Middle East, and a few other places of lesser importance that kept the Allied Forces in motion on land and sea and in the air, the world around, and even provided them with some of the most potent of their weapons. It was the progressive attrition of Germany's supplies of oil that clipped the wings of the Luftwaffe and made possible the astonishingly swift advance of the Allied Forces from the periphery of Hitler's ill-gotten empire to its nerve center in Berlin. It was the cutting of the supply lines from the oil fields of the East Indies to Japan and the exhaustion or destruction of the Japanese stores of petroleum that presaged the capitulation of the Japanese war lords, even before the bombs fell on Hiroshima and Nagasaki. Verily, the Allied Powers rode to victory on a flood of oil.

Now that the "shooting war" is ended, and as we turn to the distressingly difficult task of arranging a peaceful world in which men may use the rich resources of our bountiful earth for the welfare of all mankind, petroleum continues to hold its leadership among the natural resources of the earth. Both as fuel and as raw material for chemical industries, petroleum will hold the center of the stage for many years to come. Hardly any other substance illustrates so fully the manner in which science and technology may be combined to achieve the utmost success in contributing to human efficiency and comfort.

Fundamental to any understanding of the problems implied by my topic is the comprehension of the fact that petroleum is a nonrenewable resource; it is in the category of nature's stored capital, not of man's annual income. It is, of course, true that the geologic processes responsible for oil pools are continuing to operate today as in

the past. On the sea floor off the coast of southern California, for example, there are broad hollows where the tissues of marine animals and plants are now accumulating in mud and ooze at depths of 200 or 300 fathoms. The conditions are closely similar to those that occurred repeatedly during the Paleozoic era in Oklahoma and Texas, when the oil of certain rich oil fields was being generated. But millions of years must elapse before that organic material can be transformed into petroleum, stored in the interstices of overlying sandstones, and made available by crustal movements for recovery from wells to be drilled by some future inhabitants of the earth's surface.

In relation to the feverish haste of mankind's insatiable demands, the creative processes of nature's laboratory operate very slowly. For all practical purposes our planet must be reckoned as a storehouse of such minerals as petroleum, not as a factory in which that substance is generated year by year, or even millenium by millenium. Mother Earth has made available a cupboard richly stocked with a vast amount and a great variety of goods indispensable to us in an age of science and technology, and among these stores we find petroleum. Each year we go to the shelves of that cupboard and take away a few packages of the goods stored thereon; if we keep going long enough, some day someone will find that the cupboard is bare. Indeed, petroleum is now being used at such a rate in relation to its total amount in the earth's crust that its complete exhaustion is, from a geological viewpoint, alarmingly imminent.

Between 1859, when the first oil well was drilled in the United States, and January 1, 1947, the production of petroleum from all parts of the world has totaled nearly 52,000,000,000 barrels. Of that total, slightly more than 30,000,000,000 barrels were produced in the United States. As shown in Fig. 1, the annual production, both for the world as a whole and for the United States, has increased each year since 1938, with the sole exception of 1942, the first year of American participation in the war, and there is every indication that these increases will continue for the next few years. Indeed, it is a conservative estimate that the world's oil production will average

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more than 3,000,000,000 barrels per year during the decade 1947-56.

Such figures begin to take on real significance when we note that the most recent estimates made by competent

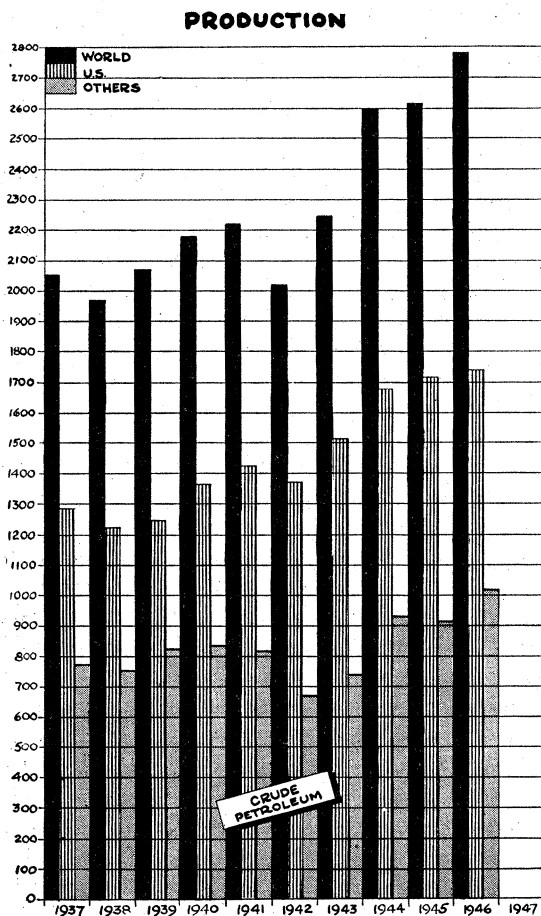


FIG. 1. Annual production of petroleum, 1937-46, in millions of barrels.

petroleum geologists (see Fig. 2) give a figure slightly less than 70,000,000,000 barrels (68,924,000,000) for the proved reserves of petroleum throughout the world on January 1, 1947. It would, however, be far too simple and quite erroneous to make the easy arithmetical calculation and announce that the world's oil will be exhausted in 23 years. The proved reserves are only a fraction of the actual reserves. Whether the fraction is one-half or one-tenth is a matter of great moment, requiring careful consideration.

The particular combination of specifically defined geological conditions requisite for an oil accumulation of economic value is now well known to petroleum geologists. Every oil field fulfills the specifications in one way or another, and the failure to find oil in an exploratory borehole can almost always be explained by an observable lack of one or more of the requisite geological conditions.

The first requirement is an adequate source of supply of the organic materials from which petroleum may be

formed by natural processes of a biochemical and geochemical character. Source beds are sedimentary rocks, most commonly shale, but in some instances limestone or sandstone, in which the tissues of plants or animals were buried, before they were completely oxidized, while the sediments were accumulating on a sea floor, lake bottom, or stream bed. Certainly, almost all, and very probably all adequate source beds are of marine origin.

In the second place there must be a suitable reservoir rock in fairly close proximity to the source beds. Reservoir rocks must be both porous and permeable, in order to provide space for the oil in the interstitial voids and to permit its movement, first from the source beds into its interstices and later from them into a borehole. The best

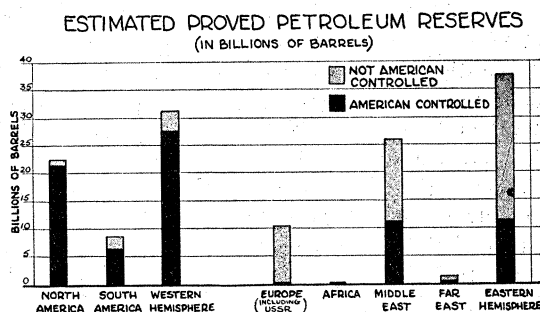


FIG. 2. Proved reserves of petroleum as of January 1, 1947.

reservoir rocks are sandstones and limestones with a porosity of 5-25 per cent of their volume and with permeability ranging from 100 or 200 to 1,000 or 2,000 millidarcies. It is not essential that a reservoir rock be marine in origin; lacustrine, fluvial, or eolian sandstones will do just as well. In fact, a volcanic ash deposit, a tuff or agglomerate, might be quite satisfactory.

Thirdly, there must be some sort of trap to prevent the upward migration of the oil as it seeks to ascend to the surface because of its lesser density than that of water. The trap may be (1) "structural," produced by folding or faulting of the rocks or a combination of the two, or by the intrusion of salt or igneous rock into the sedimentary series, or (2) "stratigraphic," resulting from the pinching out of the reservoir rock updip or from excessive lateral reduction in porosity or permeability within the reservoir bed, or formed by the unconformable deposition of relatively impermeable beds across the eroded edges of tilted strata that include a reservoir rock.

Finally, the sedimentary system containing source beds and reservoir rocks must not have been unduly metamorphosed, either as a result of deep burial, horizontal compression during mountain-making movements, or igneous intrusions on a large scale. Moderate pressures stimulate geochemical changes conducive to the evolution of petroleum from its source materials, but excessive pressure destroys petroleum. Gentle folds are desirable to provide structural traps and to tilt reservoir rocks so that the oil can move upward into stratigraphic traps, but closely compressed folds do not yield oil. The greatest

depth from which oil has thus far been produced is slightly greater than 13,000 feet, although several holes have been drilled deeper than 15,000 feet and at least one exceeds 17,000 feet. It is extremely unlikely that oil will ever be produced anywhere from depths greater than 20,000 feet, for the pressures and temperatures are too great to permit petroleum to exist in the fluid state.

Although geological and geophysical surveys at the earth's surface permit the discovery of places beneath which one or more of these four requisites for an oil field are known to be met, no one can guarantee in advance of drilling that oil will be encountered at depth. Satis-

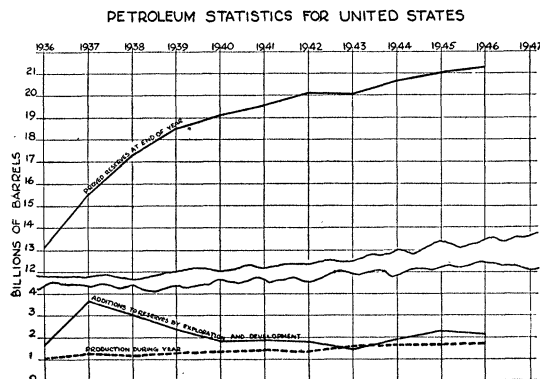


FIG. 3. Relation of petroleum production to proved reserves, United States, 1936-46.

factory criteria for the identification of source beds as such are not yet known. Sedimentary rocks are notorious for their facility to change in textural, lithologic, and mineralogic characteristics when traced laterally from place to place. There was no reason, for example, to expect in advance of drilling that the structural trap a few miles south of Lincoln, in Nottinghamshire, would be devoid of oil, whereas the very similar structure in similar rocks at Eakring, only 25 miles distant, would yield very considerable production. Not until the drill has yielded information concerning the texture and thickness of potential reservoir rocks within the favorable structure itself and has demonstrated the actual presence of petroleum can one begin to calculate the quantity of proved reserves for any oil field.

The relation between proved reserves and the total supply of petroleum in the ground is best indicated by the history of American oil fields. Almost every minor variant of the geological conditions essential for an oil pool is found somewhere within the extensive petroliferous area of the United States. Accurate records of nearly all drilling operations and of the resulting production of oil and gas are available over a long period of years. American geologists have specialized in the computation of known and probable reserves for each of the many oil fields at various stages in their development, from the drilling of the "discovery well" to the exhaustion and abandonment of the older fields.

The broad picture is indicated in Fig. 3. During the 11 years from 1936 to 1946, inclusive, there has been an intensive search for new oil fields, the results of which have made possible the increase in annual production from approximately 1,000,000,000 barrels in 1936 to nearly 1,750,000,000 barrels in 1946. In spite of the removal of this vast quantity of oil, the proved reserves have been greater at the end of each year than at the beginning, with the sole exception of 1943, when there was a relatively small amount of exploratory drilling because of the limitations upon steel for well-casings, imposed by the necessity of allotting large quantities of

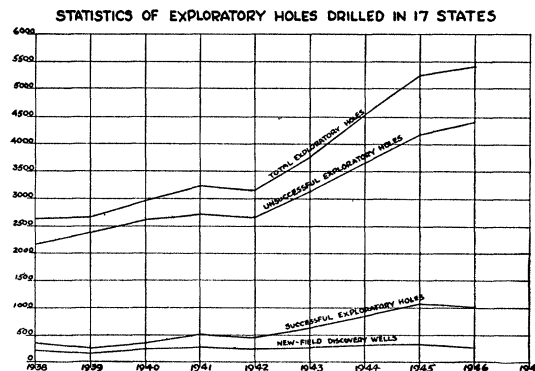


FIG. 4. Results of exploratory drilling in the 17 most important petroleum-producing states of the United States, 1938-46.

steel to ship-building and military equipment. It will be noted, however, that the curve entitled "Proved Reserves at End of Year" rises steeply for only four years, from 1936 through 1939, and thereafter shows a definite tendency to level off. There is little doubt that the peak of that curve will be recorded by 1950 and that thereafter it will descend toward zero.

This somewhat gloomy forecast is borne out by a more detailed study of drilling operations in the 17 states that include the major part of America's petroleum resources. The essential data are depicted in Figs. 4, 5, and 6. The number of exploratory holes drilled in that area increased from 2,700 in 1938 to 5,400 in 1946, but the number of wells that discovered new fields fluctuated within very narrow limits and was only a little larger at the end of the selected period than at its beginning. Especially disappointing is the fact that there were fewer successful exploratory wells in 1946 than in 1945, although the total exploratory holes drilled in that year was appreciably greater. In spite of the increased expenditure for exploratory drilling, the number of new fields discovered has decreased each year since 1943. Especially significant is the fact that the number of major fields (confidently estimated to contain over 10,000,000 barrels of oil each at the start of drilling operations) has decreased steadily since 1940. There is no doubt that in this area nearly all the large oil pools have now been located, and with rare exceptions only small pools containing only a few million

barrels await future discovery. Inasmuch as many of the more recent exploratory wells are deep tests, the more accurate presentation of results is expressed not by the simple number of holes drilled but by the relation between

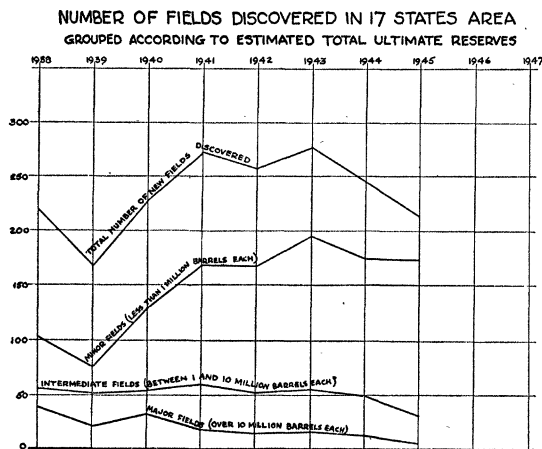


FIG. 5. Statistics concerning new oil fields discovered in the 17 most important petroleum-producing states of the United States, 1938-45.

the number of feet drilled in exploratory holes and the number of barrels of oil discovered by the successful holes. The curve in Fig. 6, entitled "New Proved Reserves per Exploratory Foot Drilled," tells the story with impressive solemnity. Its decline from 1938 to 1946, com-

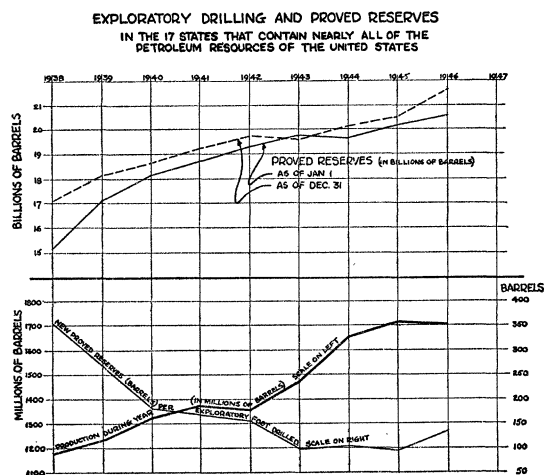


FIG. 6. Results of exploratory drilling for oil in the 17 most important petroleum-producing states of the United States, 1938-46.

pared to the increase in production from this 17-state area during the same years, is the crux of the problem and fully justifies the gloomy prediction with which the preceding paragraph was closed. This, of course, is the inevitable story for every oil-producing region in the world. Although for a time a locality or a nation may profit greatly from the rich stores of oil within its bounds, sooner or later those stores will be exhausted. We are dealing with a nonrenewable resource. We are burning up the capital provided by nature.

The United States is now enjoying the greatest petroleum production of all time. It is a safe expectation that the actual reserves of oil beneath its surface are two or three times the proved reserves of 20,000,000,000 barrels, but it is equally probable that its domestic production will fail to meet its needs within 5 or 10 years from now. Production will probably be maintained at levels far above 1,000,000,000 barrels per year for 25 or 30 years to come, but even such quantities will not be adequate to meet the steadily increasing demands.

Although we are prone to think of petroleum largely in terms of gasoline and diesel oil for internal combustion motors and of fuel oil for heating our homes and operating steam engines, the fact is that many other uses are now increasing the consumption of this most flexible of liquids. Not only are American farmers using power machinery to a larger extent as the years go by, but they are also using petroleum derivatives for insecticides and fungicides and many other purposes. Synthetic rubber, based upon butadiene derived from petroleum, is a war-time development, but it is here to stay. At many an oil refinery the butadiene storage tanks bulk large against the maze of pipes and towers.

Faced by this prospect of increasing demands and dwindling supplies, petroleum geologists, engineers, and economists must employ every weapon in the arsenal of science and technology to meet the situation. Every barrel of oil brought to the surface must be used as effectively as possible. Much progress has been made in the last few years in the development of such refinery techniques as catalytic cracking, alkylation, and the fractionating of the lighter compounds in the mixture of hydrocarbons comprising every crude oil. Research continues to blaze the trail toward the most efficient use of natural resources, always an important aspect of their conservation.

At the same time, every effort must be made to insure the maximum production from the dwindling reserves. This involves two factors. First, there is the increase in percentage of recovery from pools, after they have been discovered, by improved methods of production, such as maintaining the optimum gas-oil ratio throughout the life of a well, and by using such methods of secondary recovery as the water drive and repressuring by gas injection. Second, there is the discovery of new pools, either in new localities or by deeper drilling in old fields. This is the function primarily of the petroleum geologist and involves continuing research as well as the application of procedures already well established by long practice.

The importance of geology and geophysics is now well recognized throughout the entire industry in the United States, if not also in every other country. The statistics pertaining to the exploratory wells drilled in the United States in 1943 may be cited as illustrative of the reasons why geologists and geophysicists have established a

secure place for themselves and may expect to continue their activities in the search for petroleum for many years to come. In that year 3,843 exploratory wells were drilled. The location of 3,242 of these is known to have been selected on the basis of geological or geophysical surveys, or a combination of the two. Of these scientifically located wells, 626 proved to be productive—that is, approximately 20 per cent were successful. Of the remainder, 523 are known to have been located by non-technical methods. Only 23 of these or less than 5 per cent, were successful. The method of determining the location of the other 78 wells is unknown; 6 of them were productive.

It is not to be expected, however, that this excellent record of geological and geophysical achievement can be maintained in future years. Less favorable locations must be tested with the drill, if every oil pool, no matter how small, is to be discovered. A smaller percentage of successful wells to total exploratory tests is inevitable as the search becomes concentrated upon stratigraphic traps and the doubtfully effective structural traps.

Accepting the fact that almost all the large oil pools within the land area of the United States have by this time been discovered, attention at the moment is being given to the possibilities of oil production from the submerged portion of the continent, known to geologists as the continental shelves. The Coastal Plain of Louisiana and Texas continues far out beneath the waters of the Gulf of Mexico, and the present position of the shoreline has no relationship whatsoever to the occurrence of oil beneath its surface. From the standpoint of geology there is no reason to doubt the presence of salt domes beneath the marginal waters of the Gulf, quite similar to those beneath the adjacent shore.

Petroleum engineers have already had considerable experience with drilling operations in shallow water. Hundreds of wells have been drilled in Lake Maracaibo, Venezuela, near its eastern shore. But off-shore drilling in the Gulf of Mexico is a very different proposition from that in the quiet waters of Lake Maracaibo close to shore. Drilling platforms must be high enough above the water to escape damage from storm waves, and out in the open waters of the Gulf where hurricanes occur almost every year, that means a height of at least 30 feet above high-tide level. The engineering problems involved in constructing stable bases for drilling operations are obviously very difficult.

Surveying techniques to determine favorable drilling sites depend largely upon the portable seismograph and the gravity meter. Adaptation of their use for underwater surveys has been greatly facilitated by certain of the ingenious devices developed for military purposes during the war. Similarly, radar has proved most satisfactory for precise location of points occupied by the surveyors—an extremely difficult operation when one is out of sight of land.

In spite of all the difficulties, two wells have already been completed off the Louisiana shore, one 5 miles, the other 30 miles, from land. The former, although drilled to a depth of 12,786 feet, failed to produce oil. The latter encountered the crest of a salt plug at a depth of 2,613 feet, thus verifying the interpretation of the geophysical survey, as a result of which the drilling site had been selected, but at last reports it, too, had failed to encounter commercial amounts of oil. Other wells are even now in various stages of preparation or drilling at distances of 10–40 miles from land. Similarly, among the Bahama Islands and elsewhere on the continental shelf bordering the south Atlantic states, surveys have been in progress for nearly two years, and drilling operations are scheduled to begin at an early date.

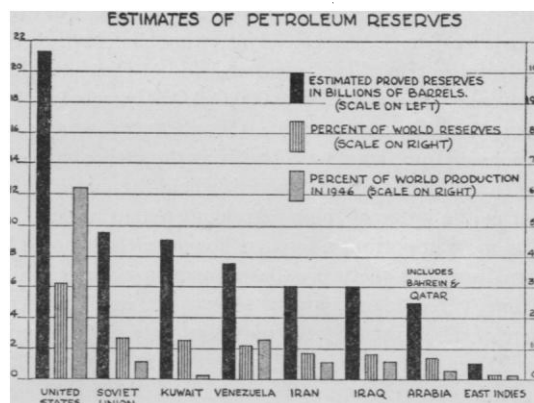


FIG. 7. Petroleum reserves and 1946 production of oil in 8 countries, each of which is believed to have possessed more than 1,000,000,000 barrels of proved reserves on January 1, 1947.

This extension of the search for oil to the continental shelf may confidently be expected to add a few billion barrels to American reserves, but at best it will postpone by only a few years the time when American production will lag far behind American consumption of petroleum products. It is therefore appropriate to look next at the prospects for meeting the future needs of America by importing oil from other countries.

As shown in Fig. 2, American interests control 75 per cent of the nearly 9,000,000,000 barrels of proved reserves in South America, more than 40 per cent of the 26,000,000,000 barrels of proved reserves in the Middle East, and nearly 30 per cent of the 1,400,000,000 barrels of proved reserves in the Far East. Thus, if political factors are favorable, the United States may draw upon nearly as many barrels of foreign oil reserves for its domestic needs as are presently available within its own boundaries.

But the United States does not exist in a geographical vacuum. It is but one among many nations having needs and rights with respect to petroleum. It is therefore imperative to consider this reserve from a world point of view. The broad features of the world picture are shown in Fig. 7, based upon the best estimates of proved

reserves made by competent geologists as of January 1, 1947. In all probability, such a graph portraying conditions 10 years hence would show a decrease in the proved reserves for the United States and an increase for every other country, with the possible exception of Venezuela, inasmuch as discovery and development have already advanced so much further in the States than elsewhere. One could almost venture the guess that, whereas the actual reserves beneath the United States are probably not much more than twice the amount shown as proved reserves, in the other countries they average at least three times the amounts shown for them.

Most amazing is the position of Kuwait, the tiny country at the head of the Persian Gulf, exceeded only by the United States and the Soviet Union in the volume of its proved reserves of petroleum. I am, however, assured by Mr. E. L. DeGolyer, who has studied the petroleum potentialities of the Middle East at close range, that the estimate of 9,000,000,000 barrels for that country is very conservative. Significant also are the positions of Iran, Iraq, and Arabia as the fifth, sixth, and seventh countries of the world, when the nations are listed in the order of their petroleum potentialities.

The most important inference, however, that should be drawn from this picture is based upon a comparison of the two percentage columns shown for each country. Whereas the United States possesses only a little more than 30 per cent of the world reserves, its production has been running well over 60 per cent of the world production each year. Venezuela is the only other country, possessing more than 1,000,000,000 barrels of proved reserves, in which the percentage of world production in 1946 exceeded the percentage of world reserves. The deduction is obvious: if present trends continue, 10-20 years from now the United States will be a "have-not nation" so far as petroleum is concerned; the "have nations" will be the Soviet Union, Kuwait, Iran, Iraq, Arabia, and the East Indies. It is no accident that practically all of the potential oil fields of the 5 last-named countries are under the control of American, British, and Dutch corporations.

This raises the question of the adequacy of the world's supply of oil for meeting the future world demands for petroleum products. At the moment, world consumption of petroleum is running at an annual rate of approximately 2,800,000,000 barrels. That is 4 per cent of the world's proved reserves and something like 1 per cent of the world's actual reserves. Demands are certain to increase greatly in the next few years, not so much as a result of increase in world population, but because of increased consumption by people who have not hitherto been large consumers of petroleum products. Whereas, for example, the annual peacetime consumption of petroleum within the United States is 450 gallons per capita, in the United Kingdom it is 80 gallons, in the Soviet Union, 50 gallons, and for the world as a whole,

other than the United States, it is only 15 gallons per capita. This marked disparity is certain to be reduced in the future by a great increase in the per capita consumption of petroleum products outside the United States.

Even so, it would appear that world petroleum reserves are quite adequate to meet world needs for half or three-quarters of a century to come. But to use those reserves in the most efficient way, there must be almost complete freedom for distribution of the oil and its products from the regions of supply to all parts of the world, regardless of political boundaries. Never was there more convincing evidence of the fact of mineral interdependence in the modern world, a fact that should be thoroughly comprehended by every person concerned with international relations. In all probability, the optimum distribution of the abundant, but locally concentrated supplies of petroleum can best be attained by some sort of voluntary allotment or quota system, established and maintained by agreements among the nations and corporations possessing and controlling the sources of supply and the means for discovery, extraction, and transportation of the oil.

There are, however, two reasons why alternative sources of gasoline, diesel oil, fuel oil, and lubricants are even now being sought. One is the fear that political and economic barriers may be raised against the free flow of oil from South America and the Middle East to the United States a few years hence, when American production fails to meet American needs. A variant of that fear is probably present in Great Britain, stemming from the contemplation of British dependence upon foreign oil fields and the possibilities of a future war. Despite the superb ingenuity responsible for the discovery of the small oil fields in Nottinghamshire, there is absolutely no possibility of finding sufficient oil in the British Islands to meet more than a very small fraction of Britain's needs. The other reason is the fact that it is by no means too early to begin preparing for the inevitable day, which may come even before the end of the present century, when world production of oil will be inadequate for world needs.

Already, an appreciable fraction of American requirements for petroleum products is being met by the synthesis of liquid hydrocarbons from natural gas. At the moment, a pilot plant for the synthesis of petroleum from oil shale is being completed and put into operation in Utah by the U.S. Bureau of Mines. Methods of synthesizing petroleum products from coal, developed by German scientists before and during World War II, are being checked and improved in the research laboratories of governmental bureaus and private corporations in the States. The success of the oil-shale industry in Scotland and the great quantity of synthetic gasoline that helped so materially in providing power for the German war machines are sufficient guarantee that science and technology have provided an alternative source of supply,

long before the petroleum resources of the world have even begun to approach exhaustion.

These alternative sources are almost unbelievably abundant. In the United States alone, there is enough oil shale and coal available to provide the equivalent of 2,000,000,000 barrels of crude oil each year for at least 1,000 years. Similarly, if known techniques of producing petroleum products from coal by chemical synthesis were applied to the coal reserves of Great Britain, all British requirements for such products could be met for at least a few hundred years.

But such application of technical knowledge is not by any means an easy and simple matter. Processes now available are too expensive to permit competition with natural petroleum products except under extraordinary conditions, such as those that make the Scottish and Swedish oil-shale industries economically feasible. The necessary equipment is extremely complicated, very costly, and requires extensive plants. Its installation is not yet practical on a sufficiently large scale to permit such a substitution of mineral fuel sources in the immediate future.

Nevertheless, there is every reason to expect the gradual replacement of natural petroleum products by synthetic products in the more distant future. As the supplies of crude oil are exhausted, this alternative source will take their place. Thanks to science and technology, the mineral fuels stored within the earth will

prove adequate for all human needs for as long a time as they are needed. Long before the oil-shale and coal are exhausted, still other sources of energy, such as the atomic energy released by nuclear fission, will be available to do the work that men want done.

Far more difficult than the technical problems involved in meeting the physical needs of humanity are the psychological and spiritual problems that retard the process of learning how to live properly in a world community. Perhaps knowledge of the fact that our small world is a world of potential abundance but inescapable interdependence, as illustrated by such an enquiry as this concerning one typical, nonrenewable resource, may help to accelerate that learning process.

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UNESCO Initiates Cooperation in the Abstracting of Biological and Medical Sciences

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A QUESTION OF INTEREST TO SCIENTISTS and physicians was the subject of a Conference on the Coordination of Abstracting Services for Medical and Biological Sciences, held by UNESCO in Paris, on October 3, 4, and 5.

The group of interested experts who gathered at UNESCO House were told by Dr. Julian Huxley, the director-general, in his address of welcome, that coordination in this important field was of importance in helping to remove barriers to the free dissemination of scientific ideas and information and, therefore, pertinent to international understanding. He also believed that coordination is important for the abstracting systems of all fields of knowledge.

Dr. Joseph Needham, director of the Natural Sciences Section, discussed some of its activities and stressed the importance of good abstract services for people working

in remote parts of the world—for example, in China. Dr. I. M. Zhukova, medical counselor of the Natural Sciences Section, reviewed the events which finally culminated in the Conference. She pointed out that comments in the *British Medical Journal*, the report and recommendations of a committee of the Medical Library Association (USA) based on its recent study of the abstracting of medical literature, communications from the National Research Council (USA), and letters from Dr. John E. Flynn, editor of *Biological Abstracts*, had all served as an inspiration to call a discussion group together.

Dr. Hugh Clegg, editor of the *British Medical Journal*, was appointed chairman of the Conference, and Mrs. Eileen R. Cunningham, of the Vanderbilt University School of Medicine, president of the Medical Library Association, was named vice-chairman. Others present were Dr. Zygmunt Deutschman, director of Technical